Study on the asymmetric QRE network game simulation of the South China Sea route trade cooperation

ABSTRACT: This paper explores in depth the cooperative mechanism of the "Community of Shared Future" and its influencing factors. According to the theory of geo-economics, the trading network of the South China Sea Route (SCSR) was constructed on the basis of trade routes and weighted by trade volume. The asymmetric Quantal Response Equilibrium (QRE) model was introduced to establish a complex network game model of trade cooperation in the SCSR in order to investigate the influencing factors on community cooperation. Through simulation tests, the influence of the participants' cognitive beliefs on self-action sensitivity, cognitive beliefs about the reaction sensitivity of other participants, the proportion of initial collaborators, rewards from neighboring countries, and implementation cost of environmental barriers on the cooperation of the SCSR were investigated. We conclude that the subjective cognitive asymmetry among countries will restrict the trade cooperation of SCSR to a certain extent. Policy recommendations to promote the cooperation of the SCSR were provided based on our findings.

Keywords: the South China Sea Route; asymmetric QRE model; network game; simulation

1. Introduction

The South China Sea is an important traffic hub for the global trade of goods and an important passage of the 21st Century Maritime Silk Road, as well as a key junction for energy transportation and an important military channel, with high economic value and strategic position [1, 2]. Under the recent situation of increasingly severe Sino-US trade frictions and expanding scope of Sino-US game, the South China Sea, as an important strategic fulcrum of Sino-US game, continues to attract the attention of all countries. Such issues in the South China Sea presents new uncertainties. In this context, guided by the concept of prosperous community, Chinese President Xi Jinping emphasized and advocated "adhering to the Path of peaceful development and promoting the construction of a Community of Shared Future for Mankind" at various occasions such as the 2017 Annual Meeting of the World Economic Forum and the Shanghai Cooperation Organization Summit [3-5]. Building a new type of economic cooperation platform along the SCSR and analyzing the factors affecting cooperation among countries will help countries to take various response measures to promote regional trade cooperation and marine economic development, and thus maintain the peace and stability of the global economic and political pattern.

A well-developed literature have discussed the potential areas of cooperation and the establishment of cooperation mechanism in the South China Sea. According to political theory, fundamental facts and cooperation practices in other regions, some scholars believed that the conservation and management of marine living resources is currently the most promising area of cooperation in the South China Sea [6], and on this basis, the specific objectives and approaches for fishery cooperation in the South China Sea are proposed [7, 8]. At the same time, cooperation in the fields of energy, security, scientific research and environment also has broad potentials [9-14]. However, in these potential areas of cooperation, there is currently no effective cooperation mechanism in the South China Sea. On the one hand, most existing cooperation mechanisms focus on Marine environmental protection, such as “The East Asian Seas UNEP Regional Seas Programme” [15], “The Partnership in Environmental Management for the Seas of East Asia” and “The South China Sea Large Marine Ecosystems Project”, while the cooperation mechanisms in other fields are relatively less. On the other hand, because it is based on soft law and most of the funding is not led by actors in the region, existing cooperation mechanisms are not binding [16]. Therefore, the establishment of an effective South China Sea cooperation mechanism has become the common aspiration of all governments and scholars.

In this context, some scholars proposed to learn from the cooperation experience of the polar treaty system or other similar regions [17-19], suggesting that the cooperation should start from low-sensitive fields [20], and the cooperation in environment and trade may be more operable than that in energy, security and other fields. The proposal of “Pan-South China Sea economic cooperation circle” [21, 22] and researches on trade cooperation among stakeholders in the South China Sea [23, 24] demonstrated the feasibility of establishing trade cooperation mechanism in the South China Sea and the broader region around the South China Sea. These achievements have laid a theoretical foundation for the study of this paper. However, different from the existing studies, this paper will discuss the South China Sea cooperation mechanism in a larger scope. Although it still centers on the South China Sea and its surrounding areas, it will break through the restrictions of regional scope, extend outward according to ports and routes, and include the main international trade subjects on the main routes and even the extended routes of the SCSR, so as to build a global trade community.

Game theory is a common method in the study of international cooperation, especially in trade cooperation and environmental cooperation. In general game analysis, cross-border environmental problems are often assumed as prisoner’s dilemma games [25]. Due to the externalities of environmental production and consumption, environmental costs cannot be internalized. Although cooperation is beneficial to both sides, it is still difficult to maintain cooperation. On the contrary, according to the theory of comparative advantage [26] and the theory of international division of labor [27], international trade can enable countries to achieve specialized economies of scale, so trade games are mostly balanced by mutual cooperation or opening up. This game equilibrium difference between environment and trade and the complementarity of their benefits make many scholars attempt to link the two to make game analysis. The results show that the substantial benefits brought by trade cooperation can be used as an effective incentive to promote environmental cooperation, and the “free-riding” behavior in global environmental protection can be effectively suppressed, thus bringing environmental protection out of the “prisoner’s dilemma” of cooperation [28, 29]. Therefore, although cooperation mechanisms in various fields in the South China Sea need to be established and improved, it is clear that economic and trade cooperation is the basis for other cooperation. This paper will focus more on game analysis of trade cooperation.

At the same time, some scholars pointed out that free trade and environmental protection have a certain mutual restriction relationship [30], while discussing international trade cooperation, the impact of environmental problems cannot be avoided, and some studies showed that the correlation game between trade and environment can promote both trade cooperation and environmental cooperation [31]. However, the related game will also make the original complex trade issues more complex, and thus make cooperation more difficult to achieve [32]. Therefore, this paper adopts a compromise approach, although only a single game of trade cooperation is conducted, the discussion of environmental factors will be introduced when exploring the factors affecting trade cooperation.

Most of the above researches use game theory alone to analyze the general international cooperative behaviors, and lack of game analysis for specific situations such as a specific region or some specific subjects. By contrast, the game based on complex networks seems to be more practical and specific. In the game analysis based on the construction of a complex trade network, the relationship and influence among individuals will also be taken into consideration in the selection of game strategies [33], which is more in line with the complex states' relations in reality than using the game theory alone. Few studies have applied the network game method to the research of the "Belt and Road", RCEP and other regional trade cooperation, verifying the powerful practicability of this method in the field of international cooperation [34-36].

