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The relationship between regional natural gas markets and crude oil markets from a multi-scale nonlinear Granger causality perspective

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ABSTRACT

This study first decomposes the daily returns of regional gas and crude oil at different time scales, using the ensemble empirical mode decomposition (EEMD) method. It then investigates the causality relationship between each pair of components at the different time scales, by employing the linear and nonlinear Granger causality tests. For the original returns series, this study finds that unidirectional linear Granger causality exists from crude oil markets to North American and European gas markets. However, for nonlinear characteristics, the crude oil and regional gas markets exhibit bidirectional nonlinear Granger causality. On the medium-term time scale, a bidirectional nonlinear spillover effect is found between the markets. The long-term trends for the markets suggest a significant linear relationship; however, no nonlinear spillover effect is found between the crude oil and regional gas markets.

1. Introduction

To address climate change and ensure energy supply security, many countries have increased the proportion of natural gas for primary energy consumption. Currently, the global natural gas market is divided into three distinct regional markets: North America, Europe and Asia. For different regional natural gas markets, the level of market development and pricing mechanisms vary. Early on, all regional natural gas markets were primarily based on crude oil prices, which were used as a pricing benchmark. Along with the development of the markets, the pricing mechanism of different regional natural gas markets changed. Currently, the pricing mechanism is based on the market supply and demand in the North American natural gas market, while European and Asian markets are mainly still indexed to crude oil prices. Although pricing mechanisms have changed, the link between natural gas prices and crude oil prices remains strong (Brown and Yücel, 2008). These markets exhibit complex dynamic relationships; in particular, recent increases in global liquefied natural gas trade year-over-year and the appearance of the North American shale gas revolution could change the relationships between regional natural gas markets and the crude oil markets. Analysing the spillover effects between regional natural gas markets and the crude oil markets can reveal the dynamic characteristics of regional markets. This is important information for energy policy makers and energy-related financial institutions to have for the development of appropriate energy policies and to make appropriate decisions to avoid market risks.

The dynamic relationship between natural gas and crude oil prices is very complex. In particular, fluctuations in both crude oil prices and natural gas prices have shown inner multi-scale characteristics; these include, for example, short-term market fluctuations, medium-term fluctuations caused by minor irregular and significant events, and long-term trend (Geng et al., 2016a; Zhang et al., 2008). Therefore, this research analyses the dynamic relationship between crude oil prices and regional natural gas prices from a multi-scale perspective, which is useful for energy policy makers, energy-related financial institutions and investors with various horizons with respect to their strategic investment and risk management decisions. Additionally,

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nonlinearity property and structure has been found to exist in crude oil and regional natural gas markets. The existence of these nonlinearities might owe to nonlinear transaction costs, the role of noise traders, and to market microstructure effects, or to an asymmetric adjustment process in the crude oil and regional natural gas markets (Bekiros and Diks, 2008; Chiou-Wei et al., 2008; Silvapulle and Moosa, 1999). The existence of jumps and extreme volatility in the crude oil and regional natural gas prices can also create such nonlinearity (Wilson et al., 1996; Yaya et al., 2015). In addition, regime changes such as some significant changes in economic circumstances, significant economic events, and changes in energy policy can also create structural changes in the pattern of crude oil and regional natural gas prices (Fan and Xu, 2011; Geng et al., 2016a, 2016b; Zhang et al., 2008). Hence, crude oil and regional natural gas markets are expected to exhibit a nonlinear relationship. This study undertakes linear and nonlinear Granger causality tests to analyse the linking mechanisms between these two kinds of markets.

Many studies have indicated that there exists a long-term cointegration relationship between the natural gas and crude oil markets (Hartley et al., 2008). Villar and Joutz (2006) analysed the relationship between Henry Hub and West Texas Intermediate (WTI) prices, and the results showed that the prices exhibited a long cointegration relationship. Asche et al. (2006) found that after the deregulation of the natural gas market in the UK, natural gas prices had a long cointegration relationship with crude oil prices. Panagiotidis and Rutledge (2007) analysed the relationship between UK natural gas prices and Brent crude oil prices from 1996 to 2003, and the results showed that there was a cointegration relationship between the two prices. In this case, the shock that the crude oil market suffered also had an impact on natural gas prices—there was no separation between crude oil and natural gas prices. Ates and Huang (2011) used the recursive cointegration estimation method to analyse the relationship between crude oil and natural gas prices, and the results indicated that there existed a stable long-term equilibrium relationship between prices. Asche et al. (2012) found that the relationship between natural gas and crude oil prices varied in the short term but remained in an equilibrium relationship in the long term. Ramberg and Parsons (2012) suggested that despite natural gas prices having a transient separation from crude oil prices, natural gas and crude oil prices still maintained a long-term cointegration relationship. Brigida (2014) found although natural gas and crude oil prices exhibited a temporary shift in the early 2000s, they had the long-term equilibrium relationship.

