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# Dynamical Features of International Natural Gas Future Price and Spot Price in Different Periods

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**Abstract:** This paper mainly explores the fluctuation laws of natural gas future and spot price based on complex network. We use coarse graining method and build the network model of natural gas future and spot price at different periods and analyze the topological properties including strength distribution, diameter and average path length. We reveal the power law degree distribution and the periodicity of the network model of natural gas future and spot price at different periods.

**Keywords:** natural gas future price; natural gas spot price; dynamic feature; complex network

## 1 Introduction

The research on natural gas price is an outstanding issue, on account of paramount importance in new energy resource, where future and spot price accelerate each other. Spot price determines the development tendency of future price and future price forecast prospective price of the spot price.

Complex network aims to treat each part of the real system as a complex network and unscramble the relationship between them with the form of the network. Complex network used in more fields provides a new complex perspective.

Reviewing the past academic achievements, we found some researches probed into the factors influencing the natural gas price. Wu, et al. reached that the variation of natural gas future price was due to the seasonal climate influence on daily consumption [1]. Sebastian and Stefan came up with the factors influencing the natural gas price including the temperature and storage of natural gas price, the change of other energy price [2]. Apart of these, the natural gas price was also connected with the news of natural gas storage, global economic activities and global crude prices [3–4]. There exist other researches on the connections between different prices of natural gas, and the connections between natural gas prices and other energy prices, such as natural gas price and natural gas stock price, natural gas price and crude prices [5–7]. Some researches concentrated on non-price factors of natural gas such as pricing mechanism, market structure and trading association of natural gas [8–10].

To sum up, there exists no direct complex network model based on natural gas price. International natural gas future and spot price fluctuation network are established for analyzing network topological properties and studying their dynamical features. We pay most attention on the next two ways: (1) 3 symbols—$\{S, e, X\}$ are replaced by 4 symbols—$\{S, s, x, X\}$, which increases their complexity from a very large extent; (2) we also take periods of time into account. This paper aims to analyze the topological properties of natural gas future and spot price network and find out their fluctuation law with time.

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# 2 Materials and methods

## 2.1 Data processing

The data used in the paper is derived from Henry Hub Natural Gas Spot Price (Dollars per Million Btu) and New York Harbor Regular Gasoline Future Contact 2 (Dollars per Million Btu) in EIA (Energy Information Administration) from January 7, 1997 to April 25, 2016.

The sequence of natural gas future price is denoted by $P_{fut}(k), k = 1, 2, \cdots, N = 4826$, and the same of natural gas spot price is by $P_{spt}(k), k = 1, 2, \cdots, N = 4826$. The fluctuation sequence of natural gas future price is denoted by $\Delta P_{fut}(k) = P_{fut}(k) - P_{fut}(k-1)$. Similarly, another is $\Delta P_{spt}(k) = P_{spt}(k) - P_{spt}(k-1)$.

Let $A_{\Delta P_{fut}} = \frac{\sum_{k=1}^{N-1} |\Delta P_{fut}(k)|}{N-1}$, when $\Delta P_{fut} > A_{\Delta P_{fut}}$, it means dramatic increase of natural gas future price; when $0 < \Delta P_{fut} \leq A_{\Delta P_{fut}}$, it means stable increase of natural gas future price; when $-A_{\Delta P_{fut}} < \Delta P_{fut} \leq 0$, it means stable decrease of natural gas future price; when $\Delta P_{fut} \leq -A_{P_{fut}}$, it means dramatic decrease of natural gas future price. Each $\Delta P_{fut}$ will correspond with an appointed letter based on the change of its value. The fluctuation sequence of natural gas future price is replaced by the sequence of letters. Suppose each $\Delta P_{fut}$ corresponds with a symbol $f_{sk}$,

$$f_{s_k} = \begin{cases} S, & \Delta P_{fut} > A_{\Delta P_{fut}}, \\ s, & 0 < \Delta P_{fut} \leq A_{\Delta P_{fut}}, \\ x, & -A_{\Delta P_{fut}} < \Delta P_{fut} \leq 0, \\ X, & \Delta P_{fut} \leq -A_{P_{fut}}, \end{cases} \tag{1}$$

where the symbols '$S$, $s$, $x$, $X$' mean 'dramatic increase, stable increase, stable decrease, dramatic decrease' of natural gas future price respectively. As a result, the sequence of natural gas future price is transformed into that of symbols like

$$SF = \{f_{s_1}, f_{s_2}, f_{s_3} \cdots\} \qquad f_{s_k} \in \{S, s, x, X\} \tag{2}$$