In addition, we find that most of the existing game studies are based on the assumption of rational economic man and complete information, but this is not the case in practice. Due to differences in comprehensive strength, countries have incomplete cognition of themselves and other countries in the network, and their trade cooperation is an irrational strategic choice based on incomplete information. Therefore, this paper introduces the asymmetric QRE model of behavioral economics theory, adds the endogenous factors that affect game equilibrium, such as the participants' cognitive beliefs on self-action sensitivity and cognitive beliefs about the reaction sensitivity of other participants, thus innovatively constructs a complex network game model, which will improve the explanatory power of network game simulation results.

In summary, this paper attempts to introduce asymmetric QRE model to simulate the trade cooperation game between countries on the basis of building the SCSR trade network. By analyzing the subjective, objective and network structure factors affecting trade cooperation, and comparing the nature and degree of different factors, the possibility of establishing the SCSR Trade Community is explored. The rest of this paper is organized as follows: The construction of SCSR trade network is provided in Section 2. The network game with asymmetric QRE model is given in Section 3. The simulation experiments and evaluation results are provided in Section 4. Finally, conclusions and policy implications are discussed in section 5.

2. Construction of the SCSR trade network

2.1. Scope definition of the SCSR trade network

According to the geo-economic theory [37], the scope of SCSR Trade Network should be defined by taking into account both geographical and economic factors. Firstly, with routes as the main dimension, according to the actual freight routes operated by Maersk and China Ocean Shipping Group, all global routes passing through the South China Sea and routes extending from ports around the South China Sea were divided into two regions: the main channel of the SCSR and the extension line of the SCSR. In addition, countries whose lands, islands and coastal waters belong to the South China Sea region are also stakeholders of the SCSR. The three parts together constitute the geographical scope of the SCSR trade network, covering hundreds of ports and more than 120 countries in the world. In order to seize the core countries and find the key partners, priority should be given to the trade cooperation between countries with large bilateral trade volume, high trade dependence and close trade links, thus we set the bilateral trade volume as another standard for network construction.

Accordingly, countries with bilateral trade volume of more than 1 billion USD in the South China Sea region, the main channel of the SCSR and the extension line of the SCSR were identified as the core countries of the SCSR trade network, while other non-core node countries were not included. On this basis, the scope of the SCSR trade network was determined, including 46 countries in Asia, Europe, America, Africa and Oceania, as shown in Table 1:

Table 1

Scope of the SCSR trade network.

Area of belonging	Countries
the South China Sea region	China, Singapore, Thailand, Vietnam, Malaysia, Indonesia, Philippines
the main channel of the SCSR	India, Pakistan, Bangladesh, Iran, Oman, Qatar, Saudi Arabia, United Arab Emirates, Egypt, Turkey, Israel, Italy, Spain, Romania, France, United Kingdom, Germany, Netherlands, Belgium, Poland, United States, Brazil, Argentina, Angola, South Africa, Australia
the extension line of the SCSR	Japan, South Korea, Russia, Portugal, Sweden, Ireland, Norway, Denmark, Finland, Canada, Mexico, Colombia, Chile

Note: The trade volume data of the countries in the table are from the UNCTADstat database.

2.2. Construction of the SCSR trade network

There are various economic and trade cooperation relations among the selected countries. The economic dependence degree and the trade contact degree of countries in the network vary with the trade volume, thus based on the value of trade flow we built a weighted network. Taking 46 countries covered by the SCSR trade network as nodes of the network, the bilateral trade volume data of 46 countries in 2017 were obtained from the UNCTADstat database, then an initial trade matrix of 46*46 was constructed. In order to facilitate the follow-up study, the data were binarized by taking the total exports of node countries to other countries exceeding 1 billion USD as the standard for the existence of economic and trade cooperation between two countries. If it exceeds 1 billion USD, it is believed that economic and trade cooperation relations exist between the two countries, and the adjacency matrix is assigned a value of 1; otherwise, it is considered that there is no economic and trade cooperation relation between the two countries, and the adjacency matrix is assigned a value of 0. UCINET software was used to plot and process the binarization data. The graph of the SCSR trade network was shown in Figure 1:

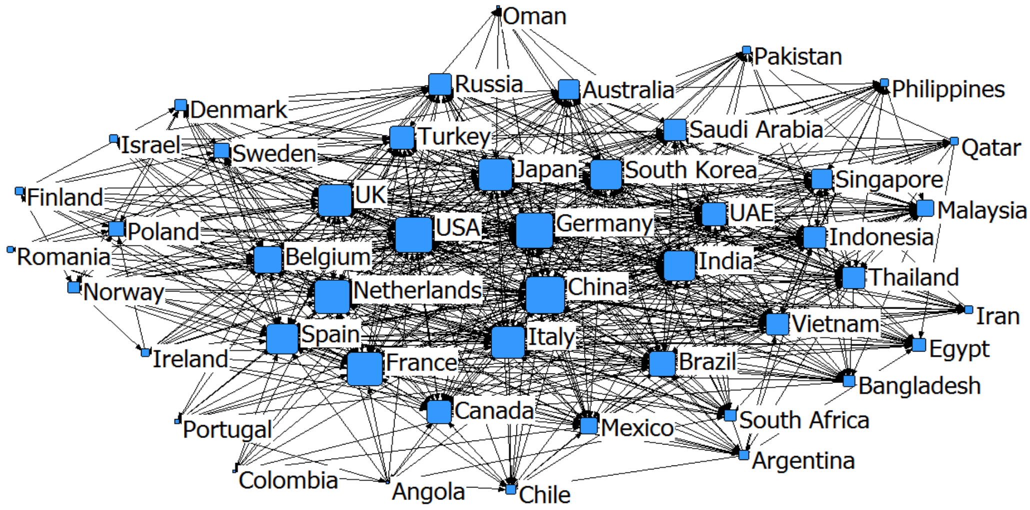

Fig. 1. The SCSR trade network

In Figure 1, the size of the nodes represents the status and influence of the country in the network. The area of each node in the network shown in Fig. 1 is different, indicating the different influence of countries in the network. There are many large nodes at the same time, which shows that the power in the network is centralized as well as decentralized, and the cooperation and competition relationship between countries is more complex. The game behavior under such network structure is more complex and dynamic.

