Research on interregional oil cooperation-sanctions with evolutionary game

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Abstract

Purpose – The game strategies differ when different regions participate in the oil game. Under what circumstances will different participants choose cooperation or sanction strategies? This is the core issue of this paper.

Design/methodology/approach – Regarding the current and future game behavior between different regions in the oil trade, this paper constructs an evolutionary game model between two regions to explore the possibility of sanctions strategies between the two sides in different situations.

Findings – The research finds: (1) When the benefits of in-depth cooperation between the two regions are greater, both sides tend to adopt cooperative strategies. (2) When the trade conflict losses between the two regions are smaller, both sides adopt sanctions strategies. (3) When a strong region trades with a weak region, if the former adopts a sanctions strategy, the net profits are greater than the benefits of in-depth cooperation between the two regions. If the latter adopts a sanctions strategy, the net profits are less than the trade conflict losses between the two regions. There will be the strong region adopting a sanctions strategy and the weak region adopting a non-sanctions strategy. At this time, the latter should reasonably balance the immediate and future interests and give up some current interests in exchange for in-depth cooperation between the two regions. Otherwise, it will fall into the situation of unilateral sanctions by the strong against the weak.

Originality/value – There is no paper in the existing literature that uses the evolutionary game method to analyze the oil game problem between the two regions. This paper constructs a two-party evolutionary game model composed of crude oil importers and crude oil exporters and, based on this, analyzes the evolutionary stability between the two regions under sanctions and cooperation strategies, which enriches the energy research field.

Keywords Evolutionary game, Cooperation-sanctions, Interregional game, Oil game

Paper type Research paper

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1. Introduction

With the rapid development of the global economy, the demand for energy in various regions has risen steeply. Energy supply is related to the socio-economic development and energy security of a region (Nyga-Lukaszewska and Napiórkowski, 2022), which has attracted widespread attention around the world [1]. Traditional fossil fuels are still a key component of various energy sources. According to the Statistical Review of World Energy 2023, traditional fossil fuels such as coal, natural gas, and oil account for up to 82% of total energy consumption. Furthermore, the demand for and production of oil has increased significantly and is still rising. For example, in 2022, global oil production increased by 3.80 million barrels per day, and Saudi Arabia alone had a daily production increase of 1.182 million barrels [2]. Oil plays a critical role as a strategic scarce resource. Oil resources are still indispensable for economic recovery in all world regions (Yu *et al.*, 2023), but the rapid consumption of oil resources and the increasing participation of more and more regions in the international oil trade markets have made the relationship between oil resources in global trade increasingly complex (Ji *et al.*, 2014). Therefore, oil and oil products will remain the focus of the development game between regions.

Issues of benefit distribution and energy security always accompany the oil game between different regions [3]. Therefore, different regions will adopt cooperation or sanctions to participate in the game (An *et al.*, 2014). For example, in February 2022, China and Russia signed an oil cooperation agreement to guarantee the supply of crude oil to refineries in western China [4]. In July 2022, Russia and Saudi Arabia plan to jointly maintain the oil cooperation concept of "OPEC +" (OPEC and non-OPEC participants) and avoid unnecessary losses caused by malicious competition [5]. Different regions also often defend their interests through sanctions or confrontation. For example, oil-exporting countries such as the United States and OPEC countries compete for market share in oil exports, ultimately ending with OPEC countries boycotting large-scale crude oil exports from the United States and reducing competition intensity through production cuts (Zhou *et al.*, 2022). The European Union countries and Russia have adopted a sanctions strategy against each other. Specifically, the European Union countries prohibit the import of Russian crude oil and oil products by sea, and Russia stops sending natural gas and oil energy to European Union countries [6]. So, the game strategies differ when different regions participate in the oil game. Under what circumstances will different participants choose cooperation or sanctions strategies? This is the core issue of this paper.

Therefore, this paper examines interregional oil gaming through the construction of a two-party evolutionary game, and explores the impact of the key factors, i.e. the benefits of in-depth cooperation, the trade conflict losses, and the net profits obtained from sanctions strategies, on the trend change of the evolutionary results. Compared to the net profits obtained from both regions adopting sanctions strategies, if the benefits of in-depth cooperation are greater, both regions are inclined to choose cooperation strategies. Furthermore, lower levels of trade conflict losses between the two regions would increase the likelihood of adopting sanctions strategies. When one region's net profits from adopting a sanctions strategy exceed the benefits of in-depth cooperation, while the other region's net profits are lower than the trade conflict losses between the two regions, a scenario of unilateral sanctions may evolve. The above illustrates that, for policymakers, paying more attention to the long-term interests of the regions and potential losses from trade conflicts is advantageous for strategic choices and adjustments at the regional level.

There are three contributions to this paper. Specifically, (1) There is no paper in the existing literature that uses the evolutionary game method to analyze the oil game problem between the two regions. This paper constructs a two-party evolutionary game model composed of crude oil importers and crude oil exporters and, based on this, analyzes the evolutionary stability between the two regions under sanctions and cooperation strategies, which enriches the energy research field. (2) Based on the complexity of the oil game problem, this paper investigates the key factors influencing the choice of sanctions and cooperation strategies in oil games between two regions, and clarifies the boundaries of different strategy choices between the two regions. This enriches the research on oil games between regions. (3) This paper constructs an evolutionary model of oil games between two regions, and theoretically depicts the possible evolutionary paths of oil games between the two regions. This can provide a basis for practical decision-making on oil issues between regions.

The rest of this paper is structured as follows: The second section reviews the relevant literature on oil games between regions. The third section establishes a game model and analyzes the evolutionary states in various situations. The fourth section conducts a numerical simulation analysis. The fifth section gives the research conclusion and puts forward the management implications.

2. The oil game between regions

The oil game has always been the center and focus of the energy game, and the game between different regions around oil is also the focus of this paper. Many scholars have studied the oil game between regions from the perspective of cooperation and confrontation between different regions.