The recent North American shale gas revolution may cause natural gas prices to disconnect from crude oil prices. Erdős (2012) found that the US and UK natural gas prices remained in a long-term equilibrium relationship with crude oil prices before 2009; after 2009, the relationship remained unchanged in the UK, while US natural gas prices disconnected from crude oil prices. Loungani and Matsumoto (2012) found that US natural gas prices had separated from crude oil prices, perhaps due to the US shale gas revolution, which caused a sudden increase in natural gas production in the United States, resulting in an oversupply of natural gas. Geng et al. (2016b) analysed the relationship between regional natural gas markets and crude oil markets, and the results showed that North American natural gas prices deviated from crude oil prices while European gas prices remained in a stable, long-term equilibrium relationship with crude oil prices.

The nature of the spillover effect between the natural gas and crude oil markets remains unclear. Some scholars believed there was only a unidirectional effect, from crude oil to natural gas prices. Pindyck (2004) analysed the interrelationship between crude oil and natural gas returns since 1990, and the results showed crude oil price returns had impacted on natural gas price returns but not the other way around. Brown and Yücel (2008) considered the impact of seasonality, weather, natural gas inventory and reduction of natural gas production, among other factors, on natural gas prices. The results showed that crude oil prices played an important role in the determination of natural gas prices when additional factors were considered. Nick and Thoenes (2014) used a structural vector autoregression model to analyse the German natural gas market and found that natural gas prices were primarily affected by crude oil prices in the long term. Ji et al. (2014) found that crude oil price fluctuations had a negative impact on import prices in three regional natural gas markets with a varied degree of response, while the response of natural gas import prices to the increases and decreases in crude oil prices revealed an asymmetric mechanism for the three regional markets, in which the impact of the decrease was relatively stronger. Recently, some scholars have pointed out that in addition to crude oil prices having an impact on natural gas prices, the natural gas market has an impact on the crude oil market. Tonn et al. (2010) found that the price volatility of crude oil and the North American natural gas markets were mutually influenced by each other. Ramirez and Karali (2014) showed that there was a bidirectional volatility spillover effect between crude oil and natural gas markets. Wolfe and Rosenman (2014) also found that the crude oil market and North American natural gas market impacted each other using the price volatility of intraday oil and gas futures contract. Yoncu and Bahramian (2015) showed that there was a bidirectional causality relationship between natural gas and crude oil prices among European regional markets. Lin and Li (2015) used the VEC-MGARCH model to analyse volatility spillover effects between the crude oil market and North American, European and Asian regional natural gas markets, and the results showed that there was a bidirectional volatility spillover effect between the crude oil prices and natural gas prices in the North American and European markets, but this effect did not exist in the Asian market.

The above literature primarily analysed relationships between natural gas and crude oil markets for the original data series, and the conclusions of the existence of a dynamic relationship between the crude oil and natural gas markets are inconsistent. Both market systems are complex with multi-scale characteristics. On different time scales, internal impact mechanisms of the natural gas and crude oil markets are different, which makes the linear and nonlinear Granger causality between the two markets differ at different time scales. This research comprehensively investigates the linear and nonlinear dynamic relationships between daily regional natural gas and crude oil returns from a multi-scale perspective. Generally, this paper makes two main contributions: (1) A multi-scale analysis approach to comprehensively analyse the complex relationship between regional natural gas markets and crude oil markets can identify the internal impact mechanisms of the link between the two kinds of markets at different time scales; (2) A nonlinear Granger causality test is applied to further analyse the contemporaneous causality between regional natural gas and crude oil markets at different time scales.

This paper is organised as follows. Section 2 describes the ensemble empirical mode decomposition (EEMD) method, the linear and nonlinear Granger causality test methods and the data sources. Section 3 presents the empirical results and discussions. Finally, Section 4 presents the conclusions and policy implications of this research.

2. Methodology and data sources

This paper uses the EEMD method and linear and nonlinear Granger causality tests to analyse the market relationships. First, natural gas and crude oil market returns are decomposed using the EEMD method. Then, the linear and nonlinear Granger causality relationships between each pair of decomposed components for the natural gas and crude oil market returns are analysed.

2.1. EEMD method

The EEMD method is developed by Wu and Huang (2009), based on the empirical mode decomposition proposed by Huang et al. (1998). Compared to the wavelet decomposition and other traditional decomposition methods, the EEMD method has several advantages. Firstly, the EEMD method can deal with nonlinear and non-stationary data