In the same way, the sequence of natural gas spot price is transformed into that of symbols like

$$TF = \{s_{t_1}, s_{t_2}, s_{t_3} \cdots\} \qquad s_{t_k} \in \{S, s, x, X\} \tag{3}$$

## 2.2 Period division

We group the data above with a time horizon of 12 months and count the frequency of each symbol '$S$, $s$, $x$, $X$' in each unit of time, which are denoted as $GS, Gs, Gx, GX$ respectively. As showed in Figure $1(a)$, during the fluctuation of natural gas future price, the lines representing states of 'dramatic increase, stable increase, stable decrease, dramatic decrease' interlace complicatedly. In order to further distinguish the period of dramatic and stable increase-and-decrease state, we count as follows

$$Gsx = Gs + Gx, \qquad GSX = GS + GX, \tag{4}$$

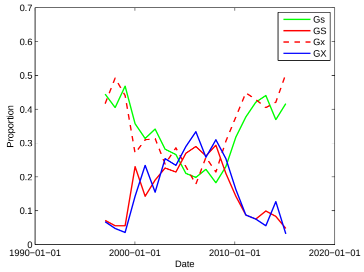
where $Gsx$ represents the frequency of the stable increase-and-decrease state of natural gas future price and $GSX$ represents the frequency of the dramatic increase-and-decrease state. As showed in Figure $1(b)$, the lines representing the frequency of dramatic and stable increase-and-decrease state of natural gas future price intersect at two points, which means the fluctuation of natural gas future price make change. We count

$$GsS = Gs + GS, \qquad GxX = Gx + GX \tag{5}$$

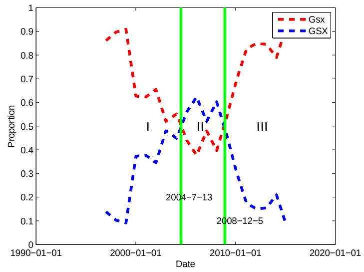
to make clear whether it increases or decrease in increasing-dramatically period, where $GsS$ represents the frequency of the dramatic-increase state of natural gas future price and $GxX$ represents that of the dramatic-decrease state as showed in Figure $1(c)$. From the above, the fluctuation period of natural gas future is divided into three as showed in the Table 1. Similarly, Table 1 also shows the fluctuation periods of natural gas spot price.

Based on the symbol sequences of natural gas future and spot price, five continuous days in a week consist of a fluctuation mode and a new one keeps in the same way day out. Natural gas future and spot price both have 4822 fluctuation modes. (The same modes can be counted respectively). The directed weighted network model of natural gas future and spot price are established by nodes and edges, whose nodes are made up of fluctuation modes and whose edges are composed of directed connecting between modes.

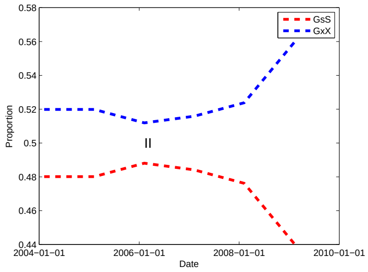
Fluctuation mode changes with the movement of sliding window and the sequence of fluctuation mode. The switch times between nodes consist of node weight. On account of coarse graining processing, there are 965 and 932 different nodes in the directed weighted network model of natural gas future and spot price respectively.




