The evolutionary stability of shareholders' co-holding behavior for China's listed energy companies based on associated maximal connected sub-graphs of derivative holding-based networks

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HIGHLIGHTS

• A novel method on studying relationships of listed energy companies’ shareholders.
• A new perspective of studying the stability of energy stock market.
• An empirical study of the frontier of complex network-derivative equivalence network.
• Improved the Heuristic Algorithm to find the associated maximal connected sub-graph.
• A long term analysis about the evolutionary stability of China’s energy stock market.

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ABSTRACT

Listed energy companies play an important role in both the energy financial market and energy commodity market. As owners of listed energy companies, shareholders can influence the stability of the energy stock market by increasing or decreasing their holdings. To analyze the evolutionary features and stability of shareholders’ co-holding behavior, we constructed a derivative holding-based structural equivalence network of the shareholders (holding-based network) based on the primitive shareholding network of the listed companies and their shareholders. The main data used in this paper are the semi-annual reports from 2003 to 2012 that contain information about Chinese listed energy companies’ top 10 shareholders. The holding-based network takes the shareholders as nodes, whether holding the same listed energy companies’ stock at the same time as the edges, and the number of listed energy companies co-held as the weights. Due to the unique topological features of the holding-based network, we improved the Heuristic Algorithm to find the associated maximal connected sub-graph of the network, which is the main group of shareholders with shareholding consistency of the listed energy companies. This paper creates a new approach to analyze the relationships in the energy stock market, presenting a new method to analyze shareholder behavior.

1. Introduction

Energy is the basis for modern economic and social development [1]. Rapidly increasing demand for energy from both developed market economies, such as America and Japan, and emerging market economies, such as China and India, coupled with the shortages and scarcity of traditional energy will lead to much higher energy prices in the future, so both countries as well as institutions and individuals are increasingly focused on the energy market [2,3]. As an
important part of the energy market, listed energy companies play an important role in both the energy financial market and energy commodity market. As owners of listed energy companies, shareholders can control or influence the stock price of the listed energy companies by increasing or decreasing their holdings; if shares change hands in large numbers at once, it will affect the stability of the energy stock market. Usually, great holding changes are not undertaken by a single shareholder, but by two or more shareholders together. Therefore, to reveal the relationships among shareholders, it is important to study their holding behavior.

As with the development of econ-physics and statistical physics, the study of complex networks is useful for revealing relationships in the real world, and it has become a new but active area in empirical studies for scientific research [14–7]. In the stock market, complex networks are widely employed to analyze the direction of stock price indexes [8], stock market returns [9], investment behavior [10], and relationships between listed companies and their shareholders [11,12], and the relationships between shareholders [13,14]. Most scholars primarily researched the topological structure and topological features, the correlation, and the dynamic evolution and the power-law distribution of different empirical complex networks in the stock market. In energy research, complex networks have been used to analyze the global energy trade [15–18], energy consumption [19], energy flow [20,21], energy transfer [22], energy companies’ connection [23], etc. However, few scholars have studied the listed energy companies, especially the relationships of the listed energy companies and their shareholders.

Both the ownership structures and the relationship between the shareholders play a central role in the stability of the energy stock market and the whole stock market. Reviewing the literature, we find that ownership structures of the stock market are well documented [24,25]. However, only a few papers address the indirect effects arising from the so-called “holding-based network” of the shareholders. The “holding-based network” is a derivative network that is constructed according to the co-holding relationship in the primitive shareholding network [13,14]. Previous studies have found that the correlation of the holding behavior between shareholders may exist when the shareholders share geographic locations [26] or have formal or informal information communications [27]. Therefore, the relationships of the shareholders can influence the structure and the stability of the energy stock market to some extent [14]. Meanwhile, as the basic unit of the networks, the structure of the sub-graphs has a great effect on the network [28]. To analyze the stability of the relationships of the shareholders more precisely, it would be useful to analyze the stability of the sub-graphs of the holding-based network of the listed energy companies’ shareholders.

Previously, we analyzed the primitive relationships of shareholding network between shareholders and listed companies as well as the shareholders’ cross-shareholding relationships [11]. For the shareholders, derivative equivalence relationships based on the primitive shareholding relationships are also important as mentioned above. Usually, there is obvious “friends of friends are friends” (“FFF” for short) phenomenon for equivalence relationships in social networks [29]. In this paper, we draw lessons from the idea of the ‘structural equivalence network’ [13,30], a derivative holding-based structural equivalence network (holding-based network for short) based on the investment consistency (or co-holding behavior) of the primitive shareholding network of China’s listed energy companies and their shareholders. Because of the unique topological features of the holding-based network and the ideas of “FFF”, we improved the Heuristic Algorithm to find the associated maximal connected sub-graphs of the network (AMCS-Gs for short), and then we analyzed the evolutionary stability of the holding-based network and the AMCS-Gs. Finally, we made our conclusions on the basis of the results of our analysis.

