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Analyzing volatility spillovers and hedging between oil and stock markets: Evidence from wavelet analysis

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ABSTRACT

This paper examines the linkage of crude oil market (WTI) and stock markets of the G-7 countries. We study the mean and volatility spillovers of oil and stock market prices over various time horizons. We propose a new approach incorporating both multivariate GARCH models and wavelet analysis: wavelet-based MGARCH approach. We combine a bivariate GARCH-BEKK model with wavelet multiresolution analysis in order to capture the multiscale features of mean and volatility spillovers between time series. For optimal portfolio allocation decisions, we analyze the multiscale behavior of hedge ratio. Empirical results show strong evidence of significant volatility spillovers between oil and stock markets, as well as time-varying correlations for various market pairs. However, results of wavelet coherence indicate that in most, the WTI market was leading. In addition, it is stated that the decomposed volatility spillovers permit investors to adapt their hedging strategies.

1. Introduction

Multivariate generalized conditional heteroskedasticity (MGARCH) models have been widely used in the empirical studies to estimate the volatility spillover effects among different markets. In this study, we used bivariate GARCH models to simultaneously estimate the mean and conditional variance of oil and stock market prices. We employ a BEKK representation of the multivariate GARCH model, which has been widely used in order to study the international linkage of multiple markets. Specifically, we adopt a bivariate GARCH(1,1)-BEKK model which allows us to study the volatility transmission between global oil market and stock markets of G-7 countries. It is important for energy and financial researchers, market participants and policy makers to understand the volatility spillover effects from one market to another.

While previous works have examined the mean and volatility transmission between oil markets and stock markets using the return time series and a full period framework, in this paper we develop a new approach which examines the volatility spillover of oil and stock market prices on level prices (without computing returns of the original series) and the multiscale behavior, in order to study the spillover effects from oil markets and the G-7 stock markets at different time horizons. We combine the multivariate GARCH models and wavelet multiresolution analysis. In our work we study the spillover effects using level prices.

The link between oil markets and stock markets has been investigated by a large number of researchers. Recently, there has been an increasing interest in modeling the equity volatility and analyzing the volatility transmission mechanism that exists across major financial markets. Nevertheless, studies focusing on relationship between major developed financial markets and global crude oil market are limited. Some papers have explicitly examined the transmission of mean and volatility across oil and financial markets, for instance Malik and Hammoudeh (2007) studied the volatility and shock transmission between US equity market, global crude oil market, and equity markets of major rich Gulf countries

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(Saudi Arabia, Kuwait, and Bahrain). Arouri and Nguyen (2010) studied the relationship between oil price changes and stock returns at the disaggregated sector level in Europe by investigating their short term linkages over the last turbulent decade using different econometric techniques. Singh et al. (2010) examined the temporal volatility spillovers between developed and emerging stock markets using VAR–GARCH models. Zhang and Wei (2010) tested the relation between the crude oil and gold markets from January 2000 to March 2008. Arouri et al. (2011) analyzed the return links and volatility transmission between oil and stock markets in the Gulf Cooperation Council (GCC) countries. Filis et al. (2011) studied the time-varying correlation between stock market prices and oil prices for oil-importing and oil-exporting countries based on a DCC–GARCH–GJR approach. Vo (2011) models the volatility of stock and oil futures markets using the multivariate stochastic volatility structure. Du et al. (2011) tested the factors that have a potential influence on the volatility of crude oil prices and the relationship between this volatility and agricultural commodity markets. Kumar et al. (2012) argued that the variation in the indices of clean energy stocks is explained by past movements in oil prices, the stock prices of high technology firms and interest rates. Sadorsky (2012) modeled the volatility dynamics between oil and the stock prices of clean energy and technology companies using the dynamic conditional correlation MGARCH models and Awartani and Maghyereh (2013) investigated return and volatility spillover effects between oil and equities in the GCC countries during the period from 2004 to 2012.

A number of previous studies dealing with wavelet filter are applied in financial literature. For instance, see Gencay et al. (2002, 2005) proposal of a new approach based on wavelet analysis to estimate the systematic risk of some stock market indices, Fernandez (2006) estimated the beta in capital asset pricing model (CAPM) at different time-scales in order to study the impact of time scaling on the computation of value-at-risk. Kim and In (2007) studied the relationship between changes in stock prices and bond yields in the G7 countries. Rua and Nunes (2009) analyzed the co-movement among international stock market returns by developing a new approach based on wavelet analysis. He et al. (2009) analyzed the crude oil prices using wavelet analysis and artificial neural network technique. Masih et al. (2010) analyzed stocks in emerging Gulf Cooperation Council (GCC) equity markets by wavelet analysis. Gallegati (2010) tested the financial market contagion using a wavelet-based approach. Boubaker and Boutahar (2011) focused on modeling the conditional mean and conditional variance of exchange rates. They estimated the GARMA–FIGARCH model using the wavelet-based maximum likelihood estimator. Sun and Meinl (2012) proposed a new filtering algorithm based on MODWT to decompose pattern and noises and Fernández-Macho (2012) analyzed the correlation and the cross-correlation of the Eurozone stock market returns on a scale-by-scale basis.

