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Time-varying Granger causality tests for applications in global crude oil markets

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ABSTRACT

This paper proposes time-varying Granger causality tests based on the tests developed by Hong (2001) and two dynamic correlation estimators (i.e., rolling correlation and dynamic conditional correlation multivariate GARCH), here called the rolling Hong and DCC-MGARCH Hong tests, respectively. The proposed tests are used to examine time-varying information spillover among global crude oil markets. The results provide empirical evidence of time-varying information spillover. In particular, the instantaneous causal effects of Dubai and Tapis crudes on Brent and WTI become stronger when a major event or events occur in major oil-producing countries. Such events include the Iraq War in March 2003, OPEC's announcement of a record production cut in December 2008, and the Libyan civil war in early 2011. And consistent with previous studies, WTI and Brent play dominant roles in global crude markets. Impulse response analysis shows that market information has a positive influence on the spillover effect in global crude oil markets. Moreover, the DCC-MGARCH Hong test consistently leads the rolling Hong test, which indicates that the former performs better.

1. Introduction

It is quite possible that the causal relationships and information spillover among financial markets change over time. Financial and economic environments usually vary with time. For example, with economic globalization, financial markets have become more and more integrated, and the development of telecommunication technology has made information transmission quicker. Certain major events, such as global financial crises and wars also have considerable impact on investors' confidence and asset allocation behaviors, which may lead to financial contagion. Changes in causal relationships among financial markets usually indicate varying patterns, so it is important to detect and assess these dynamic causal relationships.

The Granger causality test has attracted much attention. Many different methods have been proposed since Granger first introduced the concept of causality in 1969. The most widely used test methods are based on vector autoregression (VAR) models introduced by Sims (1972). Other regression models, such as VECM, GARCH, MGARCH, and some nonlinear models, have also been used to test Granger causality thereafter. The CCF-test methods based on cross correlation functions (CCF) are also used in these situations. Haugh (1976) proposed an asymptotically χ^2 test based on the residual cross correlations to test Granger causality in mean. Cheung and Ng (1996) extended the tests proposed by Haugh (1976) to test causality in variance. Hong (2001) proposed test statistics, which included Cheung and Ng (1996) test and Granger (1969)-type test as the special cases. Because Granger causality tests are very useful for analysis of causal relationships and forecasting, they have been widely applied in economics and finance.

Recently, time-varying Granger causality has attracted much attention from researchers, and a few new tests have been proposed. Aaltonen and Östermark (1997) used a rolling Granger causality test (rolling F-test) with a window length of 150 to examine time-varying Granger causality between the Finnish and Japanese securities markets in the early 1990s. Cogley and Sargent (2001) built Bayesian VAR with time-varying parameters for inflation, unemployment, and interest rate to study the dynamics of inflation in the United States. Cogley and Sargent (2005) built a VAR with drifting coefficients and stochastic volatilities for quarterly inflation, nominal interest, and unemployment and examined the changes in monetary policy rules in the U.S. after World War II. Primiceri (2005) proposed a time varying structural VAR, where the coefficients and the variance covariance matrix of the innovations vary over time. They used the model to

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Table 1
Descriptive statistics for returns of WTI, Brent, Dubai and Tapis crudes.

Returns	WTI	Brent	Dubai	Tapis
Mean	0.070	0.075	0.079	0.078
Maximum	16.410	12.707	16.477	15.054
Minimum	−13.065	−12.744	−12.508	−11.589
Standard deviation	2.493	2.259	2.117	2.114
Skewness	−0.050	−0.199	−0.302	−0.250
Kurtosis	7.062	5.773	6.968	6.989
Jarque–Bera test	1706.101	811.128	1664.460	1669.838
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
ADF (Augmented Dickey–Fuller) test	−51.521	−52.837	−52.689	−34.673
	[0.0001]	[0.0001]	[0.0001]	[0.0000]
Q(5)	13.954	12.101	13.050	37.515
	[0.016]	[0.033]	[0.023]	[0.000]
Q(10)	16.095	16.150	24.771	48.819
	[0.097]	[0.095]	[0.006]	[0.000]
Observations	2480	2480	2480	2480

Note: Q(5) and Q(10) are the Box–Pierce statistics for 5th and 10th order serial correlations, and values in [] are t-values.

study the dynamics of the inflation–unemployment relationship in the United States. Christopoulos and León-Ledesma (2008) proposed a time-varying parameter VAR model (LSTAR-VAR) for the study of the money–output relationship using quarterly U.S. data.

Several papers also have tested causal relationships among global crude oil markets, but few have focused on time-varying causality. Brunetti and Gilbert (2000) applied cointegrated bivariate FIGARCH models to the New York Mercantile Exchange (NYMEX) and IPE crude oil markets and found that NYMEX played a dominant role. Lin and Tamvakis (2001) used GARCH and VAR to study NYMEX and IPE crude oil markets and observed substantial spillover effects when both markets were trading simultaneously. Hammoudeh and Li (2004) used VECM to examine the impact of the Asian crisis on the behavior of U.S. and international petroleum prices. They found that the causal relationships in the post-crisis period had either changed the direction or weakened. Lin and Tamvakis (2004) examined information spillover between Brent and WTI futures with an autoregressive conditional duration (ACD) model and found that NYMEX had a dominant effect on Brent. Bentzen (2007) examined the causal relations among Brent, OPEC, and WTI crude prices. They found causality was most likely to be bi-directional. Lu et al. (2008) used Hong (2001) tests to study information spillover among WTI, Brent, Dubai, Tapis, and Minas crudes. Results showed that WTI and Brent crudes were dominant and that WTI crude oil futures had a slight edge over Brent. Fan et al. (2008) used Hong (2001) tests to examine spillover in value-at-risks between WTI and Brent. They found significant two-way risk spillover effects. Bekiros and Diks (2008) investigated the linear and nonlinear causal linkages between daily spot and futures prices of WTI crude oil. Chai et al. (2011) applied BVAR-TVP to the analysis of dynamic impacts of core factors on oil prices.