2. Data and methods

2.1. Data

The data used in this paper are mainly downloaded from the CSMAR Financial Research Database (http://www.gtarsc.com/). The selected documents include the semi-annual report of the Listed Energy Company List and the Main Stockholders List of the Shanghai Stock Exchange and the Shenzhen Stock Exchange from 2003 to 2012. The Listed Energy Company List contains a stock code and the listed company’s name. The Top 10 Stockholders List contains the stock code, the stockholder’s name, the stockholding rate and the end date. To analyze the data more effectively, we deleted duplicate items and the individual shareholders and then we coded the listed company name and the stockholder name, with each code representing a unique company.

2.2. Methods

2.2.1. The construction of the holding-based network

As mentioned, the relationships of the shareholders can influence the structure and the stability of the energy stock market to some extent. In this paper, we constructed the derivative holding-based network of the shareholders based on the primitive shareholding network between the listed energy companies and their shareholders. The primitive shareholding network is an two-mode un-weighted directed network that is constructed on the basis of the shareholding relationship between the listed energy companies and their shareholders [14,31]. Fig. 1 (A) presents the two-mode relationship matrix between the shareholders (X) and the listed energy companies (Y), where X is the set of all the shareholders of the listed energy companies (xi ∈ X), Y is the set of all China’s listed energy companies (yi ∈ Y), and aij represents the shareholding relationships between the listed energy companies and their shareholders, which is defined as Formula (1), as follows:

\[
\begin{align*}
   a_{ij} = 1 & \text{ if } x_i \text{ is one of the shareholders of listed energy company } y_j \\
   a_{ij} = 0 & \text{ if } x_i \text{ is not the shareholder of listed energy company } y_j
\end{align*}
\]  

(1)

In the primitive shareholding network, there are many shareholders who have the same relationship with the listed energy companies when they co-hold the same listed energy companies’ stock without considering the shareholding rates, and as the “structural equivalence network” [13,30] describes, when the two nodes have the same relationship with the third node, the two nodes are structurally equivalent; thus, we can obtain the derivative structural equivalence holding-based network of the shareholders on the basis of the structural equivalence relationship (co-holding) of the primitive shareholding network. Fig. 2 presents the holding-based relationships matrix between the shareholders, while wij represents the quantity of the co-holding listed energy companies between shareholder xi and the shareholder xj at the same time, which is calculated by Formula (2).

\[
\begin{align*}
   Y & = y_1 \ldots y_m \\
   X & = x_1 \ldots x_n \\
   a_{ij} & = a_{11} \ldots a_{1m} \\
   \vdots & = \vdots \\
   a_{nj} & = a_{n1} \ldots a_{nm}
\end{align*}
\]

Fig. 1. Primitive two-mode shareholding relationship matrix.
\begin{align*}
\text{where } X_i \text{ is the set of listed energy companies which shareholder } x_i \text{ holds, and } X_j \text{ is the set of listed energy companies which shareholder } x_j \text{ holds.}
\end{align*}

2.2.2. The improved Heuristic Algorithm

Because the structure of the sub-graphs has a great effect on the network, after constructing the “holding-based network” of the shareholder of the listed energy companies, we continued to divide the network into sub-graphs. A sub-graph in the holding-based network represents a group in which the economic agents are well connected by shareholding. There are many algorithms employed for searching sub-graphs [32,33]; in this paper, we chose an algorithm developed by Vincent et al. named the Heuristic Algorithm [11,34] and improved it considering the characteristics of the holding-based network.

