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Evolution of the world crude oil market integration: A graph theory analysis

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ABSTRACT

This paper investigates the evolution of the world crude oil market and the pricing power for major oil-producing and oil-consuming countries using graph theory. A minimal spanning tree for the world crude oil market is constructed and some empirical results are given. The integration of the world crude oil market is verified. Furthermore, the world crude oil market is characterised as a geographical and organisational structure. The crude oil markets of adjacent countries or regions tend to link together, while OPEC is well-integrated. We also found that the links in the South and North American region and the African region are relatively stable. The crude oil markets in the U.S., Angola and Saudi Arabia take up the core, with a higher 'betweenness centrality' and lower 'farness', whereas the markets in the East and Southeast Asian countries are on the fringe. Finally, the degree of globalisation for the world crude oil market is becoming further entrenched, verified by a decreasing normalised tree length; hence, its systemic risk may increase due to the future uncertainty of world politics.

1 . Introduction

With the increasing demand for oil and the high liquidity of the global oil trade, more and more regional oil markets have involved in the global oil pricing system. In this process, oil market integration seems to be enhanced due to an open market environment and the improvement of information transmission technology, making the world oil market appears to be 'one great pool'. This suggests that the various types of crude oil from different countries are likely to move together. However, some varieties of crude oil play a more significant role than others, which is primarily due to changes in the power games played by the different parties involved—meaning the relationship among national oil markets can reflect the roles played by the countries in the world crude oil market. OPEC can no longer occupy the only monopoly position with its decreasing influence on oil pricing. The share of non-OPEC oil supply continues to increase, which is attributed to the development boom in the oil industry in non-OPEC countries and the continued growth in unconventional oil production, such as the U.S. tight oil formations and Canadian oil sands. Consequently, the structure of the world oil market and the leading/lagging role of crude oils in the major oil-producing and oil-consuming countries have changed in response to the new global economic and energy environment. Therefore, the implications of the dynamic evolution of the world crude oil market integration and the status changes for major oil countries, in terms of international oil market construction and energy regime maintenance, need to be identified and explored.

For oil markets, research on the relationships among crude oil markets in different regions has been the key issue of the study. The previous literature has used different evidence to furiously debate the hypothesis that the world oil market is globalised or regionalised. Adelman (1984) considers the world oil market as 'one great pool', which indicates that the changes of market conditions in one region can rapidly affect other regional markets. However, Weiner (1991, 1994) argues that oil prices move independently in response to local government polices and regional shocks and supports the regionalisation hypothesis across oil markets. Subsequently, some empirical studies have analysed this issue in order to test it. Rodriguez and Williams (1993, 1994) discuss the definition of markets differently than Weiner, and they support Adelman's assertion. Gülen (1997, 1999) investigates the regionalisation hypothesis using cointegration tests and argues that the world oil market is unified.

Entering into the 21st century, due to the emergence of new electronic trading techniques and mature Internet information services, oil futures market has developed rapidly and information transmission across markets has accelerated, thereby strengthening the association between the different regional oil markets (Silvapulle and Moosa, 1999; Silverio and Szklo, 2012). More studies have been focused on the leading–lagging

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relationship between different benchmark crude oil prices. Lin and Tamvakis (2001) use a GARCH model to investigate the information spillover effects between crude oil futures in the New York Mercantile Exchange (NYMEX) and London's International Petroleum Exchange (IPE). They found that IPE morning prices were affected by the close of the previous day on the NYMEX, and they note that the NYMEX seemed to play a leading role. Milonas and Henker (2001) examine the price and volatility behaviour of West Texas Intermediate (WTI) crude oil and Brent crude oil and find that the two oil markets are not fully integrated. Hammoudeh and Li (2004) investigate the relationships among the oil spot and futures prices using cointegration and an error correction model. They find that the strong long-run relationships are weakened after the Asian crisis, as manifested in less cointegration. Bentzen (2007) examines the price relationships between Brent, OPEC and WTI using an error correction model and indicates that the OPEC price influences Brent and WTI. Fattouh (2010) analyses the price differentials of seven types of crude oils imported into the U.S. using a two-regime threshold autoregressive (TAR) model. They found that within one great pool, oil markets are not necessarily integrated in every time period. Chang et al. (2010) find some volatility spillover effects from WTI and Brent to Dubai and Tapis using multivariate GARCH models, which confirms the benchmark role of Brent and WTI. Wlazlowski et al. (2011) apply Granger causality tests to study the price dependence of 32 crudes and found that the Russian Urals crude has emerged as a significant driver of global prices.

Most literatures mentioned above have proven that the world oil market is 'one great pool', where the price changes in one market can exert an influence on other geographic markets. This means that crude oil produced in different countries constitutes a unified world crude oil market. Obviously, in this framework no country can ensure its oil supply security within a specific region without interference and threat from other regions. Therefore, an investigation of whether or not the world crude oil market is integrated has significant economic and political implications in term of judging fuel costs and safeguarding countries' oil security. It also has important implications at firm levels for portfolio optimization and arbitrage strategies.

