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Risk-neutral moments in the crude oil market☆

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ABSTRACT

In this paper, we provide a comprehensive study on the higher-order risk-neutral moments (RNMs) and differences in RNMs (DRNMs) in the crude oil market, implied by options written on the United States Oil Fund (USO). Based on the *t*-statistic, the in-sample and the out-of-sample R^2 statistics, we compare the USO return predictability and USO option return predictability by using RNMs and DRNMs from May 2007 to April 2016. We find that (i) all RNMs have a poor out-of-sample performance of predicting USO returns and simple option returns, while the risk-neutral volatility (VOL) outperforms in terms of both in-sample and out-of-sample predicting delta-hedged option returns; (ii) most of the DRNMs can significantly predict the future USO returns, and (iii) differences in the risk-neutral third cumulant (DTC) and differences in the risk-neutral fourth cumulant (DFC) are two important predictors for the future USO option returns.

1. Introduction

The crude oil market has become the most active energy market in terms of trading volume and the variety of derivative products. For example, in 2017, the trading volume of crude oil futures accounted for over 50% of the total trading volume of energy contracts at the New York Mercantile Exchange (NYMEX). The United States Oil Fund (USO) holds near-month NYMEX West Texas Intermediate (WTI) Light Sweet Crude Oil futures (ticker: CL) in order to track their daily price changes, which are the world's most liquid energy futures contracts, with an average daily volume of nearly 1.1 million and open interest of over 2 million contracts. Since USO, as a great vehicle for riding short-term moves in crude prices, delivers its exposure to oil using near-month futures, it has become one of the largest and most liquid oil exchange-traded funds (ETFs) available. Because of that, this paper is interested in studying the USO market. As for a tradable asset, predicting its future return is one of the most important tasks for investors and researchers; this paper therefore mainly focuses on the study of return predictability in the USO market.

Options on USO were launched by the Chicago Board Options Exchange (CBOE) in 2007. This enables us to obtain the risk-neutral moments (RNMs), including the Bakshi, Kapadia and Madan (Bakshi et al. 2003) risk-neutral moments (BRNMs), the nonparametric risk-neutral moments (NRNMs) and the risk-neutral cumulant (RNCs) as our return predictors. All RNMs are option-implied, so that they are forward-looking. In terms of return predictability, as there are two assets, USO and USO options, traded in the USO market, in this paper, we concentrate on both the USO and USO option return predictability by using different RNMs.

We first filter the USO option data obtained from OptionMetrics Ivy DB and then get around 90,000 options across different maturities and strike prices from 09 May 2007 to 29 April 2016. By using the model-free methodology in Bakshi et al. (2003), we obtain the daily BRNMs and RNCs. Following Xing et al. (2010) and Bali et al. (2016), daily NRNMs are also calculated. We further compute the monthly RNMs by averaging the daily RNMs over a month. In order to calculate monthly option returns, at the end of each month, we

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collect a pair of options that are closest to being at-the-money (ATM) and have the shortest maturity among those with more than one month to expiration. The time to maturity of the chosen options ranges from 32 to 52 calendar days across different months, with an average of 45 days. The moneyness defined as the USO price divided by the strike price is very close to 1. The simple option return over a particular period T is defined as the difference between the exercise value of an option and the future value of saving the initial option premium in the bank after a period of T, scaled by the initial option premium. The option is delta-hedged (or delta-neutral) only at the initial time when we calculate the delta-hedged option return. We therefore analyze the USO and USO option return predictability by using the RNMs.

In line with Ang et al. (2006), Chang et al. (2013) and Chatrath et al. (2016), we are also interested in the first differences in RNMs (DRNMs), which are good proxies of innovations in RNMs. Empirically, we find that the risk-neutral fourth cumulant (FC) outperforms the other RNMs in terms of the in-sample predictability of USO returns. During our sample period, all RNMs have a poor out-of-sample performance of predicting USO returns and simple option returns, while the risk-neutral volatility (VOL) outperforms in terms of in-sample and out-of-sample predictions of delta-hedged option returns, based on their Newey and West (1987) t-statistics, in-sample R^2 statistics and out-of-sample R^2 statistics. Most of the DRNMs can significantly predict the future USO returns. Finally, we provide some evidence that differences in the risk-neutral third cumulant (DTC) and differences in FC (DFC) are two important predictors of USO option returns.

This paper contributes to the finance literature in a number of ways. First, the paper extends the study of the RNMs. Demeterfi et al. (1999) and Carr and Madan (2001) propose a model-free method to price variance swaps by using a static replication with options. It promotes the development of the over-the-counter (OTC) volatility derivatives trading.[1] Bakshi et al. (2003) further develop it into higher-order RNMs. A voluminous recent literature follows this BKM methodology to study the information contained in those forward-looking option-implied moments. For example, Conrad et al. (2013), Chang et al. (2013), Stilger et al. (2017) and Bali et al. (2016) study the relationship between the BRNMs and the future stock returns. Bali and Murray (2013) find a strong negative relation between risk-neutral skewness (SKEW) and the returns of skewness assets, which are delta and vega neutral portfolios in stocks and options. Instead of a cross-section analysis, in this paper, we study the relation between the RNMs and the future stock and option returns at the time-series level. In addition, Xing et al. (2010) find that the nonparametric risk-neutral skewness (NSKEW) can predict the cross-section of stock returns. Yan (2011) uses NSKEW as a proxy of the jump size and also find there is a negative predictive relation between the NSKEW and stock return. Bali et al. (2016) use NRNMs as a robustness check for their BRNMs. In this paper, we also consider NRNMs.