The traditional Heuristic Algorithm contains two main phases that are repeated iteratively. In the first phase, we assume the network has N groups; that is, each group has one and only one node. Then, we combine any two groups (i and j) into one group and calculate the gain of the modularity (∆Q), the variable of the Heuristic Algorithm: if the gain is positive, then we combine the two groups and move on to another two groups; otherwise, the two nodes still remain in their own group, and we choose another group to combine with. This process was carried out sequentially for all nodes until we gain the maximal value of the modularity. ∆Q is calculated by Formula (3).

\begin{align*}
\Delta Q = \left[ \frac{\sum_{in} + k_{in}}{2m} - \left( \frac{\sum_{rot} + k_{in}}{2m} \right)^2 \right] - \left[ \frac{\sum_{in}}{2m} - \left( \frac{\sum_{rot}}{2m} \right)^2 - \left( \frac{k_{in}}{2m} \right)^2 \right]
\end{align*}

where \( \sum_{in} \) is the sum of degrees of all the nodes inside the combined group, \( \sum_{rot} \) is the sum of the degrees of all the nodes of the combined group, \( k_{in} \) is the sum of the degrees of \( i \), \( k_{im} \) is the sum of the degrees of the links from \( i \) to all the nodes in the combined group, and \( m \) is the sum of the degrees of the network.

With the maximum value of the modularity gained in the first phase, we move on to the second phase. In this phase, we build a new network that takes the new groups gained in the first phase as nodes, and the sum of links between different groups as the weight, and the links between the nodes in the same group are considered self-loops. Then, we return to the first phase to gain a new maximal value of the modularity. The two phases will operate iteratively until the maximum value of modularity is gained.

As above, the holding-based network we constructed has unique topological features. Actually, it is stacked by many fully maximal connected sub-graphs (MCS-G for short), as Fig. 3 demonstrates. Each MCS-G represents the derivative holding-based equivalent relationship of the shareholders based on holding the same listed energy company’s stock. When one shareholder holds more than one listed energy company’s stock, they can form different derivative holding-based MCS-Gs, and these MCS-Gs will be connected (stacked) on the shared point or points (shareholder), and the shareholders who are linked directly or indirectly will share some information and present correlation of shareholding behavior, which is also called competition and cooperation relationships [13]. Due to the “FFF” phenomenon in equivalent relationships, we know that two shareholders which both have equivalent relationship with the same shareholder also have equivalent relationship with each other to some extent. However, using the traditional Heuristic Algorithm to find the sub-graphs of the network, the MCS-Gs that have common nodes can most likely be divided into different sub-graphs. Thus in the improved phase, we marked the sub-groups divided by the two phases above, and recorded the attribute of each sub-group, then we estimated whether there are any links between various groups; if true, the two sub-groups would be combined; otherwise, the process would move on and be conducted repeatedly. The improved Heuristic Algorithm is applicable to a network with many independent groups and would help to find the AMCS-Gs, which are the main parts and an effective information sharing group of the holding-based network. For the energy stock market, it is useful to help researcher find the majority shareholders with the possibility of correlation on shareholding behavior, and then discover the main features and the evolutionary stability of the majority shareholders in the energy stock market.

2.2.3. The evolutionary stability coefficient

As with the construction of the holding-based network that was mentioned, the derivative holding-based network is constructed based on the co-holding relationship. Thus to calculate the evolutionary stability coefficient of the holding-based network and the AMCS-Gs gives a good perspective for presenting the holding relationship of the shareholders. That is to say, when the co-holding relationship is stable, there is no instantaneous, large-scale shares change (overweight or underweight) of the shareholders of the listed energy companies over time, the shareholding behavior of the shareholders is consistent, and the evolutionary stability coefficient will be high; otherwise, when the shareholding behaviors of the shareholders are different and fluctuate, the evolutionary stability coefficient will be low.

In this paper, we draw lessons from the idea of the “auto-correlation function” [35] and the “jaccard-coefficient” [36,37] to measure the evolutionary stability of both the holding-based network and the AMCS-Gs. Formula (4) is widely employed to determine group dynamics to measure the overlap between two networks from \( t - 1 \) to time \( t \) [11,38,39].

\begin{align*}
Es(t) = \frac{N_{i1} \cap N_{i(t+1)}}{N_{i1} \cup N_{i(t+1)} - N_{i1}}
\end{align*}

where \( Es(t) \) is the stability coefficient of the holding-based network or the AMCS-Gs. \( N_i \) represents the set of nodes in the holding-based network or the AMCS-Gs at time \( t \), and \( N_{i-1} \) represents the set of nodes in the holding-based network or the AMCS-Gs at time \( t - 1 \). \( N_i \cap N_{i+1} \) is the number of common nodes (shareholders) at \( N_{i+1} \) and \( N_i \), and \( N_i \cup N_{i+1} \) is the number of nodes at the union of \( N_{i-1} \) and \( N_i \).