From the perspective of cooperation between oil exporting regions, for example, Berk and Çam (2020) studied how cooperation agreements between the Organization of the Petroleum Exporting Countries and non-OPEC producers affect the structure of the crude oil market. They constructed a crude oil market equilibrium model with a spatial structure to predict future oil export production. Moreover, they believed that the cooperation of oil exporters would revolutionize the oil market. Mohammad (2021) studied the resource sharing and economic similarities among the GCC (Gulf Cooperation Council) countries within the regions, and concluded that although regional environmental cooperation among GCC countries is not comprehensive, it has high value for interregional environmental cooperation and policy coordination.

From the perspective of cooperation between oil-importing regions, Zhang *et al.* (2018) analyzed the possibility of China and India cooperating on oil tariffs in the face of the threat of oil supply disruptions from a game theory perspective. They concluded that cooperation can bring higher benefits and greater resistance to the threat of oil supply disruptions. Therefore, they called on China and India to adopt more cooperative strategies in the oil game. Chang *et al.* (2023)argued that cooperation among oil-importing countries is beneficial for managing the asymmetric impact of oil price volatility on their CAB and contributing to economic stability.

From the perspective of trade cooperation between oil regions, Wei *et al.* (2022) analyzed the impact of new trade relations on the efficiency of international oil trade networks under different trade cooperation strategies. Liu *et al.* (2020) used the complex network method to analyze the complexity and dynamics of oil import and export between regions from the perspective of oil security evaluation, and the results show that the global oil trade shows a pattern of diversified import sources and strengthened regional cooperation. An *et al.* (2020) analyzed the characteristics of South Korea's oil import projects. They believed that South Korea should actively establish a level of oil import and export cooperation with North Korea and Russia, actively explore opportunities for oil cooperation, and carry out diversified oil cooperation strategies. Chen *et al.* (2021) used the logarithmic mean division index (LMDI) method to study the competitiveness and complementarity of BRICS countries in oil trade and to reveal the import and export advantages of different countries. The results showed that India and Russia have high complementarity in crude oil trade, but the driving factors are unstable. China-Russia trade is stable, but further cooperation is still needed. Zhao *et al.* (2021) used the improved-entropy TOPSIS method to study the oil cooperation between China and countries on the "Belt and Road Initiative," evaluating the risk level of cooperation between China and different countries based on multiple risk indicators, providing a reference for cooperation between China and countries along the route. Duan and Duan, (2023) studied the oil and gas cooperation between China and Central and North Asian countries in the "Belt and Road Initiative", affirmed the potential of oil export cooperation with Central and North Asian countries, and gave suggestions for strengthening midstream and downstream cooperation in the oil industry.

The above pieces of literature show that regional cooperation strategies are indeed a common choice in the oil industry, and adopting a cooperation strategy can bring benefits and profits to the participants. This paper discusses the oil game problem from the perspective of evolutionary games, considering the possibility of participants choosing cooperative strategies and the possibility of further benefits when both parties choose cooperative strategies simultaneously.

From the perspective of sanctions between oil exporting regions, Zhou *et al.* (2022) found that as the United States has become the world's largest exporter of crude oil, the competition intensity of emerging crude oil exporters is gradually increasing, with the potential for intense export competition between traditional and emerging exporters. Behar and Ritz (2017) studied the competition between OPEC countries and US shale oil in oil exports and found that competition for market share among oil exporting countries will increase global oil exports and lead to significant fluctuations in oil prices. Kisswani *et al.* (2022) analyzed the competition between OPEC and non-OPEC countries and revealed that the oil exports of non-OPEC member countries strongly affected the oil exports of OPEC member countries. In the short term, the increase in non-OPEC oil production will lead to a decrease in OPEC oil production; however, in the long term, the increase in non-OPEC oil production will also lead to a further increase in OPEC production.

From the perspective of sanctions between oil-importing regions, Zhang *et al.* (2014) used complex network theory to study the competition between oil-importing countries in the Asia-Pacific region. Zhou *et al.* (2022) found that the competition center for crude oil imports has shifted from Europe and the United States to the Asia-Pacific region, and is likely to continue to shift to developing regions based on a complex network model. Hao (2023) also used complex network theory to analyze the pressure network evolution law of crude oil import trade from 2000 to 2020. They found that China is under increasing competitive pressure from Germany and the Netherlands in Russia. It is suggested that crude oil importing countries expand the global circle of trusted trading partners to improve the supply stability. The result showed a clear relationship between competition intensity and geographical location. Different regions have different competition strategies, but only by achieving diversified supply and expanding the globally trusted trading partner circle can they gain an advantage in oil competition.

From the perspective of sanctions between oil regions, Zheng *et al.* (2022) used a complex network theory and failure model to simulate the impact of sanctions on oil trade on the global energy trade pattern. They found that oil sanctions would cause oil exporters such as Russia to shift their export focus to Asian countries, and oil sanctions would also improve the energy resilience and trade efficiency of European countries. Nguyen and Do (2021) studied the impact of economic sanctions and counter-sanctions on Russian oil trade and found that economic sanctions harmed Russia's oil export interests while counter-sanctions harmed the interests of European Union agricultural product imports. The reduction in import and export quotas proves that implementing sanctions and counter-sanctions harms participating countries. Nakhli *et al.* (2021) used the Dynamic Stochastic General Equilibrium Model (DSGE) with the New Keynesian approach model to study the sanction activities of multiple countries on Iran's oil exports. They found that oil sanctions will reduce other countries' economic and technological investment in Iran, ultimately decreasing oil production. Decreased government oil revenue will increase the government's printing and coinage intensity, ultimately leading to inflation. As a country struggling to formulate a counter-sanctions strategy, oil sanctions will greatly affect Iran.

The above literature shows that adopting a confrontational or sanctions strategy is a common game strategy for participants. In order to obtain benefits, participants have the possibility of choosing sanctions strategies or making decisions to diversify their sanctioned intensity. This paper uses the method of evolutionary game to explore the problem of oil game, not only considering the benefits and losses obtained by the participating regions when making sanctions strategies and the possibility of countermeasures when the regions are sanctioned but also considering the possibility that both regions are unwilling to destroy existing cooperation.

