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Modeling the co-movements between crude oil and refined petroleum markets

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ABSTRACT

In this paper we investigate two types of asymmetries, i.e., the asymmetry in the lower and upper tail dependences and the asymmetry in the propagation of crisis (bubble), between crude oil market and refined petroleum markets based on copula models. Thirteen copula models with different types of dependence structures and time-varying dependence parameters are considered. We find that in general the MALM copula fits our sample data best based on AIC criterion. We find that lower and upper tail dependences are both positive indicating that crude oil and refined product markets tend to move together. Using the asymmetric copulas, we find asymmetry in tail dependence between crude oil and heating oil returns and that between crude oil and jet fuel returns. Interestingly, upper tail dependence is significantly greater than the lower tail dependence for the pre-crisis period, while the result is reversed for the post-crisis period. Finally, although our data prefers the nonexchangeable MALM copula, the asymmetry in the propagation of crisis (bubble) between crude oil and refined product returns is very weak.

1. Introduction

Crude oil can be refined into many useful petroleum products, such as regular gasoline (RG), heating oil (HO), diesel fuel (DF) and jet fuel (JF). Strong co-movements are always found between crude oil and refined product prices. On the one hand, as an upstream product, crude oil price is an important driving force of the refined product prices. Thus a large movement in the crude oil price is usually accompanied by a large movement in the prices of the refined products. On the other hand, extreme increases in prices of refined products due to a demand shock can also ultimately drive up crude oil prices. From the beginning of 2003 to mid-2008 (Fig. 2), West Texas Intermediate (WTI) crude oil rose from some 37 dollars per barrel to a historic maximum of 145 dollars per barrel. Meanwhile the price of major refined petroleum products also moved upwards to reach historical summits. Joint dynamics between crude oil and refined products prices were also observed after the global financial crisis when oil and refined products prices both decreased in December 2008 and then gradually turned upwards again. Therefore, an understanding of the relationship between crude oil price and refined petroleum products prices is of great interest to policy makers and market participants.

Previous studies mainly focus on the responses of refined product prices to oil price changes. Bacon (1991) shows that retail motor gasoline prices adjust faster to crude oil price increases than to decreases in the United Kingdom. Borenstein et al. (1997) find that U.S. retail motor gasoline prices respond more quickly to crude oil price increases than decreases. Using a threshold cointegration analysis, Chen et al. (2005) provide new supportive evidence for asymmetric adjustment in U.S. retail gasoline prices. Notably, Bachmeier and Griffin (2003) estimate an error-correction model (ECM) with daily gasoline and crude oil spot price data but find no evidence of asymmetry. They argue that whether the responses of gasoline to crude oil price changes are asymmetric depends on the data frequency and model specification used.

Different from the previous literature which studies the lead–lag relationship between oil price and refined products prices, this paper aims to investigate their contemporaneous relationship, or how they co-move using copula methodology. In the literature several methods have been proposed to model the linkages between multiple variables, of which the multivariate Gaussian distribution is the most popular distribution assumption (Ang and Bekaert, 2002; Ang and Chen, 2002; Chakrabarti and Roll, 2002; Longin and Solnik, 1995). However, it has been generally accepted that the financial data is usually not Gaussian distributed (see, e.g. Longin and Solnik, 2001). The inference based on Gaussian assumption might be misleading if the data is not Gaussian distributed (Embrechts, 2009a,b; Embrechts et al., 2002). Moreover,

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the correlation between assets under extreme conditions cannot be distinguished using a multivariate Gaussian model, which focuses more on the normal conditions.

The copula approach enables us to identify the dependence structures and to capture the potential nonlinear relation between variables of interest. Copula theory was first introduced in Sklar (1959), which states that the joint multivariate density function can be decomposed into density of each variable and a component known as the copula density, which contains all information on the dependence structure of related variables. This property offers flexibility for us to model the dependence structures of related variables independently from their marginal distributions, and hence stressing the advantage of copula theory over standard classical methods. Moreover, the copula approach can distinguish the dependence between variables of interests under normal and extreme conditions, which are very important for risk management and portfolio allocation.[1] For instance, through an out-of-sample analysis, Patton (2004) finds that knowledge of asymmetric tail dependence leads to gains that are both economically and statistically significant for an investor with no-short-sale constraints. Stefanova and Elkamhi (2011) demonstrate that there is a substantial welfare loss in disregarding tail dependence, even when dynamic conditional correlation has been accounted for, and vice versa.

While there is extensive literature on the static (dynamic) dependence structure in international financial markets, the studies on the application of copula functions in energy markets are few. Reboredo (2011) examines the dependence structure between different crude oil benchmarks using several copula models with different conditional dependence structures and finds no evidence of asymmetric upper and lower tail dependences. Lu et al. (2011) apply the copula-GARCH model to estimate Value-at-Risk (VaR) of an equally weighted portfolio comprising crude oil futures and natural gas futures in energy market. Additionally, using several copulas, Reboredo (2012b) studies the comovement between oil prices and food prices and finds no extreme market dependence between these variables. Reboredo (2012a) shows that oil price-exchange rate dependence is in general weak, although it rose substantially in the aftermath of the global financial crisis. Serra and Gil (2012) study the dependence between crude oil and biodiesel blend prices in Spain using copula functions and find that the practice of blending biodiesel with diesel can protect consumers against extreme oil price increases. More recently Reboredo (2013) analyses the dependence structure between gold and oil markets and finds that there is significantly positive average dependence and tail independence.