3. Results

3.1. The evolution of the co-holding behavior of the listed energy companies’ shareholders

As mentioned, the co-holding behavior represents the shareholders which hold the same listed energy company’s stock, the shareholders with equivalent co-holding behavior have competition and cooperation relationships [13]. According to the method used to construct the holding-based network, for each of the stocks, based on the co-holding behavior of the shareholders, an
equivalent MCS-G can be built with a maximum of 10 points (we can only identify the top 10 shareholders of the listed energy companies from the data), and the network is superimposed by several MCS-Gs with equivalence relations. Fig. 3 presents the visualization of the derivative holding-based network of June, 2003 and December, 2012. From Fig. 3, we can intuitively observe that the co-holding behavior of the shareholders is more complex in December, 2012 than in June, 2003, only few MCS-Gs in December, 2012 are isolated, most MCS-Gs are associated with each other by sharing one or more common node. It means that an increasing number of shareholders hold more than one listed energy company’s stock, and both the direct co-holding and indirect holding behavior between the shareholders becomes stronger. Fig. 4 presents the evolution of the quantity of nodes and edges in the 20 holding-based networks from June, 2003 to December, 2012. It indicates that both the shareholders (nodes) and the co-holding behavior of the shareholders (edges) have increased in total.

3.2. The main group of shareholders with shareholding consistency of the listed energy companies

As Formula (3) demonstrates, the shareholders in the same sub-graph mean they have strong shareholding consistency (co-holding behavior); the value of the modularity represents the independent degree of the sub-graphs. The bigger the modularity, the more independent the sub-graphs are. Fig. 5 presents the evolution of the quantity of the modularity and the quantity of the sub-groups based on the traditional Heuristic Algorithm. From Fig. 5, we find that although the nodes increase steadily (Fig. 4), the quantity of the sub-groups decrease over time. Meanwhile, the modularity also decreases.

To display the sub-graphs more clearly, we use a trellis-diagram (Fig. 6) to show the sub-graphs of the network; in Fig. 6, both the green and white grids represent the sub-graphs found by the traditional Heuristic Algorithm. According to the “FFF” phenomenon in equivalent relationships, two shareholders also have competition and cooperation shareholding relationship while both of them have co-holding equivalent relationship with the same shareholder. However, Fig. 7 shows that although the different MCS-Gs have some links between each other, they are divided into different sub-graphs by the traditional Heuristic Algorithm. From the
shareholding point of view, the shareholders who have direct or indirect potential correlation of shareholding behavior are separated into different groups.

To determine the AMCS-Gs about the co-holding behavior, we employ the third phase that is the improved Heuristic Algorithm to re-combine the sub-groups found by the traditional Heuristic Algorithm. In Fig. 6, all the green grids represent the AMCS-Gs found by the improved Heuristic Algorithm. Figs. 8 and 9 display the evolution of the quantity of nodes and edges of the holding-based network and the AMCS-Gs. Further, it is obvious that both the nodes and edges in the AMCS-Gs gained by the improved Heuristic Algorithm account for a significant proportion of the holding-based network. That means increasing numbers of shareholders exhibit co-holding behavior, and their relationship has become stronger over time. To put it another way, most of

<table>
<thead>
<tr>
<th>time</th>
<th>sub-graph (sub-group)</th>
<th>Modularity Class</th>
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Fig. 6. Trellis-diagram of the sub-group of the holding-based network. Note: a. Each grid (both green and white) represents one sub-graph found by the traditional Heuristic Algorithm; b. All the green grids represent the AMCS-Gs found by the improved Heuristic Algorithm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 7. AMCS-Gs gained by the improved Heuristic Algorithm (2003/06). Note: the nodes with the same color indicate they are in the same sub-group divided by the traditional Heuristic Algorithm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 8. Evolution of nodes of a holding-based network and the AMCS-Gs.
the shareholders of listed energy companies in China have more or less direct or indirect shareholding consistency based on co-holding behavior; only a few shareholders are totally isolated from the main group of shareholders, and the number of the isolated shareholders has decreased gradually over the last decade.

3.3. The evolutionary stability of shareholders’ co-holding behavior of listed energy companies

The evolutionary stability coefficient of the holding-based network is a useful perspective for measuring shareholders’ co-holding behavior of listed energy companies. As mentioned above, when shareholders’ holding behavior is stable and there is no significant differentiation of overweight or underweight by the shareholders, the stability will be high; otherwise, the stability will be low. Because in this paper we only analyze the holding behavior of the top 10 shareholders of the listed energy companies, if the shareholders overweight or underweight the stock to make it move into or out of the top 10 list instead of selling or newly buying the stock, that behavior can also influence the result.