Most of the above literature focuses on cases where regional cooperation or sanctions strategies have been chosen, but few papers explain that decision-makers will evolve strategies based on different situations. In addition, little literature defines the boundaries of interregional cooperation strategies and sanctions strategies. Therefore, this paper uses the method of evolutionary game to study the situation in which different strategies will be adopted in the oil game between regions, which further enriches the research in the oil field. The uniqueness of this paper compared to other studies is summarized in Table 1 below.

3. Evolutionary game analysis

This section discusses whether two oil regions, Region 1 and Region 2, will impose sanctions on each other's oil products in future trade. Furthermore, constructing an evolutionary game model analyzes the boundary of cooperation and sanctions strategies adopted by the two regions in international oil trade.

3.1 Model assumptions

Assumption 1. According to the stable evolution strategy proposed by Smith and Price (1973), the model adopted in this game is a two-party evolutionary game model. Evolution game deems that the main body participating in the game is bounded rationality, and the main body participating in the game does not need to have omniscience and omnipotence. However, the behavior choices of both parties will be adjusted and changed continuously to obtain more benefits, eventually evolving to a stable point.

Literature	Perspectives Cooperation	Sanctions	Model analysis	Tariff	Evolution
Berk and Çam (2020)	√		√		
Zhang *et al.* (2018)	√			√	
Wei *et al.* (2022)	√				
Chen *et al.* (2021)	√		√		
Zhao *et al.* (2021)	√		√		
Zhou *et al.* (2022)		√			√
Behar and Ritz (2017)		√	√		
Kisswani *et al.* (2022)		√	√		√
Hao (2023)		√	√		√
Nguyen and Do (2021)		√	√	√	
Nakhli *et al.* (2021)		√	√	√	
This paper	√	√	√	√	√

Source(s): Table 1 created by authors

Table 1. Comparative analysis with previous literature

The main body of the game in this model is Region 1 and Region 2. Both regions have the possibility of choosing a "**sanctions**" strategy or a "**cooperation**" strategy. In this paper, if one chooses the "sanctions" strategy, one will choose the means of economic sanctions against another region.

Furthermore, the probability of choosing the "sanctions" strategy in Region 1 is y, so the probability of choosing the "cooperation" strategy is 1-y. The probability of choosing the "sanctions" strategy in Region 2 is x, so the probability of choosing the "cooperation" strategy is 1-x.

Assumption 2. When deciding whether to use the sanctions strategy between the two regions, their behavior and decision-making are aimed at improving economic benefits, which means that the sanctions strategies in this paper are all economic sanctions. Refer to Nguyen and Do (2021) for research on economic sanctions. In this paper, the sanctions strategy refers explicitly to increasing the tax rate on the other region's imported oil and oil products, and reducing the amount of oil or oil products sold. The gains and losses in this game only involve the trade of oil and oil-related products between the two regions.

Assumption 3. Region 1 is where crude oil is imported, and Region 1 purchases crude oil from Region 2. After processing crude oil, various oil-processed products obtained are sold to Region 2. Region 2 is where crude oil is exported. Region 2 sells crude oil to Region 1 and purchases finished processed oil and oil products from Region 1. For example, in the international oil trade between China and Russia, China's largest oil supplier, China imports crude oil from Russia as a crude oil importer and exports oil products, such as lubricants, to Russia [7].

Assumption 4. When Region i chooses to impose sanctions on Region j, it will sanction the oil or related products sold in Region j, increase the import tax on its oil and related products, and thus obtain corresponding benefits t, but its tax behavior will cause direct and indirect losses g_i to Region i. In addition, Region i will try to reduce the amount of oil and related products sold to Region j, which will cause economic losses w_j to Region j, and this behavior will also cause economic losses u_i to itself, where $i = 1, 2; j = 3 - i$. The assumption can refer to the research of Antón *et al.* (2020) and Zhang *et al.* (2018). In addition, the benefits obtained by either party after choosing the "sanctions" strategy should be higher than the losses paid for it, that is $t_i > g_i + u_i$. Otherwise, the participants in the game should not consider the "sanctions" strategy.

Assumption 5. Referring to the study of Xin and Zhang (2023), the region will improve its oil exploration, mining, processing, transportation, storage, and obtain benefits from it. If the region is sanctioned, the speed and efficiency of development will be reduced due to the sanctions, resulting in reduced benefits. Assuming that the benefit obtained by Region i when it was not sanctioned is m_i, and the benefit obtained when it was sanctioned is n_i, then $m_i > n_i$, where $i = 1, 2$.

Assumption 6. Referring to the study of Vatansever (2020), if Region 1 and Region 2 choose the "sanctions" strategy at the same time, the behavior of both parties at this time will reduce the trading relationship between each other and may further deteriorate the trade. For example, trade cooperation between regions may cancel existing projects or even affect other normal agreements to "punish" opponents. At this time, the trade conflict losses between the two regions is C.

Assumption 7. Referring to the study of Yang *et al.* (2021), if both Region 1 and Region 2 choose the "cooperation" strategy, the behavior at this time can be regarded as a friendly relationship between the two sides, and there may be further cooperation and win-win between the two regions. For example, agreements can be reached quickly between the two places, and cooperation projects can be further expanded. At this time, the benefits of in-depth cooperation between the two regions is F.

The parameters involved in the model and the meanings are shown in Table 2.

3.2 Establishment of profit matrix

Based on the above assumptions, the payoff matrix for Regions 1 and Region 2 regarding whether to adopt sanctions strategies can be obtained, as shown in Table 3.

Based on the research of Friedman (1991), this paper can use the Jacobian matrix to verify whether the stable point formed by solving the game between the two sides is a stable point strategy.