In this study we show strong evidence of GARCH(1,1)–BEKK model to analyze the volatility spillover effects of oil market and the G-7 developed stock markets. The results show evidence of significant volatility spillovers between oil and stock markets, as well as time-varying correlations for various market pairs.

In addition, we extend our methodology to portfolio diversification strategies, which is the most important objective of market participants and market makers. We analyze the hedge ratio and hedging effectiveness across different time horizons. We define the wavelet hedge ratio and wavelet portfolio allocations. The results of wavelet hedging showed that hedge ratios are different across scales and the investor can easily understand the decision strategy by choosing the minimum portfolio risk.

The rest of the paper is organized as follows: Section 2 presents the wavelet methodology. Section 3 describes the wavelet-based MGARCH approach to study the mean and volatility spillovers among oil and stock markets. Discussion of the empirical results is given in Section 4. Section 5 concludes and the last section reports the appendix.

2. Wavelet approach

2.1. Multiresolution analysis

Wavelet theory is a powerful mathematical tool for time series analysis. It has attracted an increasing interest of economists in the last years. It provides a time–frequency representation of a time series X_t (in our study, X_t is the daily oil spot price and daily stock market index), and it can be used to analyze non-stationary time series, which are very common in finance and economics, given the continuous presence of abrupt changes and volatility. Recently, this methodology has received great interest in the financial literature including those of Gencay et al. (2005), Kim and In (2007), Rua and Nunes (2009), He et al. (2009), Genest et al. (2009), Masih et al. (2010), Rua (2010), He et al. (2012) and Jammazi (2012).

The wavelet transform uses multiresolution analysis by which different frequencies are analyzed with different resolutions.[1] For these multiresolution analyses, few conditions must be satisfied: let $L^2(\mathbb{R})$ be the space of square-integrable functions. Now consider a sequence of closed sub-spaces $\{W_k\}_{k=j}^{\infty}$ (relative to the detail spaces of the series) and V_j (relative to the approximation of the series) of $L^2(\mathbb{R})$, such that $V_j \subset V_{j+1}$ and $\cap_j V_j = 0$, and $\cup_j V_j = L^2(\mathbb{R})$, which indicates that all integrable functions should be included at the highest resolution. Moreover, we say that V_j is a multiresolution if it satisfies the following conditions:

i. dilation invariance: $X(t) \in V_j \Leftrightarrow X(2t) \in V_j$.
ii. translation invariance: $X(t) \in V_0 \Leftrightarrow X(t+1) \in V_0$.
iii. there is a scaling function $\phi(t) \in V_0$ (also called father wavelet) such that $\phi(t-k)$ is an orthonormal basis of V_0.

$$\phi_{j,k}(t) = 2^{j/2}\phi\left(2^j - k\right) \tag{1}$$

where the level j controls the degree of stretching of the function (the larger the j, the more stretched is the basis function); the smaller the time scale, the higher the frequency of the decomposed series, and k is the parameter that controls the translation of the basis function.

Assuming that the detail spaces, $\{W_j\}$, are orthogonal to each other, we can define a sequence $\{\psi_{j,k}(t)\}_k$ of orthonormal basis functions that spans $L^2(\mathbb{R})$:

$$\psi_{j,k}(t) = 2^{j/2}\psi\left(2^j t - k\right) \tag{2}$$

where wavelets are generated by shifts and stretches of the mother wavelet, $\psi_{j,k}(t)$. Let $X(t)$ be the original time series, we represent the multiresolution representation of $X(t)$ by:

$$\begin{aligned} X(t) &= \sum_k s_{j,k}\phi_{j,k}(t) + \sum_j \sum_k d_{j,k}\psi_{j,k}(t), \quad j = 1, \dots, J \\ &= S_J(t) + D_J(t) + D_{J-1}(t) + \dots + D_1(t) \end{aligned} \tag{3}$$

where

$$\mathrm{S}_J(\mathrm{t}) = \sum_k \mathrm{s}_{j,k}\phi_{j,k}(\mathrm{t}) \tag{4}$$

$$\mathrm{D}_j(\mathrm{t}) = \sum_k \mathrm{d}_{j,k}\psi_{j,k}(\mathrm{t}). \tag{5}$$

The series $S_J(t)$ provides a smooth of original time series $X(t)$ and represents the approximation that captures the long term properties (i.e. the low-frequency dynamics), and the series $D_j(t)$ for $j = 1, \dots, J$ refers to wavelet details and captures local fluctuations (i.e. the higher-frequency characteristics) over the whole period of $X(t)$ at each scale. The expression (3) represents the decomposition of $X(t)$

[1] For more details, see Mallat (1989) and Percival and Walden (2000).