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Dependence and extreme dependence of crude oil and natural gas prices with applications to risk management

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ABSTRACT

In this article, we show how the copula-GARCH approach can be appropriately used to investigate the conditional dependence structure between the crude oil and natural gas markets as well as to derive implications for portfolio risk management in extreme economic conditions. Using daily price data from January 1997 to October 2011, our in-sample results show evidence of asymmetric dependence between the two markets. The crude oil and gas markets tend to comove closely together during bullish periods, but not at all during bearish periods. Moreover, taking the extreme comovement into account leads to an improvement in the accuracy of the out-of-sample Value-at-Risk forecasts.

1. Introduction

Crude oil and natural gas are among the most important fuels in the modern economy because of their extensive use by many economic sectors. They are substitutes in consumption and also complements, as well as rivals, in production of electricity. These characteristics explain why prices of these commodities tend or are expected to comove closely over time. Understanding the dependence patterns between the prices of oil and gas, particularly in extreme conditions and given their fat tail behavior, is thus of paramount importance not only for energy-policy decision-making regarding consumption, production and investment, but also for portfolio risk management and hedging issues. Indeed, energy prices of those two fuels influence the incentives to invest in different types of energy-using equipment. Energy traders may find the tendency of the prices to adjust to a certain relative relationship or parity as the basis for a trading strategy.

Historically, there was a 10–1 price relationship between one barrel of oil and one million BTUs of natural gas in the 1990s but more recently this relative price relationship declined to a 6–1 ratio which is close to their thermal parity (Brown and Yucel, 2008; Hartley et al., 2008). None of these rules perform well over our sample. There have been periods, occurring more frequently, in which natural gas prices seemed to have decoupled from oil prices. During periods such as 2001, 2003, and 2005, natural gas prices rose above their historical relationship with oil prices. The facilities that are able to switch between natural gas and residual fuel oil declined (Brown and Yucel, 2008). More recently, especially after the discovery of hydraulic fracturing, natural gas prices dropped below this historical relationship. Moreover, these prices have recently exhibited high volatility, extreme movements and sharp spikes in responding to changes in geopolitical risk, economic factors, extraction and efficiency techniques, and occurrences of natural events. These factors and events have pushed those prices into the tails of the distributions during those periods.

Previous research concentrates on the investigation of the linear relationship between the two prices. Given the size of the global oil market relative to the regional natural gas markets, most of these studies find a stable long-run directional relationship between the two prices and a directional influence from the oil prices to the natural gas prices in the United States and the United Kingdom (Asche et al., 2006; Yucel and Guo, 1994). Recently, the movements of both prices have headed

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toward the opposite tails of their distributions, thus warranting a new examination.

The objectives of this study are: i) to examine the extreme comovements between the global benchmark prices of the WTI crude oil and Henry Hub natural gas in the tails of return distributions; ii) to discern the strength of relative dependence between these prices during bullish and bearish times such as the periods that predate and post-date the most recent financial crisis; and iii) to show the implications of these potentially asymmetric interactions on market risk forecasting for an oil and gas portfolio.

Compared to the existing literature, we make several significant contributions. First, given the recent development in the natural gas markets, we adopt a copula-GARCH approach to investigate the conditional dependence structure between the two markets. Precisely, we look at the tails of oil and gas return distributions, and examine both the degree and nature of their dependence at extreme levels conditionally on the possibility of extreme financial events such as the recent global financial crisis. As we subsequently define the co-exceedances as the joint occurrence of extreme negative return or extreme positive return (i.e., values below or above a certain pre-specified threshold), it is straightforward to explore how oil and gas returns are linked to each other during bear and bull market phases. Notice that the study of extreme comovement is an issue of particular importance if one wishes to design suitable diversification strategies and to build optimal portfolios of international assets in times of crises. In the past literature, a number of studies have investigated the issues of volatility transmission, correlation dynamics, and contagion effects between international financial markets using various econometric models (e.g., Abad et al., 2010; Forbes and Rigobon, 2002; Gilmore et al., 2008). They generally find evidence that cross-market correlation is time-varying and that it tends to increase in times of high volatility. Several studies have questioned the joint extreme movements of financial markets around the world (e.g., Bae et al., 2003; Baur and Schulze, 2005; Christiansen and Ranaldo, 2009; Longin and Solnik, 2001) and document asymmetric dependence patterns. To the extent that the oil and natural gas markets are characterized by crises of different sources and proportions, the copula approach is thus preferred to examine the asymmetry in the tail distributions of these markets, which is not the case for the family of the GARCH models.