Parameter	Name of parameter	Parameter meaning
R_i	Basic benefits	The original benefits when not participating in the game
t_i	Taxation benefits	The oil tax levied when selecting a sanctions strategy
g_i	Taxation costs	Direct or indirect losses caused by taxation
w_i	Losses when sanctioned	The losses suffered by the opponent when adopting a sanctions strategy
u_i	Cost of sanctions strategy	Reduce export losses when choosing a sanctions strategy
m_i	benefits from the natural development of technology	The benefits of technological development when not sanctioned
n_i	benefits from the development of technology when sanctioned	The benefits of technological development when sanctioned
C	The trade conflict losses between the two regions	The further losses caused by the deterioration of relations between the two regions
F	The benefits of in-depth cooperation between the two regions	The benefits of friendly diplomacy between the two regions

Source(s): Table 2 created by authors

Table 2. Parameter meanings

		Region 2 Sanctions(x)	Cooperation(1−x)
Region 1	Sanctions (y)	$R_1+t_1-t_2-g_1-w_1-u_1+n_1-C$ $R_2+t_2-t_1-g_2-w_2-u_2+n_2-C$	$R_1+t_1-g_1-u_1+m_1$ $R_2-t_1-w_2+n_2$
	Cooperation (1−y)	$R_1-t_2-w_1+n_1$ $R_2+t_2-g_2-u_2+m_2$	R_1+m_1+F R_2+m_2+F

Source(s): Table 3 created by authors

Table 3. Profit matrix

3.3 Model analysis

3.3.1 Taking region 1 as the research object. Region 1 expected benefits when selecting sanctions.

$$U_{11} = \left\{ \begin{array}{l} x(R_1 + t_1 - t_2 - g_1 - w_1 - u_1 + n_1 - C) \\ +(1-x)(R_1 + t_1 - g_1 - u_1 + m_1) \end{array} \right\} \tag{1}$$

$$= R_1 + t_1 - g_1 + m_1 - u_1 - (C + m_1 - n_1 + t_2 + w_1)x$$

Region 1 expected benefits when selecting not sanctions

$$\begin{aligned} U_{12} &= x(R_1 - t_2 - w_1 + n_1) + (1-x)(R_1 + m_1 + F) \\ &= R_1 + m_1 + F - (F + m_1 - n_1 + t_2 + w_1)x \end{aligned} \tag{2}$$

Combining (1) and (2) can be obtained, the average expected benefits of Region 1 is

$$\overline{U_1} = y * U_{11} + (1-y) * U_{12}$$

$$= \left\{ \begin{array}{l} R_1 + m_1 - (m_1 - n_1 + t_2 + w_1)x \\ -(g_1 - t_1 + u_1 + cx)y + F(x-1)(y-1) \end{array} \right\} \tag{3}$$

The replication dynamic equation when Region 1 selects sanctions is

$$F(y) = \frac{dy}{dt} = y\left(U_{11} - \overline{U_1}\right)$$

$$= (F + g_1 - t_1 + u_1 + cx - Fx)(y-1)y \tag{4}$$

The $F(y)$ in (4) represents the probability of Region 1 selecting a sanctions strategy over time.

At this time, let $F(y) = \frac{dy}{dt} = 0$, Three equilibrium solutions can be obtained: $y_1^* = 0$, $y_2^* = 1$, $x^* = \frac{g_1 - t_1 + u_1 + F}{F - C}$. The equilibrium solutions are provided in the appendix.

3.3.2 Taking region 2 as the research object. Region 2 expected benefits when selecting sanctions

$$U_{21} = \left\{ \begin{array}{l} y(R_2 + t_2 - t_1 - g_2 - w_2 - u_2 + n_2 - C) \\ +(1-y)(R_2 + t_2 - g_2 - u_2 + m_2) \end{array} \right\} \tag{5}$$

$$= R_2 + t_2 - g_2 + m_2 - u_2 - (C + m_2 - n_2 + t_1 + w_2)y$$

Region 2 expected benefits when selecting not sanctions

$$\begin{aligned} U_{22} &= y(R_2 - t_1 - w_2 + n_2) + (1-y)(R_2 + m_2 + F) \\ &= R_2 + m_2 + F - (F + m_2 - n_2 + t_1 + w_2)y \end{aligned} \tag{6}$$

Combining (5) and (6) can be obtained, the average expected benefits of Region 2 is

$$\overline{U_2} = xU_{21} + (1-x)U_{22}$$

$$= \left\{ \begin{array}{l} R_2 + m_2 - (m_2 - n_2 + t_1 + w_2)y \\ -(g_2 - t_2 + u_2 + cy)x + F(x-1)(y-1) \end{array} \right\} \tag{7}$$

The replication dynamic equation when Region 2 selects sanctions is

$$F(x) = \frac{dx}{dt} = x\left(U_{21} - \overline{U_2}\right)$$
$$= (F + g_2 - t_2 + u_2 + cy - Fy)(x - 1)x \tag{8}$$

The $F(x)$ in (8) represents the probability of Region 2 selecting a sanctions strategy over time.

At this time, let $F(x) = \frac{dx}{dt} = 0$, Three equilibrium solutions can be obtained: $x_1^* = 0$, $x_2^* = 1, y^* = \frac{g_2 - t_2 + u_2 + F}{F - C}$. The equilibrium solutions are provided in the appendix.

3.3.3 Evolutionary stability strategy. According to the above replicated dynamic equations (4), (8), the corresponding Jacobian matrix can be constructed:

$$J = \begin{bmatrix} \left\{ \begin{array}{l} (2x-1)(F+g_2-t_2 \\ +u_2+Cy-Fy) \end{array} \right\} & (C-F)(x-1)x \\ (C-F)(y-1)y & \left\{ \begin{array}{l} (2y-1)(F+g_1-t_1 \\ +u_1+Cx-Fx) \end{array} \right\} \end{bmatrix} \tag{9}$$

The construction process of the Jacobian matrix is provided in the appendix.

The stability of the equilibrium point in the research model is solved by the local stability of equation (9). From the equations (4) and (8), $F(x) = 0$ and $F(y) = 0$ can be combined to obtain five equilibrium points under the model, where $x^* = \frac{g_1 - t_1 + u_1 + F}{F - C}$, $y^* = \frac{g_2 - t_2 + u_2 + F}{F - C}$.