The edges between nodes indicate trade links between countries. Trade cooperation between countries on the SCSR is a network-based cooperative game relationship. Each node country plays a strategic game with the countries with direct contact and high trade dependence, while there is no game relationship with the countries without direct trade relationship, which suggest that node countries only play game with their network neighbors and there is no game relationship between neighbors' neighbors and them.

The total benefit of the trade cooperation of the node countries is the benefit synthesis of game between node countries and all neighboring countries. Substituting the different degree values of each country into the asymmetric QRE network game model will have different effects on the parameter conditions of game returns and the choice of game strategies of each country [38: 69]. In the SCSR trade network, the degree of a node is the total number of its neighbors, which are: [9, 13, 19, 9, 32, 31, 20, 11, 45, 7, 15, 7, 15, 39, 43, 34, 26, 11, 14, 9, 39, 35, 34, 22, 18, 37, 18, 5, 4, 9, 17, 10, 12, 11, 26, 26, 20, 12, 33, 21, 28, 20, 26, 36, 42, 26].

3. Design of the network game model

3.1. Asymmetric Quantal Response Equilibrium (QRE) model

In standard game theory, the assumption that players are always perfect maximizers is adopted, i.e. people use their beliefs about uncertain events, including other players' actions, to make decisions that are consistent with the maximization of expected payoffs [39]. Yet humans are not perfect, they sometimes take decisions irrationally that does not give them the best outcome [40].

"In general, each player does not really know the other players' value systems; this is part of the reason why in reality many games have incomplete and asymmetric information. In such games, trying to find out the values of others and trying to conceal or convey one's own become important components of strategy." [41]

In a real situation, most people make mistakes, thus in competitive situations people such as athletics, business, and politics may alter their behavior in anticipation of their own and others' mistakes. To address the shortcomings of standard game theory, McKelvey, Palfrey and others [42] began to apply QRE model in game experiments; Capra [43] established the QRE refining model and tested it in 1999; Weiszacker [44] extended the QRE model to asymmetry. It is an equilibrium concept based on bounded rational strategic behavior, assuming that players play a noisy best response. The QRE is an extended version of Nash where there is a rationality variable which adds margin of error. If the rationality variable goes towards infinity, the equilibrium approaches Nashs [45]. On the other hand, if the rationality variable approaches zero the players will pick their strategy with an irrational mind not knowing what strategy is the best. Therefore, in the actual situation, the optimal strategy in the sense of Nash equilibrium does not appear with probability 1. Use the Logit reaction function or the exponential payment reaction function to represent the QRE equilibrium model as follows:

$$P(s_i)=\frac{\exp[\beta_i\sum_{s_{-i}}\tilde{P}(s_{-i})U_i(s_i,s_{-i})]}{\sum_{s_k}\exp[\beta_i\sum_{s_{-i}}\tilde{P}(s_{-i})U_i(s_k,s_{-i})]} \tag{1}$$

$$\tilde{P}(s_{-i})=\frac{\exp[\tilde{\beta}_{-i}\sum_{s_{-i}}P(s_i)U_{-i}(s_i,s_{-i})]}{\sum_{S_{-k}}\exp[\tilde{\beta}_{-i}\sum_{s_i}P(s_i)U_{-i}(s_i,s_{-k})]} \tag{2}$$

In formulas (1) and (2), $P(s_i)$ is the probability that game participant *i* adopts strategy S_i. $\tilde{P}(s_{-i})$ is the probability that participant -*i* adopts strategy S_{-i}; β_i, $\tilde{\beta}_{-i}$ represent the participants' cognitive beliefs on self-action sensitivity and cognitive beliefs about the reaction sensitivity of other participants respectively.

In the asymmetric QRE model, the probability of the participant taking strategy S_i is related to the self-action sensitivity cognitive beliefs and other participants' expected utility, while the probability of other participants taking strategy S_{-i} is related to participants' cognitive beliefs on the reaction sensitivity of others and other participants' expected utility. $P(s_i)$, $\tilde{P}(s_{-i})$ formed a circular nested relationship.

In the SCSR trade network, due to historical reasons, cultural differences, national strength and other factors, the perception of node countries to themselves and other countries in the network is incomplete, and the trade cooperation between them is also an irrational strategy choice based on incomplete information. Using the QRE model to describe the game process of the SCSR trade network would be able to depict the relationship between them in a more realistic way, and the established model could also have a stronger explanatory power for the cooperation mechanism of the SCSR trade network.

3.2. Hypothesis of the network game model

Combining the QRE model with the actual situation of the SCSR trade network, the following eight assumptions can be made. Among them, hypothesis 1) - 4) is the general hypothesis of standard game theory. Hypothesis 5) is the endogenous factors that influence the cooperation among international trade subjects introduced according to the QRE model. In order to facilitate the comparison, we also add some objective factors that affect trade cooperation. A large number of documents have demonstrated the positive impact of "selective incentive measures" on trade cooperation [46-48] in hypothesis 6); the restrictive effect of environmental barriers on free trade [49-51] mentioned in hypothesis 7) is also a general consensus in the international trade community. Hypothesis 8) is the network structure factor that affects cooperation. From the existing literature, we know that these two objective factors have an impact on international trade cooperation, but compared with the subjective endogenous factors, which degree of impact is greater is worth discussing.

1) Assuming that each participant has two strategies to choose from: cooperation and betrayal. $S_i = \{0,1\}$ is the policy set of node *i*, and 1 represents cooperation, while 0 represents betrayal.

2) Assuming that both sides of the game have symmetric benefits, that is, the respective cooperative benefit obtained from the game is *b*, and the value range of *b* is $b>0$; at the same time, there is cost for cooperating, the cost of cooperation is expressed by *d*, and its value range is ($0<d<b$).

3) Assuming that the respective return is *e* when two neighboring node countries choose the betrayal strategy, and $e>0$.

Combining the hypotheses (1), (2) and (3), the income payment matrix can be obtained as shown in Table 2:

Table 2

Payment matrix of the single game.

