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Modelling asymmetric volatility in oil prices under structural breaks

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ABSTRACT

This paper shows that accounting for endogenously determined structural breaks within an asymmetric GARCH model reduces volatility persistence in oil prices. More importantly, we find that both good and bad news have significantly more impact on volatility if structural breaks are accounted for in a model. Thus, previous studies have significantly underestimated the impact of news on volatility as they have inadvertently ignored these structural breaks in volatility. Our empirical results suggest that it is best to include both asymmetric effects and structural breaks in a GARCH model to accurately estimate oil price volatility dynamics. Our results have important practical implications not only for option valuation and hedging decisions but also have major consequences for broader financial markets, the energy industry, and the overall economy.

1. Introduction

Understanding the behavior of volatility in crude oil prices is important for many reasons. Changes in volatility can affect the risk exposure of producers and industrial consumers of oil which may change their respective investments in oil producing assets or reserves,[1] inventories and facilities. Volatility also determines the value of commodity-based contingent claims. Thus, understanding volatility dynamics is important for decisions regarding derivative valuation, hedging, and investments in oil. There is also strong evidence that volatility in oil prices is transmitted to broader financial markets and the overall economy. Thus, both public and private sector policy makers as well as financial market participants can benefit from knowing how unanticipated news (both good and bad) affects volatility of oil prices.

There is strong evidence which suggests that volatility in equity markets is asymmetric implying that returns and conditional volatility are negatively correlated. Christie (1982) explains this volatility asymmetry based on the leverage hypothesis and argues that a drop in the value of the stock (negative return) increase financial leverage making the stock riskier thereby increasing the underlying volatility. However, asymmetric volatility could be generated by the volatility feedback as shown by Campbell and Hentschel (1992) who argue that news brings higher current volatility which increases future volatility as volatility is highly persistent. This higher volatility raises the required return resulting in a decrease in the stock price. It is now widely believed that both of the above mentioned effects are simultaneously in play as shown by Bekaert and Wu (2000) using a theoretical and empirical analysis. Although these asymmetric volatility effects are widely documented in equity markets, the literature reports mixed results on the asymmetric volatility of oil prices.

This paper studies the asymmetric volatility dynamics using daily crude oil prices from January 1, 2000 to December 31, 2015. We use modified iterated cumulative sums of squares (ICSS) algorithm to identify structural breaks in volatility of oil prices. These identified breaks are then introduced into an asymmetric GARCH model to accurately estimate how unanticipated good and bad news impacts oil price volatility. Our empirical results show that accounting for endogenously determined structural breaks within an asymmetric GARCH model reduces volatility persistence. More importantly, we find that both good and bad news have significantly more impact on volatility if structural breaks are accounted for in the model. Thus previous studies have significantly underestimated the impact of news on volatility as they have inadvertently ignored these structural breaks in the volatility process. Our empirical results suggest that it is best to include both asymmetric effects and structural breaks in a GARCH model to accurately estimate how new information in the oil market is incorporated into oil price volatility estimates. Correctly modelling volatility in oil prices is important for building accurate oil pricing models, forecasting future oil price volatility and will further our understanding of the broader financial markets, the energy industry and the overall economy.

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[1] One can find evidence of this in the Form 10-K of most publicly traded oil and gas companies in section 1A where risk factors are discussed. Specifically, it is common to see mention of oil price volatility as a major concern of energy companies.

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2. Literature review

Changes in oil prices can have a substantial effect on the financial markets and the overall economy. Hamilton (2003) gives a comprehensive survey of literature on the consequences of changes in oil prices and documents a significant non-linear relationship between oil prices and real GDP using U.S. data. Jones and Kaul (1996) find a significant impact of oil shocks on international stock markets using quarterly data. Driesprong et al. (2008) show statistically and economically significant effect of changes in oil prices on stock returns using data from both developed and emerging markets. In a recent paper, Kilian and Park (2009) show that the reaction of U.S. stock market returns to an oil price shock significantly differs depending on whether the change in the price of oil is driven by a demand or supply shock.

Although changes in oil prices have important effects, the recent focus in the literature is to examine the consequences of the oil price volatility as well. Oil price volatility is an important input in macroeconomic models and also plays a key role in determining prices of oil futures. Ferderer (1996) provides empirical evidence that shows that oil price volatility has a significant impact on aggregate output movements in the United States. Sadorsky (1999) show that oil prices as well as its volatility play an important role in affecting stock returns. Robust evidence was provided by Guo and Kliesen (2005) who show that volatility in oil prices have a significant negative effect on GDP growth in the United States. In a recent paper, Malik and Ewing (2009) report evidence of significant transmission of shocks and volatility between oil prices and equity sector returns. They attribute these findings to the idea of cross-market hedging and sharing of common information by financial market participants.