Martin (2013) proposes a consumption-based asset pricing model and finds that the equity premium can be determined by the cumulant-generating function. Furthermore, Zhang et al. (2012) use a production-based equilibrium model to show that the contribution of skewness of index return to the equity premium is from the third cumulant. Chang et al. (2015) empirically find that the third cumulant strongly predicts the market excess returns. In this paper,

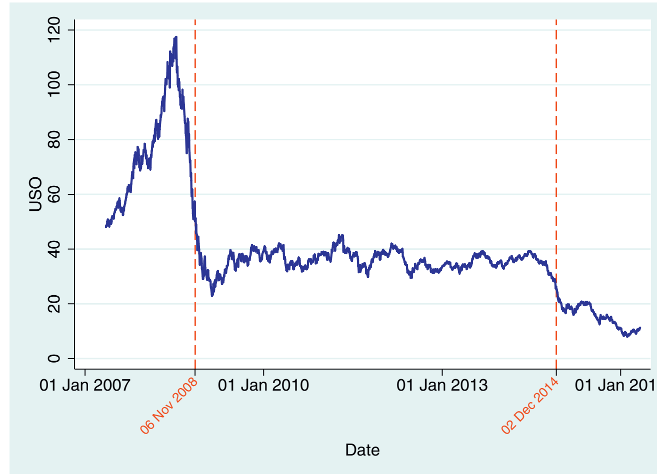

Fig. 1. Daily USO.
We plot daily USO from 09 May 2007 to 29 April 2016. The USO data are available from OptionMetrics Ivy DB.

we are also interested in the RNCs. As BRNMs are volatility-scaled RNCs, RNCs contain not only the tail and skew risks, but also the volatility risk. Therefore, RNCs may have a better predictability of the stock and option returns.

Second, our paper contributes to studies on predictors of index returns. Welch and Goyal (2008) study 14 popular predictor variables based on both in-sample and out-of-sample tests. Rapach et al. (2016) show that short interest is arguably the strongest known predictor of aggregate stock returns. Huang et al. (2015) and Jiang et al. (forthcoming) explore the aggregate stock return predictability by using some sentiment indices based on the in-sample and the out-of-sample R^2 statistics. Bakshi et al. (2011) and Luo and Zhang (2017) show that forward variances are predictive of stock returns. Chiang and Hughen (2017) explore stock return predictability by exploiting the cross-section of oil futures prices. In this paper, we treat the higher-order RNMs and DRNMs as predictors for both the stock and option returns and compare their predictability based on Newey and West (1987) t-statistics, the in-sample and out-of-sample R^2 statistics.

Third, our paper contributes to the growing literature on option returns. Most studies focus on the cross-section of option returns. For example, Goyal and Saretto (2009) claim that the option returns are sensitive to the implied volatility. Cao and Han (2013) present a robust new finding that the delta-hedged equity option return decreases monotonically with an increase in the idiosyncratic volatility of the underlying stock. Bali and Murray (2013), Boyer and Vorkink (2014) and Byun and Kim (2016) study the relationship between the risk-neutral skewness and the cross section of equity options.[2] There are a few studies on index option returns. Broadie et al. (2009), Constantinides et al. (2013), Chambers et al. (2014) and Faias and Santa-Clara (2017) investigate the puzzle of index option mispricing. Huang and Shaliastovich (2014) and Park (2015) find

[1] Mixon and Onur (2015) find that the gross vega notional outstanding for variance swaps, in 2014, is over USD 2 billion, with USD 1.5 billion in S&P 500 variance swaps. From Bollen et al. (2017), the dollar value of open interest of the CBOE Market Volatility Index (VIX) futures in 2013 is around USD 7 billion, and the dollar market value of VIX Exchange Traded Products (ETPs) linked to the short-term S&P 500 VIX futures index is around USD 2 billion. The market for volatility trading has become an important new avenue of financial markets in addition to equity and fixed income securities over last decade.

[2] Furthermore, Muravyev (2016) shows that the inventory risk faced by market-makers has a first-order effect on option prices. Kanne et al. (2016) and Christoffersen et al. (2017) provide evidence of a strong effect of the underlying stock's illiquidity on option prices. Hu and Jacobs (2017) analyze the relation between expected option returns and the volatility of the underlying securities. In addition, Vasquez (2017) finds that the slope of the implied volatility term structure is positively related to future option returns. Recently, Cao et al. (2017) have comprehensively studied the option return predictability and find that the cross-section of delta-hedged equity option returns can be predicted by a variety of underlying stock characteristics and firm fundamentals.