Single game between *i*-node and *j*-node		The strategy of *j*-node	
		cooperation	betrayal
The strategy of *i*-node	cooperation	*b-d ; b-d*	*-d; b*
	betrayal	*b; -d*	*e; e*

4) Participants choose cooperative and non-cooperative strategies according to the probability of the game. Assuming that they cooperate according to the probability of $P(s_i)$, then the probability of not to cooperate is $1-P(s_i)$.

5) There is a difference between the participants' cognitive beliefs on self-action sensitivity and cognitive beliefs about the reaction sensitivity of other participants, due to most participating countries believe that they are more considerate than other countries. That is, $\beta_i \geq \tilde{\beta}_j$.

6) In the SCSR trade network, each node country only plays game with their neighbor countries. In order to promote cooperation, network neighbors will give preferential policies and rewards to the node countries. From the perspective of rational decision makers, each country's rewards to other countries will not exceed the benefits it gains. Use *a* to represent the proportion of rewards given by each node country to its neighbors in its cooperation benefits, and $0<a<1$.

7) Environmental problems generally exist in countries in the SCSR Trade Network, so some countries will implement environmental barriers in trade to protect their ecology. However, because most of the environmental barriers are false and discriminatory [52], the countries that implement environmental barriers will not only bear a certain loss of interests themselves, but also be condemned by other countries. We name the loss and pressure in these two aspects as the implementation cost of environmental barriers, and its proportion in the cooperation benefits is expressed as *w*, then $0<w<1$.

8) The proportion of initial cooperators was r_0, it is the numbers of countries that choose a cooperative strategy at the beginning of game.

According to the above assumptions, the total utility value of participants at time *t* can be obtained as follows:

$$U_{it}\left(s_{it},s_{jt},c_{it}\right)=\sum_{j\in NBR}\sum_{s_i}\pi_i(s_i,s_j)P(s_i)+\sum_{j\in NBR,s_i=1}a_{ji}-w_i\sum_{i\neq j,s_i=0}x_j \tag{3}$$

Introducing the asymmetric QRE model:

$$P(s_i)=\frac{\exp\,[\beta_i\sum_{s_j}\tilde{P}(s_j)u_i(s_i,s_j)]}{\sum_{s_k}\exp\,[\beta_i\sum_{s_{-i}}\tilde{P}(s_j)u_i(s_k,s_j)]} \tag{4}$$

$$\tilde{P}(s_j)=\frac{\exp\,[\,\tilde{\beta}_j\sum_{s_{-i}}P(s_i)u_j(s_i,s_j)]}{\sum_{s_{-k}}\exp\,[\,\tilde{\beta}_j\sum_{s_i}P(s_i)u_j(s_i,s_{-k})]} \tag{5}$$

Combining with the game income payment matrix in Table 2, substituting the values in the matrix into the formulas (4) and (5), and the formulas (6) and (7) were obtained:

$$P_{S_{iC}} = \frac{\exp\,[\beta_i(P_{S_{jC}}(b-d)+P_{S_{jD}}(-d))]}{\exp\,[\beta_{S_i}(P_{S_{jC}}(b-d)+P_{S_{jD}}(-d))]+\exp\,[\beta_i(P_{S_{jC}}b+P_{S_{jD}}e)]} \tag{6}$$

$$P_{S_{jC}} = \frac{\exp\,[\beta_j(P_{S_iC}(b-d)+P_{S_iD}(-d))]}{\exp\,[\beta_{S_j}(P_{S_{iC}}(b-d)+P_{S_{iD}}(-d))]+\exp\,[\beta_j(P_{S_{iC}}b+P_{S_{iD}}e)]} \tag{7}$$

$$P_{S_{iC}} = 1-P_{S_{iD}} \tag{8}$$

$$P_{S_{jC}} = 1-P_{S_{jD}} \tag{9}$$

3.3. Analysis of network game model

The countries in the SCSR trade network will constantly adjust their behavioral strategies in accordance with the revenue situation in the network. When the cooperation revenue of the node countries is greater than the betrayal revenue, they will adopt the cooperation strategy, otherwise they will adjust to adopt the betrayal strategy. Substituting the formulas (6)-(9) into the formula (3), the formula (10) can be obtained:

$$U_{it} = \begin{cases} N_{it}^c(b-d)P_{S_{jt}} + (N-N_{it}^c)(-d)(1-P_{S_{jt}}) + \sum\limits_{\substack{j\in NBR\\ S_i=1}} a_{ij} & i \text{ is the cooperator} \\ N_{it}^c bP_{S_{jt}} + (N-N_{it}^c)e(1-P_{S_{jt}}) - w_{it}\sum\limits_{i\neq j} x_j & i \text{ is the betrayer} \end{cases} \tag{10}$$

In formula (10), *N* represents the total number of nodes in the network, N^c represents the number of partners in the network, and $P_{S_{jt}}$ represents the probability that node j adopts cooperative strategy.

The equilibrium condition for *i*-node to choose cooperative strategy is: the benefits of cooperation ⩾ the benefits of betrayal, as shown in formula (11):

$$N_{it}^c(b\text{-}d)P_{S_{jt}} + (N-N_{it}^c)(-d)(1-P_{S_{jt}}) + \sum_{\substack{j\in NBR\\ S_i=1}} a_{ij} \ge N_{it}^c bP_{S_{jt}} + (N-N_{it}^c)e(1-P_{S_{jt}}) - w_{it}\sum_{i\neq j} x_j \tag{11}$$

$$\sum_{\substack{j\in NBR\\ S_i=1}} a_{ij} + w_{it}\sum_{i\neq j} x_j - N_{it}^c dP_{jt} - (N-N_{it}^c)(e+d)(1-P_{S_{jt}}) \ge 0 \tag{12}$$

It can be known from formula (12) that the choice of a certain round of game strategy of each node country in the SCSR trade network is directly related to the reward for cooperation given by the neighbor node, the cost of cooperation input, the profit gained from the betrayal strategy selected by the node, the implementation cost of environmental barriers, and the probability value of the neighbor node choosing cooperation. Moreover, the probability of neighbor nodes choosing to cooperate is related to the participants' cognitive beliefs on self-action sensitivity and cognitive beliefs about the reaction sensitivity of other participants. Next section presents the simulation results of the influence of relevant variables on the game equilibrium of the SCSR trade network.