(a) The frequency of four states

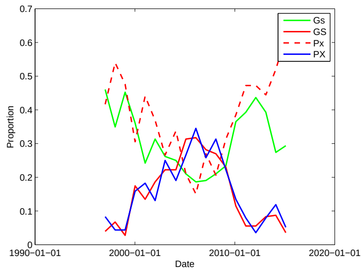



(b) The frequency of $Gsx$ and $GSX$

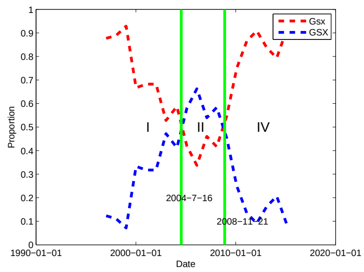



(c) The frequency of $GsS$ and $GxX$

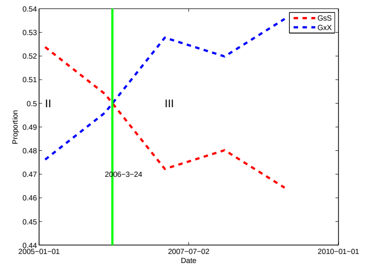
Figure 1: The Natural gas future price




(a) The frequency of four states




(b) The frequency of $Gsx$ and $GSX$

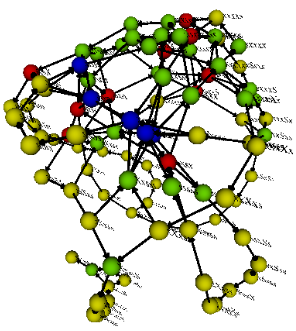



(c) The frequency of $GsS$ and $GxX$

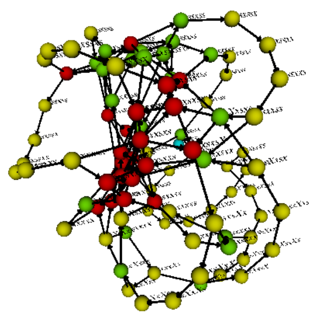
Figure 2: The Natural gas spot price

Table 1: Period division of natural gas future and spot price

| Name | Period | State |
|---|---|---|
| Future-1 | January 7, 1997-July 13, 2004 | Stable period |
| Future-2 | July 13, 2004-December 5, 2008 | Dramatic-decrease period |
| Future-3 | December 8, 2008-April 25, 2016 | Stable period |
| Spot-1 | January 7, 1997-July 16, 2004 | Stable period |
| Spot-2 | July 17, 2004-March 24, 2006 | Dramatic-decrease period |
| Spot-3 | March 27, 2006-November 21, 2008 | Stable period |
| Spot-4 | November 24, 2008-April 25, 2016 | Stable period |

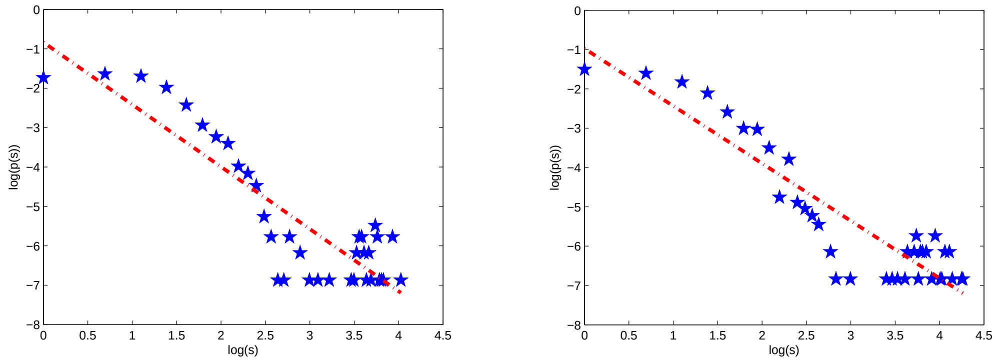


(a) Future



(b) Spot

Figure 3: The network model of natural gas future and spot price




(a) Future (b) Spot

Figure 4: The double logarithmic images of node strength distribution of the directed weighted network model of natural gas future and spot price

# 3 Results and analysis

## 3.1 The directed weighted network model of natural gas future price

There should be $4^5 = 1024$ fluctuation modes in the directed weighted network model of natural gas future and spot price on account of ways above in theory, however, only 965 different fluctuation modes (nodes) exist in the network of natural gas future price and 932 in the network of natural gas spot price. We find that the number of modes of the network of natural gas future price is larger than that of natural gas spot price, which suggests the structure of the network of natural gas future price display more complicatedly.

## 3.2 Dynamical features of the directed weighted network model of natural gas future price

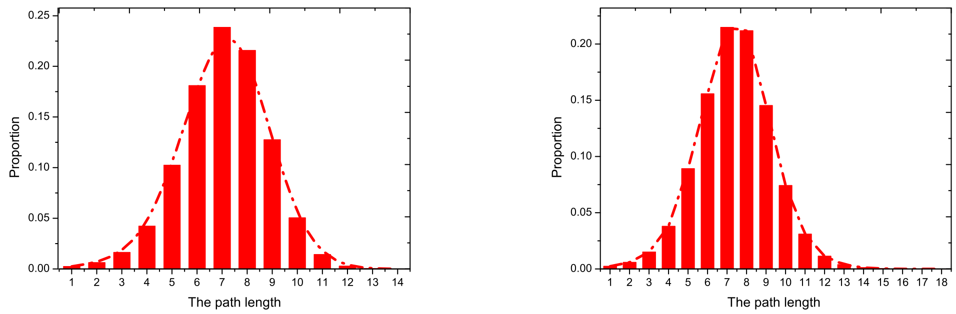
### 3.2.1 Node strength distribution

Node strength not only reflects the connecting condition between the one with another, but also indicates the length of edge. It is showed as Figure $4(a, b)$ that double logarithmic images of node strength distribution of the directed weighted network model of natural gas future and spot price. From the observations, we find the larger the node strength of the directed weighted network model of natural gas future price is, the less the number of the nodes is on the whole. Apart from this, most nodes have small node strength. By the least square method, the double logarithmic images of node strength distribution of the directed weighted network model of natural gas future and spot price are reached on the whole and at different periods. Fitting parameters of node strength are showed as the following Table 2.

