[*THEORY OF STORAGE IN ENERGY MARKETS: THE ROLE OF FINANCIAL STRESS IN NONLINEARITY OF SHOCKS TRANSMISSION*]

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Overview

The first idea about the relationship between storage of commodities and spread between nearby and more distant futures prices raised by Working (1933, 1934). Kaldor (1939) is the first who theorized the relationship between storage of commodities and spread between nearby and more distant futures prices. Working (1948, 1949) provided the first evidences of the existence of convenience yield in the U.S. wheat market, as stocks were held even when the inter-temporal spread within Chicago prices was inverted. Brennan (1958) developed the theory of storage estimating demand and supply curves for storage. Brennan (1958) and Tesler (1958) empirically examined this theory on some agricultural commodities and confirmed the Working curve in many markets. The difference between spot and futures prices is formulated in above described literature, specifically Fama and French (1987, 1988), in two seminal articles, defined it as:

$$F(t,T) - S(t) = S(t)R(t, T) + W(t, T) - C(t, T) \qquad (1)$$

S(t) is the spot price of commodity at time t and F(t,T) is the futures price at time t for delivery at T. This indicates that the gain from purchasing the commodity at t for delivery at T, F(t,T)-S(t), is identical to the risk free interest lose, S(t)R(t, T), and marginal storage cost, W(t, T), minus marginal convenience yield of inventory, C(t, T), which is equivalent to:

$$\frac{F(t,T)-S(t)}{S(t)} = R(t,T) + \frac{W(t,T)-C(t,T)}{S(t)} \qquad (2)$$

$\frac{F(t,T)-S(t)}{S(t)}$ is called the basis. The difference between the basis and the risk free rate is 'interest adjusted basis (iab)', which is equal to the difference between relative warehousing cost w(t,T)=(Wt,T)/S(t,T), and relative convenience yield c(t,T)=C(t,T)/S(t,T):

$$iab= \frac{F(t,T)-S(t)}{S(t)} - R(t,T)= w(t,T)-c(t,T) \qquad (3)$$

While the studies that test the implications of the theory of storage in energy markets are not many, the theory is accepted by participants of energy futures markets. For example, a large negative basis is known by the energy market participants as a signal to draw energy products out of storage and a small negative or positive basis as a signal to store commodities. Cho and McDougall (1990) applied an indirect test for theory of stirage on crude oil, gasoline, and heating oil futures. They find, for gasoline and heating oil, that, consistent with the theory of storage, the volatility of spot prices is greater than futures prices when the basis is negative and tends to be equal when the basis is positive. In the case of crude oil, their results are not conclusive. Geman and Ohana (2009) revisited some implications of the theory in the markets for oil and natural gas. They document the remarkable relationship between inventory and basis and show that in the case of oil, inventory is negatively correlated to volatility of prices and in the case of natural gas, the negative correlation holds only in low inventory periods.

This study examines the theory of storage and its implications in crude oil and heating oil markets, by considering for the first time, the role of financial markets conditions. The applied data cover the period from January 1994 to August 2017. First, we use the Fama & French (1988) indirect tests of the theory of storage. Then, we perform a direct estimation to investigate the validity of the theory and the relative importance of the financial markets conditions. To achieve this, we apply the threshold structural VAR (TSVAR) approach proposed by Balke (2000) to examine the time-varying responses of the interest-adjusted basis to inventory shocks, financial stress shocks and shocks to stock market uncertainty. The advantage of the TSVAR approach are the followings. First, it enables us to estimate the model during different regimes, namely, high and low inventory and high and low financial stress regimes. Second, it decomposes the responses of the basis to positive and negative shocks. Consequently, nonlinearity and asymmetry of the basis responses with respect to different shocks are measured. The results of estimation during high and low inventory regimes lead us to conclude about the validity of the theory of storage, and during high and low financial stress regimes enables us to deeper analyze the impact of financial condition on petroleum markets.