4. Analysis of network game simulation results

Using MATLAB software, the effects of the participants' cognitive beliefs on self-action sensitivity β_i, cognitive beliefs about the reaction sensitivity of other participants β_j, the proportion of initial cooperators r_0, rewards from neighboring countries *a*, and the implementation cost of environmental barriers *w* on the number of cooperators in the SCSR trade network were simulated.

In the simulation process, the initial game matrix and related variables can be randomly selected within a given range. The overall trend of simulation results will not change as long as other variables remain fixed while testing the influence of one variable. The assumed values given in the paper are based on empirical analysis and data trial-and-error. Firstly, a critical point interval where the trend line may be reversed was roughly determined according to the value range of variables and the experience of previous research results. Then, a group of variables with obvious trend can be determined through small range data adjustment and trial-and-error. The simulation results are as follows:

4.1. Analysis of the influence of participants' cognitive beliefs on self-action sensitivity on the number of cooperators in the SCSR trade network

Assume that the initial game matrix of node countries i and j of the SCSR trade network is (5, -2; 7, 3), the proportion of initial cooperators is 0.5, the value of neighboring countries' reward is 0.08, and the value of the implementation cost of environmental barriers is 0.025. Let β_j=0.1 to test the influence of β_i （$\beta_j < \beta_i$） on the number of cooperators in the SCSR trade network. When β_i=0.11, 0.2, 0.3, 0.5, 0.8 respectively, the simulation results are shown in figure 2:

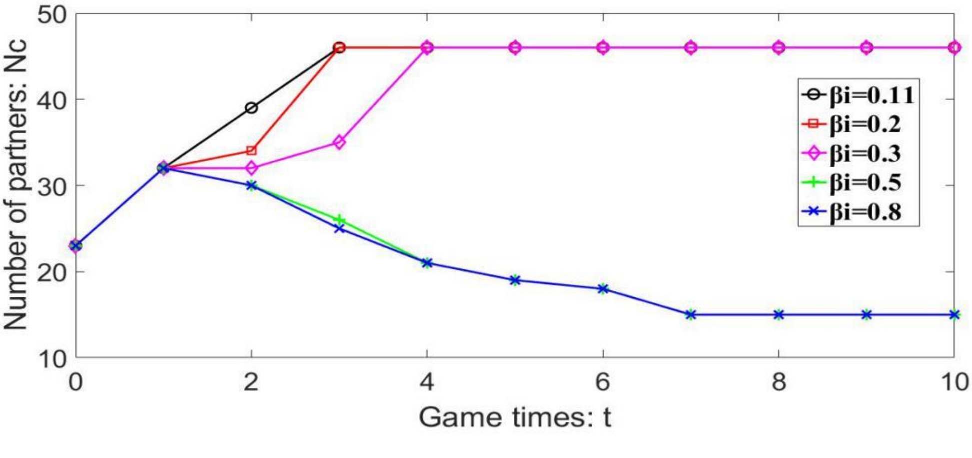

Fig. 2. The simulation diagram of the influence of participants' cognitive beliefs on self-action sensitivity on the number of cooperators in the SCSR trade network.

As can be seen from Figure 2, when other variables remain unchanged, when β_i=0.11, after three rounds of game, the number of cooperators in the SCSR trade network stabilizes at 46, that is, all countries adopt cooperative strategies; when the value of β_i increased to 0.3, after four rounds of game, all countries also chose the cooperative strategy; when the value of β_i is greater than 0.5, no matter how the value changes, the number of cooperators in the network was stabilized at 15 after several rounds of game. So it can be concluded that the value of self-belief has a negative impact on the cooperation of the SCSR trade network. The greater the value, the more likely the node countries in the network tend to adopt the betrayal strategy, which is more detrimental to the cooperation of the SCSR trade network.

4.2. Analysis of the influence of participants' cognitive beliefs about the reaction sensitivity of other participants on the number of cooperators in the SCSR trade network

Assume that the initial game matrix is (5, -2; 7, 3), the proportion of initial cooperators is 0.5, the value of neighboring countries' reward is 0.08, and the value of the implementation cost of environmental barriers is 0.025. let β_i=0.5 to test the influence of β_j （$\beta_j < \beta_i$） on the number of cooperators in the SCSR trade network. When β_j=0.01, 0.09, 0.15, 0.3, 0.48 respectively, the simulation results are shown in figure 3:

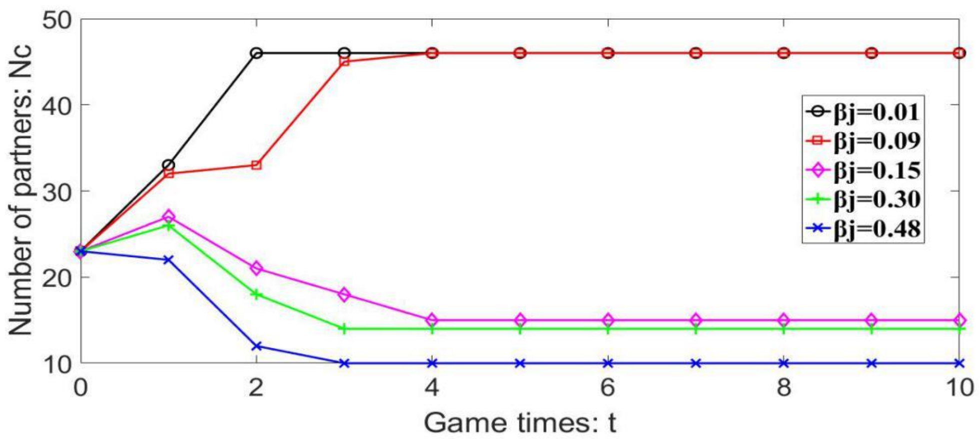

Fig. 3. The simulation diagram of the influence of participants' cognitive beliefs about the reaction sensitivity of other participants on the number of cooperators in the SCSR trade network.