The results of partial derivatives at each equilibrium point are shown in Table 4.

Where $a = (C - F)(x^* - 1)x^* = \frac{(t_1 - g_1 - u_1 - C)(t_1 - g_1 - u_1 - F)}{C - F}$, $b = (C - F)(y^* - 1)y^* = \frac{(t_2 - u_2 - g_2 - C)(-t_2 - u_2 - g_2 - F)}{C - F}$.

According to the stable conditions of the evolutionary strategy, for easy of analysis, assume that the determinant of the matrix is $Det(J)$ and the trace of the matrix is $tr(J)$. It can be seen that when $Det(J) > 0$ and $tr(J) < 0$, the equilibrium point is a stable point. Assuming $\xi_1 = t_1 - g_1 - u_1$, $\xi_2 = t_2 - g_2 - u_2$, the economic meanings of ξ_1 and ξ_2 respectively refer to the net profits obtained from another region after sanctions were imposed in Regions 1 and Region 2. Then, this paper analyzes the local stability of each equilibrium solution in the system. The determinants and traces of each equilibrium solution are shown in Table 5.

According to the constructed model, 14 different situations will evolve based on the relative sizes of ξ_1 and ξ_2 and F and C. And the evolutionary stable points in each case are shown in Table 6.

Equilibrium ponit	$\frac{\partial F(x)}{\partial x}$	$\frac{\partial F(x)}{\partial y}$	$\frac{\partial F(y)}{\partial x}$	$\frac{\partial F(y)}{\partial y}$
A(0,0)	$(t_2 - g_2 - u_2) - F$	0	0	$(t_1 - g_1 - u_1) - F$
B(0,1)	$(t_2 - g_2 - u_2) - C$	0	0	$-(t_1 - g_1 - u_1) + F$
C(1,0)	$-(t_2 - g_2 - u_2) + F$	0	0	$(t_1 - g_1 - u_1) - C$
D(1,1)	$-(t_2 - g_2 - u_2) + C$	0	0	$-(t_1 + g_1 + u_1) + C$
E(x^*, y^*)	0	a	b	0

Source(s): Table 4 created by authors

Table 4. Partial derivative value at equilibrium point

In Table 5, "$-$" and "$+$" refer to the positive or negative values of $Det(J)$ or $tr(J)$. The meaning of "$\sim$" is that the value of $tr(J)$ is uncertain. ESS refers to the evolutionarily stable strategy for this case.

Figures 1 and 2 are the schematic diagrams of the evolution of the game in various cases. The evolutionary schematic diagrams can express the evolution of the subjects participating in the game in different cases when choosing sanctions or cooperative strategies in different situations during the oil game, and visualization of the meaning and trend of stability in different cases in Table 2.

According to the evolutionary stability strategy calculated and analyzed in Table 2 under different cases and the evolutionary schematic diagram of Figures 1 and 2, the following 6 propositions can be obtained.

Proposition 1. Combining Case1, Case2, and Case3, it is found that the evolutionary stable points are all (0,0) points. This indicates that when both Region 1 and Region 2 adopt sanctions strategies, if the net benefits obtained are less than the benefits F brought by cooperation between the two regions, that is, $\xi_1 < F$ and $\xi_2 < F$. At this time, Regions 1 and Region 2 all prefer the cooperation strategies, and will try to obtain more potential benefits or higher communication benefits through further cooperation. For example, China cooperates closely with major oil resource countries along the Belt and Road Initiative, such as Russia, the Middle East, and Central Asia (Chen *et al.*, 2023). This not only deepens oil trade cooperation but also drives the upgrading of the entire industry chain, such as refining, pipelines, and technology, and this promotes the import or export of oil equipment and instruments [8]. The "Belt and Road Initiative" has brought great cooperation benefits to the participants, making the regions participating in the game choose cooperation strategies.

Proposition 2. Combining Case4, Case5, and Case6, it is found that the evolutionary stable points are all (1,1) point. This indicates that when both Region 1 and Region 2 adopt sanctions strategies, if the net benefits obtained are greater than the trade conflict losses C between the two regions, that is, $\xi_1 > C$ and $\xi_2 > C$. At this time, Regions 1 and Region 2 all prefer the sanctions strategies. This is because there may not yet be deep cooperation and many projects between the two regions. When both sides choose the sanctions strategies, although it will lead to the collapse of all kinds of cooperation signed between regions, the losses thus suffered are within the scope completely acceptable to the sanctioners, and they can also earn additional profits from the implementation of the sanctions strategies.

Equilibrium point	$Det(J)$	$tr(J)$
A(0,0)	$(\xi_2 - F)(\xi_1 - F)$	$\xi_1 + \xi_2 - 2F$
B(0,1)	$-(\xi_2 - C)(\xi_1 - F)$	$\xi_2 - \xi_1 + F - C$
C(1,0)	$-(\xi_2 - F)(\xi_1 - C)$	$\xi_1 - \xi_2 + F - C$
D(1,1)	$(\xi_2 - C)(\xi_1 - C)$	$-\xi_2 - \xi_1 + 2C$
E(x^*, y^*)	$-\frac{(\xi_1 - C)(\xi_1 - F)(\xi_2 - C)(\xi_2 - F)}{(F - C)^2}$	0