Unlike most studies, which select major oil benchmarks and parts of the market in the world as representative, this paper explores the behaviour of countries' oil markets. Three main issues therefore should be investigated as follows: (1) What are the crude oil price relationships of different regional markets; (2) How the behaviour of integration among crude oil price differentials evolve over time; (3) Which crude oil price has played like a price setter and which simply follows others. To visualise the structure and interaction among crude oil markets, we consider the world crude oil market as a graph in which the crude oils of oil-producing and oil-consuming countries are vertices. On this basis, we have constructed a minimal spanning tree (MST) for oil markets. Using this method, we have investigated the systematic evolution of the world crude oil market, which is composed of 24 oil-producing and oil-consuming countries, and we have analysed the price relationship among the countries' oil markets and their status in the market spanning tree during different periods. We perform this research from the countries' perspective, taking into consideration quality differences between the various types of crude oil, geopolitical developments in the world and the segments of OPEC and non-OPEC crude oils.

The remainder of the paper is organised as follows. The following section introduces the methodology. Section 3 presents the data and sample analysis, while major empirical results are shown in Section 4. Finally, Section 5 provides some conclusions.

2 . The world crude oil market modelling

Generally, the price changes of the world major crude oil markets present strong comovement and complex linkages. This collective behaviour of crude oil markets can be well described by the correlation matrix, which can be represented from a topological perspective using a graph. However, the main difficulty of such an approach is that the information is often massive as it contains all the pairs of correlation coefficients. Therefore, we constructed a minimal spanning tree to reflect the structure of the world crude oil market and identify the close–sparse relationship between regional crude oil markets; in this method, oil markets are considered to be the vertices and their linkages are seen as edges.

In order to better investigate the evolution rule and intrinsic attribute of the world crude oil market and determine the status of the different countries' oil markets, threefold response has been made. First, the minimal spanning tree and hierarchical tree are constructed to disclose the structure of the world crude oil market; second, three important measures are built for individual crude oil market to identify its core-fringe situation in the world; third, three dynamic measures are constructed to find the time-varying characteristics and stability of the world crude oil market.

2.1. Market integration methodology

2.1.1. Minimal spanning tree

Before constructing the minimal spanning tree, correlation coefficients of the countries' oil price returns are calculated as follows:

$$C_{ij}^{T} = \frac{\sum_{t=1}^{T}\left(r_{i,t}-\bar{r}_i\right)\left(r_{j,t}-\bar{r}_j\right)}{\sqrt{\sum_{t=1}^{T}\left(r_{i,t}-\bar{r}_i\right)^2\sum_{t=1}^{T}\left(r_{j,t}-\bar{r}_j\right)^2}} \tag{1}$$

where C_{ij}^{T} is the correlation coefficient and i and j are the numerical labels of crude oil markets; r is the crude oil price return, $r_{i,\ t} = ln(P_i(t) - ln(P_i(t-1))$; $P_i(t)$ is the price of the crude oil market i at t; $\bar{r}_i$ is the average of $r_{i,t}$ for the whole period; and T is the sample length.

The correlation coefficient C_{ij}^{T} cannot be used as a distance d_{ij}, because it does not fulfil the three axioms of Euclidean distance (Gower, 1966): (1) $d_{ij} = 0$ if and only if $i = j$; (2) $d_{ij} = d_{ji}$; and (3) $d_{ij} \le d_{ik} + d_{kj}$.

Thus, each correlation is converted to a metric distance as follows (Mantegna, 1999):

$$d_{ij} = \sqrt{2\left(1-C_{ij}^{T}\right)} \tag{2}$$

where d_{ij} is the distance between crude oil market i and crude oil market j. Small values of d_{ij} imply high correlations and strong compactness between oil markets. Then, the distance matrix is used to construct the MST.

Minimal spanning tree is a classic tree derived from graph theory which is uniqueness if each edge in a given connected and undirected graph has a distinct weight. One advantage of MST is that it can provide an easy way to extract the most important correlations and information in the system while retaining the simplest structure and enabling the ability to visualise the relationships across oil markets, which has been widely applied in the financial market (Mantegna, 1999; Onnela et al., 2003). For N markets, the number of possible links is $N(N-1)/2$. However, MST can greatly reduce this complexity by choosing only $N-1$ stronger links which correspond to the shortest path covering all the vertices of the graph. In this paper, the minimal spanning tree is constructed using Prim's algorithm (Prim, 1957).

2.1.2. Crude oil market hierarchical tree

Following Mantegna's (1999) design, the MST gives, in a direct way, the subdominant ultrametric hierarchical organisation of the crude oil markets. Thus, we constructed a crude oil market hierarchical tree to disclose the internal clustering relationship in the world crude oil market and to differentiate the close–sparse linkages among the crude oil markets, capturing the entire structure and systematic risk of the market.

According to Hughes's research, the MST and ultrametric space is equivalent (Hughes, 2004). The ultrametric space has an exactly