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Risk factors and their associated risk premia: An empirical analysis of the crude oil market

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ABSTRACT

This paper sheds new light on higher-order price risks in crude oil markets. A model-free analysis reveals that crude oil variance risk behaves fundamentally different from variance risk in equity markets. Most importantly, a skewness swap is no valid hedge for a variance swap and investors fear large price jumps in both directions. A model-based assessment confirms this and reveals that while stochastic volatility is important to capture the statistical properties such as volatility clusters and time-varying variance swap rates, only jump risk seems to be priced with a premium. Empirical evidence from a pricing and hedging exercise confirms these findings.

"*Most highly risk-averse people (and firms) never realise the high price they pay for their conservatism.*"

-Peter R. Rose, founder of Rose & Associates (major E & P Oil Risk Analysis firm).

Despite being vital for the global economy, crude oil prices remain highly unpredictable and volatile and markets have experienced both temporary extreme events ("jumps") as well as longer periods of increased uncertainty ("volatility clusters"). This uncertainty also affects players outside the oil business greatly. For instance, it has been demonstrated that oil price variance seems to be an important priced systematic factor in the cross section of equity-returns (Chiang et al. (2015) or Christoffersen and Xuhui (2017)) and shorting it yields sizable Sharpe ratios (Trolle and Schwartz (2010) or Prokopczuk and Simen (2017)). However, oil price variance itself is still not well understood. An active management of crude oil portfolios, be they physical or non-physical, requires an in-depth understanding of the role of different risk factors driving oil price variance and their associated risk premia. In this study we seek to fill this gap.

Previous empirical studies have analyzed risk factors and their associated risk premia mostly in equity markets. We now understand that (diffusive) volatility and jump risks, along with the fundamental diffusive price risk, are the most prominent risk factors under the physical measure. On top of that, studies making use of equity index options demonstrate that market participants heavily price in jump risks.[1] More recently, Kozhan et al. (2013) have shown that once a long-position in equity variance is hedged with a so-called skewness swap – an instrument similar to a risk-reversal offering a hedge towards large downside-risks – the negative risk-adjusted returns disappear. Thus, the variance risk premium in equity markets mostly seems to be a compensation for large downside movements. It is not at all clear whether these findings are of relevance when implementing trading and hedging strategies in a different environment such as the crude oil market

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[1] See e.g. Bakshi et al. (1997), Bates (2000), Chernov and Ghysels (2000), Pan (2002), Bakshi and Kapadia (2003), Jones (2003), Eraker (2004), Broadie et al. (2007), Carr and Wu (2009), Todorov (2010), Bollerslev and Todorov (2011), Kaeck and Alexander (2013), Ait-Sahalia et al. (2015) or Neumann et al. (2017).

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though. While bearing crude oil variance risk is compensated for with a premium as well, it remains unknown what kind of price movements are causing this – or in other words: What kind of price movements do crude oil market participants fear the most? Is it an aversion towards volatility clusters (diffusive volatility risk) and/or jump risk?

In this paper, we address this issue for the West Texas Intermediate (WTI) crude oil market, one of the most liquid energy commodity markets worldwide. We start our investigation with an analysis of (model-free) trading strategies tied to the second and third moment of price returns based on a comprehensive data set of short-dated futures and option contracts from 1996 to 2014. For comparison, we also consider corresponding equity option strategies. This allows us to assess whether variance risk premia can be traced back to the fear of large downside or upside movements such as in the case of equity markets. We then complement this analysis with a model-based investigation. To learn more about the distinct pricing of risk factors which could contribute to the observed negative variance risk premium we impose some structure on the data-generating process: We estimate a parsimonious stochastic volatility model with jumps offering convenient analytical properties. The difficult task of disentangling (latent) volatility and jump processes is approached by including option market information through a suitably aggregated option portfolio given by synthetic variance swap rates. The latter have a linear relationship to latent state variables facilitating the incorporation of a large amount of option contracts in the estimation procedure.