Source(s): Table 5 created by authors

Table 5.
Local stability of equilibrium point

Case	Equilibrium point	$Det(J)$	$tr(J)$	Stability
Case1	When $\xi_1 < F, \xi_2 < F, \xi_1 < C, \xi_2 < C$			
	A(0,0)	+	−	ESS
	B(0,1)	−	~	
	C(1,0)	−	~	
	D(1,1)	+	+	
Case2	When $\xi_1 < F, \xi_1 < C, \xi_2 > C, \xi_2 < F$			
	A(0,0)	+	−	ESS
	B(0,1)	+	+	
	C(1,0)	−	~	
	D(1,1)	−	~	
Case3	When $\xi_1 > C, \xi_1 < F, \xi_2 < F, \xi_2 < C$			
	A(0,0)	+	−	ESS
	B(0,1)	−	~	
	C(1,0)	+	+	
	D(1,1)	−	~	
Case4	When $\xi_1 > F, \xi_2 > F, \xi_1 > C, \xi_2 > C$			
	A(0,0)	+	+	
	B(0,1)	−	~	
	C(1,0)	−	~	
	D(1,1)	+	−	ESS
Case5	When $\xi_1 > F, \xi_1 > C, \xi_2 > C, \xi_2 < F$			
	A(0,0)	−	~	
	B(0,1)	−	~	
	C(1,0)	+	+	
	D(1,1)	+	−	ESS
Case6	When $\xi_1 < F, \xi_1 > C, \xi_2 > C, \xi_2 > F$			
	A(0,0)	−	~	
	B(0,1)	+	+	
	C(1,0)	−	+	
	D(1,1)	+	−	ESS
Case7	When $\xi_1 < F, \xi_2 < F, \xi_1 > C, \xi_2 > C$			
	A(0,0)	+	−	ESS
	B(0,1)	+	+	
	C(1,0)	+	+	
	D(1,1)	+	−	ESS
	E(x^* , y^*)	−	0	
Case8	When $\xi_1 > F, \xi_1 < C, \xi_2 < F$, $\xi_2 < C$			
	A(0,0)	−	~	
	B(0,1)	+	−	ESS
	C(1,0)	−	~	
	D(1,1)	+	+	
Case9	When $\xi_1 > F, \xi_1 < C, \xi_2 < F$, $\xi_2 < C$			
	A(0,0)	+	+	
	B(0,1)	+	−	ESS
	C(1,0)	−	~	
	D(1,1)	−	~	
Case10	When $\xi_1 > F, \xi_1 > C, \xi_2 < C$, $\xi_2 < F$			
	A(0,0)	−	~	
	B(0,1)	+	−	ESS
	C(1,0)	+	+	
	D(1,1)	−	~	

(*continued*)

Table 6. Local stability of equilibrium points in different cases

Case	Equilibrium point	$Det(J)$	$tr(J)$	Stability
Case11	When $\xi_1 < F, \xi_1 < C, \xi_2 > F \xi_2 < C$			
	A(0,0)	−	~	
	B(0,1)	−	~	
	C(1,0)	+	−	ESS
	D(1,1)	+	+	
Case12	When $\xi_1 > F, \xi_1 < C, \xi_2 > F$, $\xi_2 > C$			
	A(0,0)	+	+	
	B(0,1)	−	~	
	C(1,0)	+	−	ESS
	D(1,1)	−	~	
Case13	When $\xi_1 < F, \xi_1 < C, \xi_2 > C$, $\xi_2 > F$			
	A(0,0)	−	~	
	B(0,1)	+	+	
	C(1,0)	+	−	ESS
	D(1,1)	−	~	
Case14	When $\xi_1 > F, \xi_2 > F, \xi_1 < C, \xi_2 < C$			
	A(0,0)	+	+	
	B(0,1)	+	−	ESS
	C(1,0)	+	−	ESS
	D(1,1)	+	+	
	E(x^* , y^*)	−	0	

Table 6.

Source(s): Table 6 created by authors

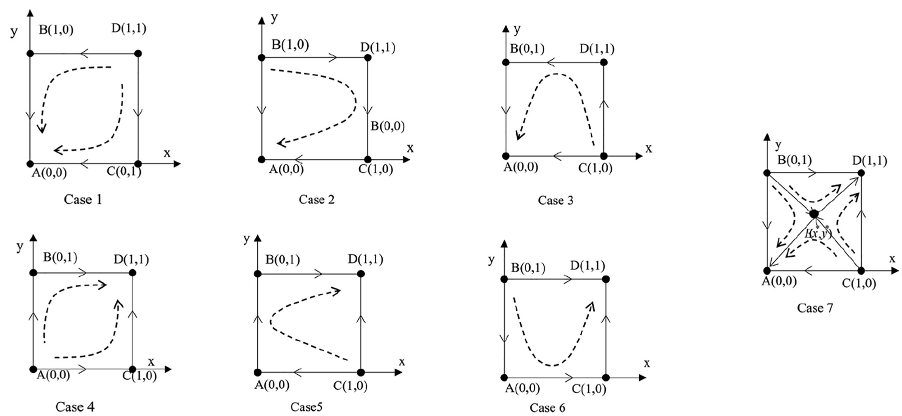

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Figure 1.
Schematic diagram of the evolution of Case1 ~ Case7

For example, Canada is the largest source of energy imports for the United States, accounting for 27% of US energy imports in 2019, with crude oil accounting for 91% of imported energy [9]. In addition, the proportion of oil imported by the United States from Canada exceeds 51% of its total oil imports [10]. It can be seen that the United States is highly dependent on Canada in various energy imports, and there is a high willingness to cooperate between the United States and Canada. Just as the two regions have launched and signed numerous oil cooperation projects and contracts, once a trade conflict arises between the two regions, it will cause huge losses, so both sides tend to adopt a cooperation strategy. In comparison, the United States and Iran have less oil trade cooperation. Iran's oil production is mainly

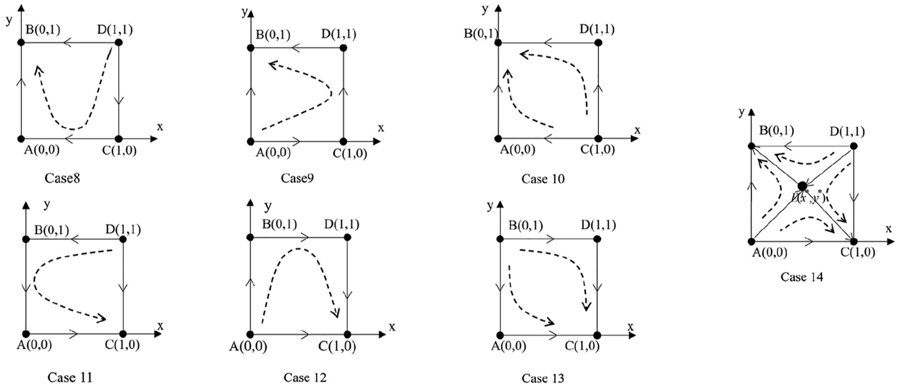

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Figure 2.
Schematic diagram of the evolution of Case8 ~ Case14

transported to Syria, China [11], etc. The United States mainly imports oil from regions such as Canada, Mexico, and Russia, etc [12]. Therefore, in the event of a trade conflict between the two regions with less cooperation on oil projects, the losses caused by the trade conflict are lower, but the benefits brought by sanctions are higher, motivating them to adopt a sanctions strategy.