Table 2: Fitting parameters of node strength

| period | $\Upsilon$ | $R^2$ |
|---|---|---|
| Future-1 | 1.93 | 0.8341 |
| Future-2 | 2.7954 | 0.9080 |
| Future-3 | 2.2084 | 0.8606 |
| Future-Whole | 1.5787 | 0.7839 |
| Spot-1 | 1.7994 | 0.8655 |
| Spot-2 | 2.2811 | 0.9467 |
| Spot-3 | 2.8465 | 0.8466 |
| Spot-4 | 1.9880 | 0.9411 |
| Spot- Whole | 1.4592 | 0.8403 |

In scale-free network, the larger a power exponent is, the higher the lever of the power-law degree distribution is. As




(a) Future (b) Spot

Figure 5: The path length distribution of the network model of natural gas future and spot price

showed in Table 2, on the whole, the lever of the power-law degree distribution of the network model of natural gas future price is higher than that of natural gas future price, but the reliability of the latter is higher. In stable periods, the network model of natural gas future price have privilege in the power law degree distribution, while it is to the contrary in dramatic period. Conclusions above indicate internal fluctuation features of natural gas future and spot price to some extent.

#### 3.2.2 Analysis on switch period between fluctuation modes

Denote $d_{ij}$ as the distance between node $i$ and node $j$. Denote diameter $D$ as maximum distance among all the nodes. Denote average path length $L$ as the average distance between arbitrary two nodes. The specific formulas of $D$ and $L$ are as follows

$$D = \max d_{ij}, \qquad L = \frac{1}{N(N-1)} \sum_{i \neq j} d_{ij}, \tag{6}$$

where N represents the number of nodes.

We count the distance between arbitrary two nodes of the network model of natural gas future and spot price by Floyd algorithm. Showed as Figure 5 are the images of path length distribution of the network model of natural gas future and spot price on the whole.

Table 3: The parameters of switch period

| period | Diameter | The average path length | Switch period of modes (day) |
|---|---|---|---|
| Future-Dramatic | 33 | 11.4606 | 11-12 |
| Future-Stable | 17 | 7.4750 | 7-8 |
| Future-Whole | 14 | 7.0725 | 7-8 |
| Spot-Dramatic | 29 | 11.2325 | 11-12 |
| Spot-Stable | 18 | 7.8298 | 7-8 |
| Spot- Whole | 18 | 7.3878 | 7-8 |

Seen as Figure $5(a, b)$ and Table 3, fluctuation modes of the network model of natural gas future and spot price show short-distance correlation and frequent switch. However, the diameter of the network model of natural gas future price is larger than that of natural gas spot price. In different periods, the switch periods of the two networks equal correspondingly. The diameters of the two networks win in the dramatic period. These observations provide evidence for predicting approaching price of natural gas future and spot price.

Table 4: The parameters of switch period

| $Network$ | $Period$ | $Diameter$ | $The\ average\ path\ length$ | $Switch\ period\ of\ modes\ (day)$ |
|---|---|---|---|---|
| $Future$ | $Dramatic$ | 33 | 11.4606 | 11-12 |
| | $Stable$ | 17 | 7.4750 | 7-8 |
| | $Whole$ | 14 | 7.0725 | 7-8 |
| $Spot$ | $Dramatic$ | 29 | 11.2325 | 11-12 |
| | $Stable$ | 18 | 7.8298 | 7-8 |
| | $Whole$ | 18 | 7.3878 | 7-8 |

# 4 Conclusions

In this paper, we translate the fluctuation sequences of natural gas future and spot price into string made up of symbols—$\{S,\ s,\ x,\ X\}$ where five continuous days consist of a fluctuation mode. We build the network model of natural gas future and spot price at different periods, whose nodes are made up of fluctuation modes and whose edges are composed of directed connecting between modes. We analyze the topological properties and find that both the network of natural gas future and spot price obey power law distribution, however the power law degree distribution shows differently at different periods. Secondly, fluctuation modes of the network model of natural gas future and spot price show short-distance correlation and frequent switch. These conclusions serve for fluctuation rule of natural gas future and spot price and the stability of energy-price market.

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