Second, our extreme-value copula-GARCH approach allows one to capture nonlinearities in the oil–gas market relationships as well as some empirical stylized facts of their return distributions such as volatility persistence, fat tail behavior and asymmetric impacts of return innovations on volatility (Aloui and Jammazi, 2009; Arouri et al., 2011; Regnier, 2007; Sadorsky, 2006), while avoiding the drawbacks of linear measures of interdependence such as Pearson correlation. Previous studies have recognized the relevance and suitability of copula models in modeling the conditional dependence structure between financial variables (e.g., Aloui et al., 2011; De Melo Mendes, 2005; Jondeau and Rockinger, 2006; Palaro and Hotta, 2006). Moreover, the use of a more recent dataset, spanning the period from January 1997 through October 2011, enables one to account for several periods of long swings in the oil and gas prices, including for example the terrorist attacks on September 11, 2001 and the 2007–2009 global financial crisis which was sparked by the US subprime market failures. Our work is thus broadly related to these studies. However, we differ from them in that we focus on the extreme (tail) dependence of energy markets using a larger set of copula functions. For instance, Jondeau and Rockinger (2006) use the Gaussian and Student-t copulas to examine the dependency between four major stock markets (France, Germany, the United Kingdom, and the United States). Palaro and Hotta (2006) discuss the application of conditional copula approach in estimating the market risk of a portfolio composed of the Nasdaq and the S&P500 stock indices by using the symmetrized Joe-Clayton (SJC), Student-t and Plackett copulas.

Finally, we show the usefulness of the proposed copula-GARCH model in forecasting the market risk exposure of an equally-weighted oil and gas portfolio by examining the out-of-sample accuracy of Value-at-Risk (VaR) forecasts. We are here motivated by the fact that the VaR is nowadays the most widely used risk measure.[1] Over the past decades, it has been shown that risk models based on standard approaches (e.g., historical simulations and GARCH) are not adequate during crisis periods as they mostly fail to anticipate the extreme fluctuations that have realized (Aloui et al., 2013). Even though our article is not concerned of banks' asset portfolios, the application of our methodology to improve the internal market risk models of banks and financial institutions is straightforward.

Using daily global spot prices of the West Texas Intermediate (WTI) crude oil and the Henry Hub natural gas, we find that these oil and gas markets exhibit extreme dependence only during bull markets and that the Husler–Reiss copula is identified as the best model for describing their extreme dependence structure. Our results also indicate that the accuracy of a portfolio's market risk measure such as the *VaR* is significantly improved when our empirical extreme value copula-GARCH model (EVC-GARCH) is used. The evidence of joint extreme movements when markets go up can be possibly explained by the simultaneous impacts of increasing economic activities. Seemingly, the metaphor that the rising tide lifts all the boats applies here, but the opposite that a dropping tide drops all the boats does not. In an expanding economy, the industrial use of natural gas and the dual conversion capacity between oil and natural gas will increase. However, in a contracting economy the conversion capacity shrinks. Moreover, the industrial use of natural gas shrinks during crises as happened in the last global financial crisis. At time of recessions, major importers particularly in Europe also press for gas prices to be delinked from oil-indexed long-term supply contracts. Hub prices for natural gas are also not oil-linked prices particularity during recessions. Finally, gas markets require heavy investments for distribution as for liquid natural gas (LNG) and pipelines on long distances with multiple jurisdictions involved, necessitating longer term contracts and constrained their supply during strong economic expansion which is not the case during severe economic recessions.

The remainder of this article is structured as follows. Section 2 provides a review of the literature. Section 3 describes the empirical methodology and the estimation strategy. Section 4 presents the data used and discusses the empirical results. Section 5 provides some concluding remarks.

2. Review of the literature

The dynamic relationship between oil and gas markets has been investigated in the extant literature. Typically, this relationship has been approached by using simple correlations and deterministic trends. For example, Alexander (2004) finds strong correlation between returns on crude oil and natural gas futures contracts, but notes that this correlation cannot be modeled correctly by a bivariate normal distribution because of the potential of nonlinear dependence between the two return series as well as of the asymmetry of their return distributions. Moreover, when data have unit roots, such analysis is faulty and subject to spurious results.

With the advancement in time series econometric techniques, more rigorous analysis has been employed. Serletis and Herbert (1999) investigate the existence of common trends in natural gas prices at the Henry Hub and Transco Zone 6, the price of residual fuel oil at New York Harbor, and electricity prices at PJM (Pennsylvania, New Jersey, Maryland) power markets. Their results from unit roots and cointegration tests indicate that the three fuel prices are cointegrated, and that the Transco Zone

[1] The VaR has also been an integral part in banks' market risk management operations since being mandated by the Basel I Accord (Basel Committee, 1996), and continuing with Basel II. Recently, the Basel Committee also seeks to increase safety in the international financial system by proposing the Basel III, and investment banks should be involved as much as commercial banks.