Proposition 3. Combining Case8, Case9, and Case10, it is found that the evolutionary stable points are all (0,1) point. When the net profits obtained by Region 1 adopting a sanctions strategy is greater than the in-depth cooperation benefit F by both parties adopting a cooperation strategy, and the net profits obtained by Region 2 adopting a sanctions strategy is less than the trade conflict loss C by both parties adopting a sanctions strategy, that is $\xi_1 > F$, $\xi_2 < C$, Region 2 does not choose a sanctions strategy when Region 1 chooses a sanctions strategy against Region 1. This is because the net profits obtained by Region 1 in selecting the sanctions strategy is high enough, even higher than the profit obtained by cooperation. However, Region 2 can't afford the high trade conflicts when both regions adopt the sanctions strategy, so it can only choose the cooperation strategy. The evolution of the common situation between the two sides has led to the emergence of unilateral sanctions.

For example, the United States has adopted unilateral sanctions against Venezuela, banning trade in Venezuelan oil and products related to the oil industry chain [13]. This is because the United States has adopted a policy of unilateral sanctions against Venezuela, which has caused the oil price to drop rapidly. This has greatly benefited American business giants such as Chevron and enabled the United States to obtain huge benefits [14]. At the same time, it has also consolidated the position of some non-economic areas. Such sanctions are far more beneficial than in-depth cooperation between the two regions. However, Venezuela, as an oil exporting country, its economic resources are completely dependent on oil exports, and the economic benefits of the Venezuelan government, which has been cut off from oil exports, have plummeted but still hopes to maintain a cooperative relationship with the United States. This is because Venezuela cannot bear the huge losses caused by the trade conflict and hopes to be still able to guarantee that some existing cooperation projects will not be further affected [15], thus causing the situation of unilateral US sanctions against Venezuela.

In this situation of economic trade, sanctioners tend to choose unilateral sanctions to seek benefits. As the sanctioned region, if it wants to eliminate the dilemma of unilateral sanctions, it should choose to make more far-sighted interest exchange behaviors. For example, sanctioned region can choose unilateral direct sales instead of selling oil through the market. Although this move makes the sanctioned give up some immediate benefits, it can allow the sanctioner to gain certain benefits and increase the losses of trade conflicts C between the two regions. At the same time, based on the oil direct sales contract, more trade agreements can be expanded between the two regions to improve future cooperation benefits F.When $\xi_1 < F$、$\xi_2 < F$ and $\xi_1 < C$、 $\xi_2 < C$, the two regions will inevitably tend to choose a non-sanctions strategy at the same time, that is a cooperation strategy, to build a friendly development relationship.

Proposition 4. Combining Case11, Case12, and Case13, it is found that the evolutionary stable points are all (0,1) point.The net profits obtained by Region 1 adopting a sanctions strategy is less than the trade conflict loss C by both parties adopting a sanctions strategy. Moreover, the net profits obtained by Region 2 adopting a sanctions strategy is greater than the in-depth cooperation benefit F by both parties adopting a cooperation strategy, that is $\xi_1 < C$, $\xi_2 > F$. Similarly to Proposition 3, when Region 2 adopts a sanctions strategy, Region 1 will not adopt a sanctions strategy. The analysis result is similar to case8 ~ case10. At this time, the profit obtained by Region 2 when choosing the sanctions strategy is relatively high, while the profit brought by Region 1 adopting the sanctions strategy is too small and cannot bear the loss cost brought by both parties when sanctioning, which leads to the situation that Region 2 adopts the sanctions strategy and Region 1 does not do the countermeasures strategy.

Proposition 5. The results of Case7 well confirm the conclusion drawn by Case1 ~ Case6, and their evolutionary stability points are (0,0) and (1,1). When $\xi_1 < F$ and $\xi_2 < F$, both Regions 1 and Region 2 tend to choose the cooperation strategies. When $\xi_1 > C$ and $\xi_2 > C$, both Regions 1 and Region 2 tend to choose the sanctions strategies. When the above two conditions are met at the same time, as shown in Case 7, Region 1 and Region 2 tend to choose a cooperation strategy when in the graphical ACEB range, and Region 1 and Region 2 tend to choose a sanctions strategy when in the range of graphical DCEB, which is related to the probability of sanctions in Regions 1 and Region 2 at the initial state. The saddle point is the point $E(x^*, y^*)$ that determines the relationship between the area of the graphic ACEB and the graphic DECB. The value of this point is closely related to the benefits of in-depth cooperation and the trade conflict losses. When the in-depth cooperation benefit F increases, the saddle point $E(x^*, y^*)$ moves to the upper right corner, making it more likely that both regions will choose cooperation strategies. When the trade conflict loss decreases, the saddle point $E(x^*, y^*)$ moves to the lower left corner, making it more likely that both regions will choose sanctions strategies.