Fig. 10 presents both the evolutionary stability coefficients of the holding-based network and the AMCS-Gs and their differences. According to Fig. 10, the total evolutionary stability can be divided into two periods: the first period is from 2003 to 2008, and the evolutionary stability is in great fluctuation; and the second period is from 2008 to 2012, and the evolutionary stability in this period increases steadily. It is well known that the financial crisis occurred in 2008 which influenced global financial market, including energy stock market. China’s stock market also experienced a sharp fall in 2008 after a high increase in 2006 and 2007, and then it kept a low situation from 2008 to 2012. Meanwhile, the global energy price and energy trading market also experienced a huge change during that time [5]. All of these conditions could affect the stability of shareholders’ shareholding and co-holding behavior directly.

Overall, it can be found that most of the stability coefficients for AMCS-Gs are lower than those of the holding-based network, which means the relationships between the members of the non AMCS-Gs are much more stable than that of the AMCS-Gs. It indicates the isolated shareholders who only co-hold one listed energy company’s stock are more stable. However, the differences of the stability between them decrease over time. The analysis of the stability coefficient indicates that the top 10 shareholders of the listed energy corporation keep a stable shareholding behavior without selling off or cutting their holdings significantly. Moreover, the gap has narrowed over time means that the consistency of the shareholding behavior of the top 10 shareholders in China’s energy stock market has improved gradually, and the investment diversity has been reduced constantly.

4. Discussion and conclusion

As the owner of listed energy companies, shareholders can influence the whole energy stock market by their shareholding behavior [11,13,14,40]. It is important to study the holding behavior of the shareholders of listed energy companies to analyze the stability and potential risk of the energy stock market. Usually, shareholders have connections with each other based on the direct shareholding behavior, and these derivative connections can strengthen the effect on the fluctuation of the energy stock market. In this paper, to analyze shareholders’ behavior, especially the co-holding behavior between shareholders, we constructed a derivative holding-based structural equivalence network based on the primitive network that reflects the holding relationships between listed companies and their shareholders. The holding-based network in our paper takes the listed energy companies as nodes, whether co-holding the same listed energy companies’ stock at the same time as the edges and the number of listed energy companies co-held as the weights. Since the holding-based network is superimposed by several MCS-Gs with equivalent relationships, and the nodes with equivalent relationships could have indirect connections (“FFF” phenomenon), we constructed an improved algorithm based on the Heuristic method to determine the AMCS-Gs, so as to determine all the shareholders with direct or indirect holding-based relationships in the energy market. Further, both the evolution of the AMCS-Gs and the holding-based network and the stability of them were calculated and analyzed. The main results and conclusions are as follow:

First, in China’s energy stock market, most shareholders have more or less direct or indirect shareholding consistency based on co-holding behavior, only a few shareholders are totally isolated from the main group of shareholders;

Second, the consistency of the holding behaviors of the top 10 shareholders of China’s listed energy companies was in great fluctuation before 2008, and has increased gradually after 2008. That is to say, due to different conditions such as the global and national economic environment as well as the situation of energy market, the portfolio of the shareholders in China’s energy stock market is diversified and unstable before 2008, but after 2008, it is more stable and convergent.

Third, the evolutionary stability of shareholding consistency of the main group of shareholders (AMCS-Gs) is less than the consistency of the holding-based network; in other words, the few shareholders who are isolated from the AMCS-Gs demonstrate stronger evolutionary stability, and their shareholding behavior is more stable. However, both the evolutionary stability of the main group of shareholders and the holding-based network increase steadily, and the differences between them have decreased apparently.
Thus, we can conclude that the shareholding consistency of the main group of shareholders has become increasingly strong over time. This paper provides a new perspective of empirical study of the energy stock market. It is useful to study the shareholding behavior of listed energy companies’ shareholders quantitatively, and to analyze the competition and cooperation relationships of the energy financial market based on the derivative equivalent co-holding relationships, then to study the stability of the energy stock market. The “improved Heuristic Algorithm” proposed in this paper is important to discover the main group with potential connections (both direct and indirect relationships) in the undirected network constructed by equivalent relationships. It does not apply to the directed non-equivalent relationships, such as two-mode (binary) investment network, and multilateral trade network. However, it can also work after constructing the derivative networks with equivalent relationships based on the primitive two-mode or multilateral relationships, such as co-investment relationships, and co-importing relationships. Meanwhile, in the study, we only considered the stability of the members and the un-weighted shareholding relationships without considering the holdings rate. In our further study, we will apply the robustness theory to research the stability of the holding-based network by considering the amount of the shareholdings.

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