The autoregressive conditional heteroscedasticity (ARCH) model given by Engle (1982) and later generalized by Bollerslev (1986) is a standard method for analyzing time varying volatility. A common finding is that shocks to volatility are highly persistent. The underlying assumption of a GARCH model is that the unconditional variance of the underlying series is constant which implies that volatility is generated by a stable GARCH process. But markets often experience structural breaks in the unconditional variance which causes breaks in the GARCH parameters. These structural breaks in volatility could be triggered by political, social, or economic events. Lamoureux and Lastrapes (1990) show that volatility persistence is overestimated when standard GARCH models are applied to a series with underlying structural breaks in variance. Mikosch and Starica (2004) give a theoretical explanation, supported with empirical evidence, to show that ignoring shifts in the unconditional variance will result in higher estimated volatility persistence within a GARCH model. Starica and Granger (2005) similarly report shifts in the unconditional variance of daily stock returns and show that forecasts based on a non-stationary model is superior to a stationary GARCH model. Thus, a GARCH model should account for structural breaks in volatility if such structural breaks are present in the time series data.

Surprisingly, there are only few papers which model oil price volatility under structural breaks. Wilson et al. (1996) examine daily data from 1984 to 1992 using a simple ARCH model and they document sudden changes in the unconditional variance of oil futures' returns. They also report that shocks are less persistent when structural breaks are accounted for in the model. Ewing and Malik (2010) model the volatility in oil prices under structural breaks and find that oil shocks dissipate very quickly but have a strong initial impact once structural breaks are accounted for in the model. Mensi et al. (2014) examine the impact of OPEC's different news announcements on the conditional expectations and volatility of crude oil markets in the presence of long memory and structural breaks. They find that accounting for OPEC's scheduled news announcements in the presence of structural breaks reduces the degree of volatility persistence which provides a better understanding of the oil market. However, none of these papers entertain the possibility of asymmetric effect of news on volatility.

The literature reports mixed findings on the asymmetric volatility in oil prices. Fan et al. (2008) examine various specifications of GARCH models for risk management purposes and find significant asymmetric volatility effects. Agnolucci (2009) compares predictive powers of GARCH and implied volatility models. They show that GARCH models outperform the implied volatility models and find no asymmetric volatility effects. Wei et al. (2010) compare a wide portfolio of GARCH models focusing on their forecasting performance. They favor the nonlinear specifications which can account for long memory as well as asymmetry but document mixed evidence when it comes to asymmetric volatility. Chang (2012) employs a combined regime switching exponential GARCH model with Student-t distributed error terms to model returns of crude oil futures. Their model is able to capture the main stylized facts of the crude oil futures but find no volatility asymmetry in oil futures. Nomikos and Adriosopoulos (2012) use a mean-reverting GARCH model focusing on risk management issues and document significant asymmetric volatility effects. Salisu and Fasanya (2013) study the crude oil market with respect to structural breaks in returns while controlling for potential volatility asymmetry. Persistence as well as asymmetry of volatility is reported even after controlling for two structural breaks. They use only two breaks (as that is the maximum number of breaks that their model allows by construction) and their model examines structural breaks in the level of returns not the structural breaks in volatility. Chkili et al. (2014) explore the relevance of asymmetry and long memory in forecasting the volatility of crude oil prices using popular linear and nonlinear GARCH-type models. They conclude that volatility of oil prices can be better described by nonlinear volatility models. Kristoufek (2014) studies the asymmetric volatility effect of crude oil prices and proposes a framework which incorporates long-term memory and correlations. He finds strong asymmetric volatility effect but reports that the strength of this effect is scale-dependent.[2]

This paper fills a void in the literature by modelling asymmetric oil price volatility by accounting for endogenously determined structural breaks in volatility using recent time series data. This will enable us to accurately estimate the impact of unanticipated good and bad news on the volatility dynamics. This study makes an important timely contribution as markets in recent times are experiencing ever more unexpected news and estimating the impact of this news on oil price volatility is becoming indispensable for financial market participants and policy makers.

3. Empirical methodology

3.1. Detecting structural breaks

Hillebrand (2005) shows that a structural break in the GARCH process will lead to a structural break in the unconditional variance. Inclan and Tiao (1994) propose a cumulative sum of squares (IT) statistic to test the null hypothesis of a constant unconditional variance against the alternative hypothesis of a break in the unconditional variance. Their method is designed for an independent and identically distributed processes. Sanso et al. (2004) show that this statistic is significantly oversized when applied to a dependent process like GARCH. However, the *IT* statistic can be modified through a nonparametric adjustment which makes it suitable for application to a dependent process like GARCH.

Inclan and Tiao (1994) further developed an iterated cumulative sum of squares (ICSS) algorithm based on their *IT* statistic for testing multiple breaks in the unconditional variance. Their algorithm can be applied to the modified *IT* statistic with the nonparametric adjustment to avoid the problems that arise when the standard *IT* statistic is applied

[2] In the interest of space, we provide here a brief literature review regarding asymmetric volatility in oil prices. Interested readers are referred to Kristoufek (2014), who provide a detailed literature review on this topic.