In Figure 3, when other variables remain unchanged and β_j=0.01, after two rounds of game, the number of cooperators in the SCSR trade network stabilized at 46, that is, all countries chose cooperation strategies and the network reached the equilibrium state of full cooperation; when β_j increases to 0.09, the equilibrium state of full cooperation was reached after four rounds of game; however, when β_j increased to 0.15, the situation of cooperation went down sharply and the number of cooperators kept decreasing. It can be seen that the greater the network node countries' cognitive belief value to others' reaction sensitivity, the more vulnerable they were to be influenced by self-interest and speculative psychology, and adopted a first-mover strategy of betrayal, which had a negative impact on the cooperation of the SCSR trade network.

4.3. Analysis of the influence of the proportion of initial cooperators on the number of cooperators in the SCSR trade network

Assume that the initial game matrix is (5, -2; 7, 3), the value of neighboring countries' reward is 0.08, and the value of the implementation cost of environmental barriers is 0.025. Let β_i=0.5 and β_j=0.1（$\beta_j < \beta_i$）to test the influence of r_0 on the number of cooperators in the SCSR trade network. When r_0=0.1, 0.3, 0.5, 0.6, 0.8 respectively, the simulation results are shown in figure 4:

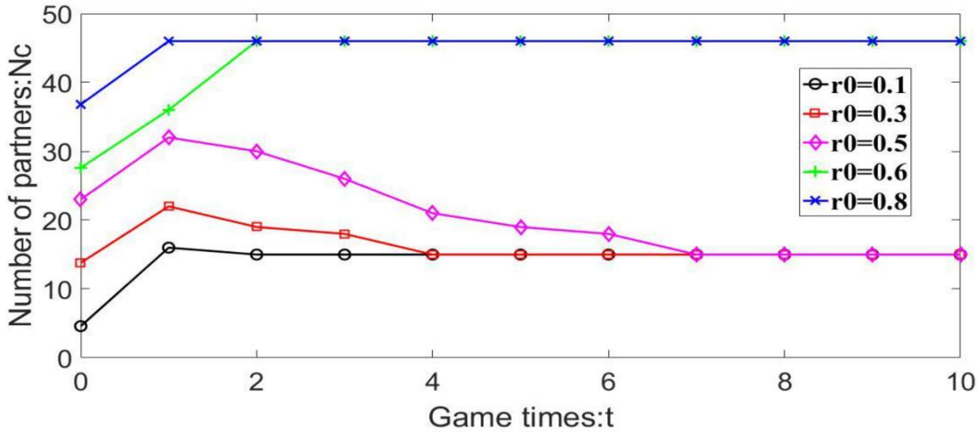

Fig. 4. The simulation diagram of the influence of the proportion of initial cooperators on the number of cooperators in the SCSR trade network.

In figure 4, other variables remain unchanged. When the initial cooperators ratio was 0.1, 0.3 and 0.5, after 2, 4 and 7 rounds of the game respectively, the number of cooperators in the SCSR trade network stabilized at 15, showing that in this range, the influence of the proportion of initial cooperators on the cooperation of the SCSR trade network is not obvious. Until the proportion of initial cooperators increased to 0.6, after two rounds of game, the number of cooperators stabilized at 46. Continued to increase to 0.8, after a round of game, all countries have also chosen cooperation strategies, and the speed of network game reaching the total cooperative equilibrium was accelerated. Therefore, the proportion of initial cooperators has a positive impact on the cooperation of the SCSR trade network. The results suggest that the higher the proportion of initial cooperators, the more cooperative-oriented the strategic choice of node countries in the network, the more conducive to the cooperation of the SCSR trade network; in addition, in order to achieve the full cooperation, the initial number of cooperators should be above a certain range (in this example, r_0 should be more than 0.5, under the limitation of the rewards from neighboring countries and public opinion pressure).

4.4. Analysis of the influence of the rewards from neighboring countries on the number of cooperators in the SCSR trade network

Assume that the initial game matrix is (5, -2; 7, 3), the proportion of initial cooperators is 0.5, and the value of the implementation cost of environmental barriers is 0.025. Let β_i=0.5 and β_j=0.1（$\beta_j < \beta_i$）to test the influence of the rewards from neighboring countries on the number of cooperators in the SCSR trade network. When *a*=0.01, 0.05, 0.08, 0.081, 0.085 respectively, the simulation results are shown in figure 5:

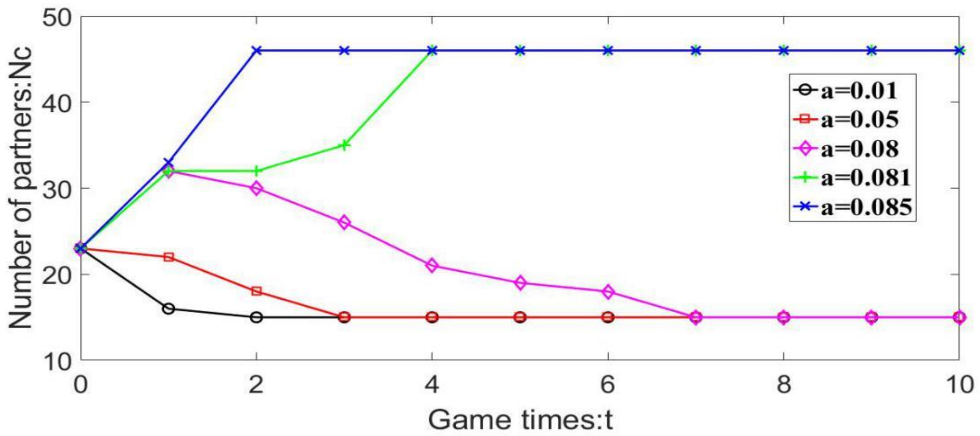

Fig. 5. The simulation diagram of the influence of the rewards from neighboring countries on the number of cooperators in the SCSR trade network.