For equities, our model-free trading strategies confirms the results of Kozhan et al. (2013): Once a variance swap is hedged with a skewness swap, risk-adjusted returns are close to zero. This is not the case for crude oil for which profits from shorting variance remain positive even after incorporating a skewness swap into the portfolio. Variance risk premia are thus not a compensation for large downside movements only as for equity markets. Using an option-based measure for positive as well as negative jump risks (Du and Kapadia, 2012) gives further indication for the distinct behavior of the crude oil market: While for equities, market participants seem to price the risk of large downside moves only, this pattern is mostly symmetric for the case of crude oil. Our model-based results confirm these findings. A stochastic volatility component is required to capture strongly fluctuating implied volatility levels ("variance swap rates") over time. However, volatility risk alone is not able to reflect pronounced implied volatility smiles of short-dated option contracts. This suggests that another temporary risk factor is priced in the option market. In a stochastic volatility model with jumps, the jump component is able to reproduce pronounced implied volatility smiles of short-dated option contracts, which reduces option pricing errors substantially compared to pure stochastic volatility models. This indicates that both jump and volatility risk are reflected in crude oil option prices. However, our findings on risk premia show that (unsigned) jump risk is priced with a significant premium, while no significant premium is paid for taking over volatility risk in the crude oil market. Market participants thus seem to fear large price movements in both directions as opposed to equity markets.

The analysis of option hedging errors is consistent with the above findings. Given the fact that (diffusive) volatility risk is mostly unspanned from (diffusive) price risk, an additional management of volatility risk reduces hedging errors significantly. However, even after removing such risks (in addition to an option's delta) we obtain upward-biased mean hedging errors for shorted out-of-the money option positions. This offers further evidence for the presence of another priced risk factor. A simulation experiment reveals that this cross-sectional pattern is better explained by the stochastic volatility model with jumps (SVJ) combined with a jump size volatility premium than by a pure stochastic volatility model. Out-of-the-money option pricing errors are still sizable though, even for the SVJ model specification and seem to be mainly caused by time-variation in implied skewness not captured by our parsimonious model specification. About one third of variance swap pricing errors on the other hand are related to time-variation in jump risk. Our study therefore also offers additional insights that could be of help to develop new option pricing models for crude oil markets.

Our study is related to a growing body of recent research looking at (diffusive) volatility or jump risk premia in commodity markets. Trolle and Schwartz (2009) test term structure models with different stochastic volatility specifications in the crude oil futures market between 1990 and 2006. They find that volatility risk is largely unspanned by price risk.[2] Consequently, traders can reduce hedging errors for a single option contract if they actively hedge volatility risk by trading in other option contracts. Indeed, their results confirm that a delta-vega hedging strategy in futures and option markets significantly reduces mean absolute hedging errors compared to a delta hedging strategy in futures markets only. Doran and Ronn. (2005) argue that positive correlation between returns and volatility in energy commodity markets should result in a negative (diffusive) volatility risk premium using simulations and Doran and Ronn (2008) confirm this premium empirically based on crude oil option data from 1994 to 2004. However, correlation between returns and volatility turns out to be low for crude oil (Trolle and Schwartz (2009)) and Doran and Ronn (2008) use at-the-money option contracts only and do not allow for a jump risk premium in the calibration to market data. Furthermore, recent literature has shown that most part of the variance risk premium in equity markets stems from out-of-the money put options (e.g. Kozhan et al., 2013 or Feunou et al., 2017). As a result, it remains unclear what kind of risks causes negative variance risk premia for crude oil. Probably closest to our study is Christoffersen et al. (2016) who calibrate a GARCH-type model with various jump components to a large panel of crude oil options and return data for a similar period as ours. Although making use of a more flexible jump risk specification their model does not distinguish (diffusive) price risk from (diffusive) volatility risk. Yet, as shown in Trolle and Schwartz (2009) these two risk factors are mostly unspanned from each other and should consequently not be modeled as a single source of risk. In this regard, our model specification is more suited to judge the distinct pricing of (diffusive) volatility and jump risk. Still, the existing literature has thus not thoroughly addressed the question whether jump or (diffusive) volatility risk are causing significant variance risk premia in the crude oil market. Interestingly, and in contrast to existing studies (e.g. Doran and Ronn, 2008), we find that jump risk is priced with a significant premium, while no significant premium is paid for taking over volatility risk in the crude oil market. These results take effects on active risk management and efficient investment decisions.

Methodologically, our study is also related to the strand of literature making use of synthetic variance swap rates to make inference on the pricing of continuous and discontinuous price components in asset prices (e.g. Amengual, 2008, Todorov, 2010, Bollerslev and Todorov, 2011, Ait-Sahalia et al., 2015 or Chiang et al., 2015). In contrast to plain vanilla option contracts, variance swap rates possess a linear relationship to the variance states within the affine class of stochastic volatility models (Duffie et al. (2000)). This facilitates the incorporation of a large amount of option contracts and thus allows inference on the wedge between parameters under the physical and risk-neutral measure without skipping too

[2] The estimated correlation parameters between futures price and volatility innovations for all model specifications are between -0.15 and 0.15.