Unfortunately, to the best of our knowledge, there has been no study on the dependence structure between crude oil market and refined petroleum markets based on copula functions. In the present paper we try to fill this gap. Since the oil and refined petroleum markets are highly intergraded (see e.g. Asche et al., 2003), a better understanding of the dependence structure between crude oil and refined products would be critical, not only for risk management practices but also for asset allocation to market participants, especially to oil companies who manage a portfolio of oil and gas assets. We specifically aim to answer the following questions: What is the dependence structure between crude oil and refined petroleum markets? Is the dependence symmetric or asymmetric? Has the dependence changed since the advent of the global financial crisis? By answering these questions we hope to improve the understanding of relationship between crude oil and refined petroleum products.

The contribution of the present paper is twofold. First, we use copula-GARCH models to characterize the dependence structure between crude oil market and four refined petroleum markets, i.e., regular gasoline (RG), heating oil (HO), diesel fuel (DF) and jet fuel (JF). Eight time-invariant copula models are employed in this paper, which are Gaussian copula, Student-*t* copula, Clayton copula, Gumbel copula, mixed Clayton copula (MCl), mixed Gumbel copula (MGu), asymmetric logistic model copula (ALM), and mixed asymmetric logistic model copula (MALM). Besides, so as to model the possible time-varying dependence structures, we also include five time-varying copula models, which are time-varying Gaussian copula, time-varying Student-*t* copula, time-varying MCl copula, time-varying MGu copula and time-varying MALM copula. Following Patton (2006b), the time-varying parameter is the correlation parameter for the first two, while weight parameter for the rest of the mixture copula models (Ning, 2009). These copulas can model different dependence structures, especially under extreme market conditions.

Second, the copulas used in this paper allow us to assess two patterns of asymmetry in dependence structure, namely, the asymmetry between lower and upper tail dependences, and the asymmetry in the propagation of crisis (bubble) in energy markets (Vaz de Melo Mendes, 2005). We use copulas that allow for asymmetric lower and upper tail dependences to characterize the first type of asymmetry. Besides, given the fact that previous literature illustrates the asymmetry in the price movements of refined petroleum products against crude oil price, we use the nonexchangeable copula to model the asymmetry in the propagation of crisis (bubble). A copula function $C(u, v)$ is exchangeable if $C(u, v) = C(v, u)$, and this family of copula models is commonly used in the previous literature. For instance, all meta-elliptical and Archimedean copulas are exchangeable (Cherubini et al., 2004; Nelsen, 2006). The exchangeability implies that the conditional probability that a crash occurs in one market given that a catastrophic event has occurred in the other is the same as the probability computed the other way around. Being downstream products, the price of refined products are driven by the crude oil price (Asche et al., 2003), therefore the propagation of crisis (bubble) might be faster in one direction than the other way around. The empirical results are consistent with our conjecture. We find that in general the MALM copula, which can characterize two types of asymmetry, fits the data best according to Akaike information criterion (AIC).

The remainder of the paper is structured as follows. In Section 2, we specify the models and the estimation method. Section 3 provides the empirical results. Section 4 concludes.

2. Model specification and estimation

2.1. Marginal models

It has been well documented in the previous literature that financial asset returns, especially when measured over short time intervals (i.e., daily or weekly), show several stylized features such as serial correlation, fat-tails, and volatility clustering. Among others, the GARCH family models pioneered by Engle (1982), Bollerslev (1986), and Nelson (1991), are most popular to model individual time series (see e.g. Lu et al., 2011; McNeil and Frey, 2000; Ning, 2010). Meanwhile, as Reboredo (2011) and Lu et al. (2011) find that the Student *t* distribution fits the univariate distribution of the crude oil daily return quite well, in this paper, we model each marginal return series using the ARMA(p,q)-GJR(1,1) model and ARMA(p,q)-GARCH(1,1) model, with Student *t*-distributed innovations. Specifically, let (r_t) be the percent return at day t proxied by the first order difference of price of oil or a refined product (logarithmically) multiplied by 100. The model is given as

$$r_t = \phi_0 + \sum_{j=1}^{p} \phi_j r_{t-j} + \varepsilon_t - \sum_{i=1}^{q} \theta_i \varepsilon_{t-i}, \tag{1}$$

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \psi \varepsilon_{t-1}^2 I_{t-1} + \beta h_{t-1}, \tag{2}$$

$$\varepsilon_t = \eta_t \sqrt{h_t}, \quad \eta_t \tilde{\ } f(0,1), \quad i.i.d. \tag{3}$$

[1] There is a considerably large body of literature on copula theory and its applications in finance and econometrics. See (Cherubini et al., 2004; Chollete et al., 2009; Genest et al., 2009a; Hafner and Manner, 2010; Hu, 2006; Joe, 1997; Jondeau and Rockinger, 2006; Okimoto, 2008; Patton, 2012; Wu et al., 2012). The latter two papers summarize and review copula-based methods in the literature for economic time series.