Methods

a) Fama and French indirect tests

Fama & French (1988) describe and test three implications of the theory of storage. The first implication is that, the interest-adjusted basis is more variable when inventory is low. We follow Fama & French (1988) and test this by the variance equality F test on standard deviation of changes in interest-adjusted basis during negative and positive periods. The second implication states that, the interest-adjusted basis is wider when inventory is low, and is tested by the mean equality Welch F test on the average values of the interest-adjusted basis when it is negative and positive. The third implication of the theory of storage is that, inventory shocks generate roughly equal changes in spot and futures prices when inventory is high (positive interest-adjusted basis) and they expect less changes for futures than spot prices when inventory is low (negative interest-adjusted basis). To test this, we compare the ratio of standard deviation of the future price changes to the standard deviation of the spot price changes.

b) Threshold structural vector autoregression (TSVAR)

The threshold structural vector autoregression (TSVAR) model proposed by Balke (2000) is applied to examine the responses of the *iab* to inventory, FSI and VIX shocks. The responses are examined during high and low inventory regimes that investigates the validity of the theory of storage, as well as during high and low financial stress regimes that provides further insights. The TSVAR is a method to capture nonlinearity, such as regime switching, asymmetry and multiple equilibria implied by theoretical models (Balke, 2000). The TSVAR model is the following:

$$Y_t = A^1 Y_t + B^1(L)Y_{t-1} + (A^2 Y_t + B^2(L)Y_{t-1})I(c_{t-d} > \gamma) + U_t \quad (4)$$

where Y_t is the vector of endogenous variables including the percentage change of inventory, financial stress index (FSI), VIX and interest-adjusted basis. $B^1(L)$ and $B^2(L)$ are lag polynomial matrices and U_t is structural disturbances. c_{t-d} is the threshold variable that determines the regimes of the system and $I(c_{t-d} > \gamma)$ is an indicator function that takes the value of 1 when $c_{t-d} > \gamma$ and 0 otherwise. A^1 and A^2 reflect the structural contemporaneous relationships in the two regimes. We suppose that A^1 and A^2 have a recursive structure with the causal ordering of inventory, FSI, VIX and interest-adjusted basis. In order to test for the threshold value, we follow Balke (2000). First, the threshold model is estimated by OLS for all possible threshold values. For each possible threshold value, the Wald statistic with the null hypothesis of no difference between regimes is calculated. Next, three test statistics for threshold behavior, namely, sup-Wald, avg-Wald and exp-Wald, are calculated.

Results

Our results from applying the Fama and French (1988) tests support the theory of storage for heating oil, while for crude oil the results are inconclusive. The results from estimating the TSVAR model suggest that, first, the theory of storage holds for both commodities. Second, for both commodities, a higher financial stress increases the interest-adjusted basis but with a weaker response in heating oil market. Moreover, the responses are higher during high stress regime and asymmetric in favor of positive financial stress shocks. Third, for crude oil, higher uncertainty in stock market increases the interest-adjusted basis with higher responses during high stress regime and asymmetric to positive uncertainty shocks, while the response of heating oil is weaker than crude oil and is time varying and regime dependent. These results warn the petroleum market participants that during turbulent periods, the interest-adjusted basis will increase, and the effect is more pronounced in crude oil market.

Conclusions

Specifications of the theory of storage suggest that if the interest-adjusted basis changes due to inventory shocks, it is wider and more volatile during backwardation, which our results find the relevant evidence for heating oil and less evident it for crude oil. Moreover, we find that, if the interest-adjusted basis of crude oil changes due to financial instability shocks, it is supposed to be wider and more volatile during contango, while this is quite less evident and mix for heating oil. This result is an interesting contribution, as statistical specification of the interest-adjusted basis during its negative and positive periods depends on the underlying reason behind its variation and inventory is not the only driver of the interest-adjusted basis. This is a matter of concern especially during turbulent periods of financial markets. Moreover, this is more important for crude oil market, as suggested by our results; crude oil is more connected to financial markets than heating oil. Therefore, variations of the spread between nearby and more distant futures, traditionally known as a signal of scarcity or abundant, has to be analyzed more carefully. These results are useful for all energy markets participants, the financial market traders, refiners and other energy users who consider the basis variation for their decision.