To sum up, most studies on Granger causality among crude oil markets have been performed using the static view. They only show the average spillover effect and cannot describe the dynamics of Granger causality, although some researchers have shown that the causal relationships in some periods are different (e.g. Hammoudeh and Li, 2004; Lu et al., 2008). For this reason, the time-varying causal relationships among global crude oil markets are examined in the present study. Because the performance of some existing methods, such as the rolling Granger causality test and LSTAR-VAR, may suffer from ARCH effects, new methods allowing for ARCH effects are proposed in this paper.

In this paper, time-varying causality tests based on Hong's tests[1] and two dynamic correlation estimators, i.e., rolling correlation and dynamic conditional correlation multivariate GARCH (DCC-MGARCH), are proposed. They are here called rolling Hong tests and DCC-MGARCH Hong tests, respectively. The rolling Hong tests follow asymptotically standard normal distributions N(0,1). Because DCC-MGARCH is usually more suitable for dynamic correlation than rolling correlation method, it is here suggested that DCC-MGARCH Hong tests perform better than rolling Hong tests. Instantaneous time-varying causality tests are also built, because there may be instantaneous (contemporary) information spillover due to nonsynchronous trading.

The contributions of this paper are as follows. First, new time-varying causality tests are proposed. The widely used time-varying parameter VAR models can detect time-varying causal relationships, but they cannot show the overall causal effects of different variables (Cogley and Sargent, 2005; Primiceri, 2005). The current tests not only show time-varying causal relationships but also their overall (bidirectional) causal effects, which makes it suitable for time-varying market integration and financial contagion. Second, few papers have examined the dynamic causal relationships among global crude oil markets. The present research fills this gap using the proposed time-varying causality tests.

The structure of this paper is as follows. Section 2 describes the proposed rolling Hong and DCC-MGARCH Hong tests. Section 3 reports on applications of the proposed tests for time-varying information spillovers among global crude oil markets, and some factors that affect time-varying Granger causality are also tested. Section 4 gives conclusions.

2. Time-varying Granger causality tests

To test Granger causality of two time series, Hong (2001) proposed one-sided asymptotically normal tests based on the cross correlation function (CCF) of standardized residuals. Consider two stationary time series $\{y_{i,t}, t = 1, \ldots, T\}$, $i = 1, 2$, where T is the sample size. Suppose that

$$y_{i,t} = E\left(y_{i,t}|I_{i,t-1}\right) + \varepsilon_{i,t} = E\left(y_{i,t}|I_{i,t-1}\right) + \sqrt{h_{i,t}}u_{i,t}, i = 1, 2 \tag{1}$$

where $I_{i,t}$ is the information set of time series $\{y_{i,t}\}$ available at period t, and $E(y_{i,t}|I_{i,t-1})$ is the conditional mean of $y_{i,t}$. The residuals $\left\{\varepsilon_{i,t} = \sqrt{h_{i,t}}\, u_{i,t}\right\}$ may be heteroskedastic, where $u_{i,t}$ is the standardized residuals and $h_{i,t}$ is the conditional variance of $\varepsilon_{i,t}$. Denote r_j as the cross correlation of standardized residuals[2] $\{u_{i,t}, t = 1, 2 \ldots, T\}$, $i = 1, 2$ with lag j, $j = 0, \pm 1, \pm 2, \ldots, \pm(T-1)$:

$$r_j = \begin{cases} \dfrac{\sum_{t=j+1}^{T} u_{1,t}u_{2,t-j}/T}{\sqrt{\sum_{t=1}^{T} u_{1,t}^2/T}\sqrt{\sum_{t=1}^{T} u_{2,t}^2/T}}, j \geq 0 \\ \dfrac{\sum_{t=1-j}^{T} u_{1,t-j}u_{2,t}/T}{\sqrt{\sum_{t=1}^{T} u_{1,t}^2/T}\sqrt{\sum_{t=1}^{T} u_{2,t}^2/T}}, j < 0. \end{cases} \tag{2}$$

Then the unidirectional Granger causality test from y_1 to y_2 is defined as follows:

$$H_1 = \frac{T\sum_{j=1}^{T-1} k^2\left(\frac{j}{M}\right) r_j^2 - C_{1T}(k)}{\sqrt{2D_{1T}(k)}}. \tag{3}$$

The bidirectional Granger causality test is defined as follows:

$$H_2 = \frac{T\sum_{j=2-T}^{T-2} k^2\left(\frac{j}{M}\right) r_j^2 - C_{2T}(k)}{\sqrt{2D_{2T}(k)}} \tag{4}$$

where M is a positive integer and k(x) is the kernel function. $C_{1T}(k)$, $C_{2T}(k)$, $D_{1T}(k)$, and $D_{2T}(k)$ are determined by k(x) and the sample size T. Under certain regularity conditions, if $\{y_{i,t}\}$, $i = 1, 2$ are mutually independent, H_1 and H_2 are asymptotically distributed as the standard normal

[1] Monte Carlo simulations performed by Hong (2001) showed that Hong's tests to perform better than some traditional Granger tests (such as Granger F test, test proposed by Haugh (1976)). For this reason, the present time-varying causality tests are based on Hong's tests.