In figure 5, other variables remain unchanged. When the reward value of neighboring countries was 0.01 and 0.05, the number of cooperators in the SCSR trade network stabilized at 15 after 2 rounds and 3 rounds of game respectively; when the value was increased to 0.08, after 7 rounds of game, the number of cooperators was still stable at 15. It was indicated that in this interval, the neighbor reward value only increased the number of game rounds that reach equilibrium, and would not change the final equilibrium result, which had no significant impact on the cooperation of the SCSR trade network. When the reward value of the neighboring country rose to 0.081, after 4 rounds of game, the number of cooperators stabilized at 46, that is, all countries chose the cooperation strategy. Continued to increase the reward value of neighboring countries, the faster the members of the SCSR trade network reached a full cooperation equilibrium. Therefore, the rewards from neighboring node countries have a significant positive impact on the cooperation of the SCSR trade network. The greater the value, the more likely countries in the network tend to choose the cooperation strategy, and the faster the cooperation equilibrium is reached, the more conducive to the cooperation of the SCSR trade network.

4.5. Analysis of the influence of the implementation cost of environmental barriers on the number of cooperators in the SCSR trade network

Assume that the initial game matrix is (5, -2; 7, 3), the proportion of initial cooperators is 0.5, and the value of rewards from neighboring countries is 0.08. Let β_i=0.5 and β_j=0.1（$\beta_j < \beta_i$）to test the influence of the implementation cost of environmental barriers on the number of cooperators in the SCSR trade network. When *w*=0.01, 0.03, 0.04, 0.041, 0.045 respectively, the simulation results are shown in figure 6:

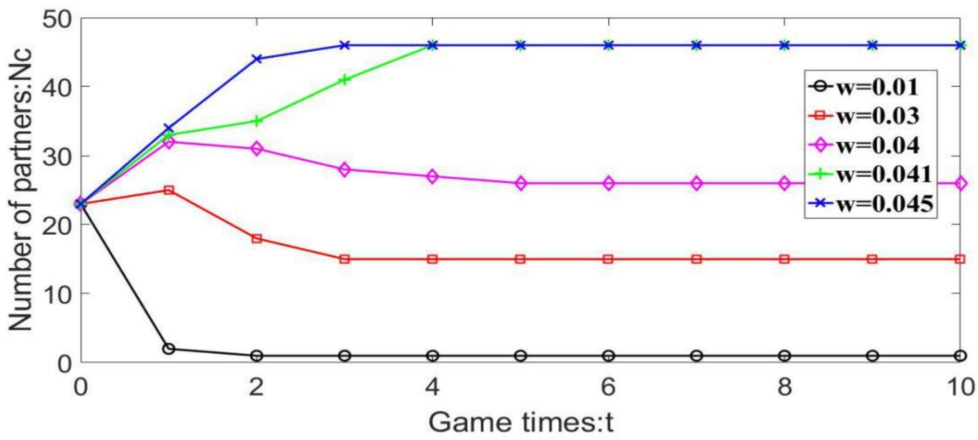

Fig. 6. The simulation diagram of the influence of the implementation cost of environmental barriers on the number of cooperators in the SCSR trade network.

In Figure 6, other variables remain unchanged. When the value of the implementation cost of environmental barriers was 0.01, after 2 rounds of game, the number of cooperators in the SCSR trade network stabilized at 2; when its value increased to 0.03, after 3 rounds of game, the number of cooperators stabilized at 15; when it continued to increase to 0.04, after 5 rounds of game, the number of cooperators was stable at 27; when the value of the implementation cost of environmental barriers increased to 0.041, after 4 rounds of game, all countries chose cooperation strategy; continuing to increase the value of the implementation cost of environmental barriers, the speed of reaching a full cooperation equilibrium in the SCSR trade network accelerated. It can be concluded that the implementation cost of environmental barriers has a significant positive impact on the trade cooperation of SCSR. On the one hand, small changes in its value will cause significant changes in the number of game rounds and the number of cooperators; on the other hand, the greater the value, the greater the pressure on the selectors of betrayal strategies, the greater the possibility that the countries in the network choose the cooperation strategy, which is more conducive to the cooperation of the SCSR trade network.

5. Discussion and conclusion

5.1. Discussion on simulation results

Through simulation, some interesting findings were discovered. Firstly, the simulation results verify the influence of the subjective factor of asymmetric cognition between countries on trade cooperation, which is undoubtedly negative. The SCSR trade network includes developed, developing and emerging countries of various types. Due to differences in economic level and cultural distance, asymmetric cognition is bound to be generated among them. Generally speaking, developed countries have more information advantages, so developing countries may be more susceptible to "egoist" in the absence of information awareness and adopt relatively conservative trade policies [53], which undoubtedly has a negative impact on cooperation.

But from the comparison of subjective factors and objective factors, we find that the influence is limited. From the simulation diagram, we can see that the small change in the value of the reward from neighbor countries and the implementation cost of environmental barriers will bring a big change in the cooperative equilibrium results, while the cooperative equilibrium result is much slower to respond to the subjective asymmetric cognition. This may be the role played by the increasingly rational and mature decision-making processes of countries. At the same time, the results also shows that subjective factors only have an impact on the cooperation among countries under certain conditions, and can not necessarily change the strategic choice of all countries in the network. Therefore, in the process of promoting trade cooperation, countries should not take subjective factors as the main consideration.

From the internal comparison of the two aspects of asymmetric cognition, we can also find that participants' cognitive beliefs about the reaction sensitivity of other participants have a greater effect on trade cooperation than participants' cognitive beliefs on self-action sensitivity. In other words, in the game of international trade cooperation, "knowing other players" is more influential than "self-confidence" on the strategic choice of international trade subjects. This may be the result of the complex political relations and lack of trust between countries in the SCSR trade network.

In addition, from the simulation results of the initial cooperative proportion, we can find that the larger the initial cooperative proportion, the more conducive to cooperation. This seems to be reasonable, because the more countries that initially choose cooperative strategies, the more they can form cooperative orientation to the strategy choice of other node countries in the network. Just based on the herd mentality, they will be more inclined to cooperate. But this may only be an ideal situation, because, as Kao [16] mentioned, some existing cooperation mechanisms in the South China Sea, such as the Asian Development Bank, cover a larger area outside the South China Sea, but have not been able to effectively promote cooperation. On the contrary, more participants mean more complex relationships and more diversified goals, which are likely to run counter to the aspirations of the South China Sea countries. Therefore, in the practice of establishing SCSR trade community, the number of initial participants should be well measured.

5.2. Policy implications

The policy implications of this research on promoting trade cooperation in SCSR are as follows:

Firstly, the establishment of the SCSR Trade Community should be carried out step by step and selectively. The friendly large and developed countries can give priority to that have established strategic partnerships at all levels on the SCSR to form a trade cooperation organization, so as to increase the proportion of initial partners and the probability of successful cooperation of this trade organization. The SCSR trade community still takes the South China Sea region and its surrounding countries as its core. As the most important cooperation organization in the region, ASEAN has made tremendous progress in achieving internal economic integration [54]. At the same time, it has carried out "export-oriented" economic cooperation, gradually forming the cooperation mechanism of ASEAN+ China, Japan and South Korea (10+3) [55]. But with the new wave of globalization, broader global cooperation is imperative. The SCSR trade community can be established by expanding the capacity of existing cooperative organizations, so that more countries with strong cooperation intentions can join in and share the development dividends.

Secondly, a reasonable incentive mechanism should be drawn up for the establishment of the SCSR Trade Cooperation Organization. Specifically, it includes the following aspects: 1) Through multilateral negotiations, a tax exemption policy of tax-free or low-tax for countries in the region can be reached to reward those who adopt cooperative strategies, thus promoting the development of intra-regional trade. 2) Increase the investment in infrastructure of the countries in the cooperation organization, especially in ports and waterways, so as to improve the level of infrastructure development in relevant countries, thereby improving logistics performance and promoting trade development. 3) Strengthen the capacity cooperation with countries within the trade cooperation organization, export China's advantageous production capacity to these countries, and help them develop manufacturing industries, thus achieving economic take-off. 4) Increase the import quotas of these countries and stimulate their production and employment through trade. 5) Adopt appropriate economic and political sanctions to punish non-cooperative countries and adjust trade weights with them, so as to promote the evolution of SCSR Trade Network to the equilibrium of cooperation.

Thirdly, appropriate sanctions should be taken against countries that implement unfair environmental barriers. Environmental barriers have a two-way impact on free trade. On the other hand, the high standards of environmental barriers to product technology and production process will also promote the development of industry and trade to a higher level. WTO is committed to global sustainable development, and its relevant regulations provide certain legitimacy for the implementation of environmental barriers [56]; but its principles of openness, equality and reciprocity also require countries to reduce tariff and non-tariff trade barriers [57, 58]. Therefore, it is very important to fully understand the rules of WTO and make rational use of them in the international trade game. In addition, the Marine Environmental Protection Committee (MEPC) under IMO has also put forward a series of technical, operational and market-oriented measures [59] in the field of green shipping, which requires countries to complete the green transformation as soon as possible, develop the environmental protection industry, and realize the coordinated development of environmental protection and free trade.

Finally, the communication among countries in the SCSR trade network should be strengthened to reduce the asymmetry of cognitive beliefs. On the one hand, China should attach importance to the flexibility of strategy, treat countries with different cognitive beliefs differently, and moderately reduce the self-belief value and belief value to other countries' reaction sensitivity. On the other hand, it is necessary to strengthen the construction of the trade destiny community of the SCSR, carry out various public service cooperation with relevant countries, establish a multi-level and diversified communication and cooperation platform, and share information through the platform, so as to increase the transparency of information among countries in the SCSR trade network, reduce transaction costs of cooperation, and reduce the asymmetric cognition in decision-making, thus promoting the cooperation of SCSR Trade Community.

5.3. Conclusion

The establishment and improvement of South China Sea cooperation mechanism has been a hot topic in the fields of international politics, law and economics. Previous studies were mostly confined to geographical scope, only around the South China Sea and its surrounding areas, to explore the possibility of establishing cooperation mechanisms of coastal countries in the South China Sea [60, 61]. The interference of complex external forces is one of the main factors that make cooperation in the South China Sea difficult, so it is understandable that scholars hope to exclude countries outside the region when establishing cooperation mechanisms. But beyond the political sphere, the trade cooperation relationship extended by the SCSR is a network connecting the whole world. Therefore, building a global SCSR Trade Community is a good way to promote regional cooperation and stabilize the global political and economic pattern.

From the existing research, we can find that game theory is widely applied in the field of international cooperation, but most of them are based on the assumption of rational economic man and complete information, ignoring the important role of subjective asymmetric cognition among countries in game decision-making. In contrast, based on the construction of SCSR trade network, this paper introduces QRE model and innovatively designs the SCSR trade network game model. The factors affecting trade cooperation are discussed from three aspects: subjective, objective and network structure, so that the explanatory power of the simulation results is more comprehensive, specific and practical.

To sum up, the SCSR trade network itself is a complex network with close trade links. At present, there are some regional cooperation mechanisms such as ASEAN in the network, and great progress has been made in promoting regional economic integration and foreign economic cooperation. Although it has not yet developed into a global cooperative organization, these organizations have laid the foundation for the establishment of a global SCSR Trade Community. At the same time, as the focus of global maritime trade shifts to the Indian Ocean [62], the number of partners in the SCSR trade network will continue to increase. But a wider range of participants means more complex relationships, and asymmetric perceptions among countries may make many countries in the network tend to choose self-interested and conservative trade policies, making cooperation a sub-optimal choice. But with the wave of digital globalisation, this information gap is likely to narrow and national decision-making will become more rational. At the same time, driven by incentive of interests and the implementation pressure of trade barriers, the SCSR trade network is evolving towards the direction of cooperation equilibrium. Of course, “Rome was not built in a day”, and the establishment of the SCSR Trade Community will be a long-term process.

Our research also has some limitations. First of all, the trade volume is only used as the standard for the construction of the SCSR trade network, based on which to explore the establishment of the community may be slightly weak; because the concept of the community contains not only common interests, sustainable development is equally important. Therefore, we will try to build a weighted network combining trade and sustainable development to improve the authenticity and practicability of the game results. In addition, the game process is carried out on an established static network, but the actual SCSR trade network is variable and dynamically changing. In the follow-up research, we will consider the impact of the dynamic changes of network topology on the game, providing a more reasonable theoretical explanation for the cooperative research of the trade community.

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