Proposition 6. On the one hand, the results of Case14 verify the conclusion of Case8~ Case13, where the evolutionary stable point is $(0, 1)$ and $(1, 0)$. At this time, the conditions are satisfied: the net benefits of Region 1 and Region 2 when choosing the sanctions strategy are greater than the benefits of in-depth cooperation F when both parties choose cooperation, and less than the the trade conflict losses C when both parties choose sanctions, that is $\xi_1 > F$,

$\xi_2 > F$, $\xi_1 < C$ and $\xi_2 < C$. On the other hand, this is an abnormal situation. For the two regions that have already had in-depth cooperation and signed various cooperation projects and trade contracts, if they both adopt sanction strategies, it will lead to huge losses in trade conflicts C. Therefore, both regions find it difficult to accept the occurrence of simultaneous sanctions. However, at the same time, it is difficult for both sides to expand further cooperation in the future, that is, the benefits of in-depth cooperation F between the two sides are low, and the possibility of future cooperation is lacking, which makes the two regions take sanctions against each other to seek benefits. At this time, the size of the net benefit brought by choosing a sanctions strategy affects the direction of the stable point. Regions with larger ξ_i will choose a sanctions strategy, and regions with smaller ξ_i will choose a cooperation strategy. If a high degree of trade cooperation has been established between the two regions, that is, there is a high degree of C, it is difficult for the two regions to take economic sanctions as deep trade partners. In addition, the two regions with a highly cooperative relationship will not lack benefits in further cooperation in the future. That is, there will not be a very low degree of F.

4. Numerical simulation analysis

Based on the analysis in the previous section, this section will use MATLAB software to simulate the model evolution in different cases. According to the replication dynamic equation obtained from formula (4) and formula (8), the parameters that affect the path trend of this evolutionary game are: Taxation benefits t_i, Taxation costs g_i, Cost of sanctions strategy u_i, The trade conflict losses between the two regions C and The benefits of in-depth cooperation between the two regions F. All the parameters involved in this paper are mainly set according to the sensitivity of each factor to regional benefits, which is not enough to represent the real value and benefits of each region in various aspects in reality. Therefore, the initial values of the parameters selected in this paper will make the conclusion of the numerical simulation clearer. In reality, it needs to be analyzed through specific situations.

Suppose the initial value of the parameters of the model is $t_1 = 1200$, $g_1 = 60$, $u_1 = 100$, $t_2 = 1000$, $g_2 = 50$ and $u_2 = 60$. Set the initial points (x, y) of the numerical simulation to (0.1, 0.3), (0.3, 0.6), (0.6, 0.9), (0.5, 0.3), (0.9, 0.6), respectively. The dynamic evolution process of the probability of participating decision-makers choosing different strategies over time is as follows.

Figures 3–12 reflect the evolution results of different cases under simulation. The evolution results obtained by the simulation analysis are consistent with the theoretical analysis results. Due to the hypothesis that $\xi_1 > \xi_2$ causes the conditions of case 2, case 6, case 11, case 12, case 13, and part of case 14 to fail, the results of these cases or complete results are not included. When the condition $\xi_1 < \xi_2$ is satisfied, a situation similar to the simulated situation can also be obtained similarly.

Taking Case 7, that is, Figure 7, as an example, further parameter adjustments are made to verify the impact of parameters the trade conflict losses between the two regions C and the benefits of in-depth cooperation between the two regions F on the evolution results, and attempts are made to find a solution to increase the probability of two-region cooperation rather than conflict sanctions. As shown below, if the benefits of in-depth cooperation between the two regions F are increased, the results are shown in Figure 13; the trade conflict losses between the two regions C are increased, as shown in Figure 14.

According to the formula $E(x^*, y^*)$, the saddle point E in Figure 7 is (0.4, 0.78).

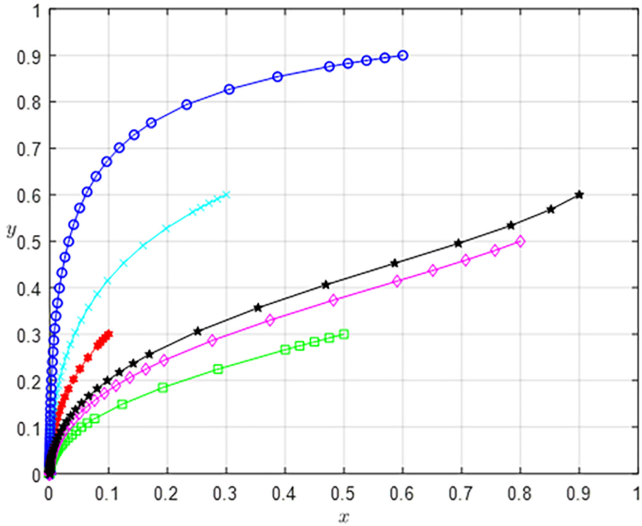

Figure 3.
Case1 evolution process

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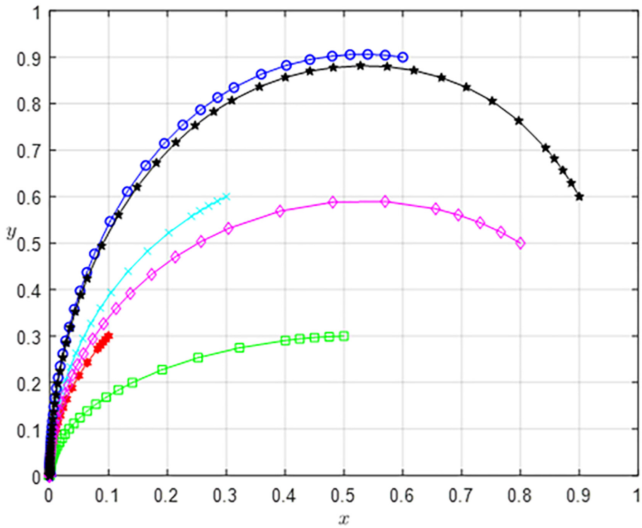

Figure 4.
Case2 evolution process

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When the benefits of in-depth cooperation between the two regions F increase, the saddle point E' increases to the upper right corner, which makes the area of the graphic ACEB increase, that is, the area tending to (0,0) increases. It can be seen that the benefits of in-depth cooperation between the two regions F are conducive to increasing the possibility of choosing cooperation between Regions 1 and Region 2. Similarly, the increase in the loss of trade conflicts between the two regions C will also increase the area of the trend (0,0). If $C > \xi_1$ and $C > \xi_2$, the evolution will change further. The evolution process shown in Figure 14 is similar

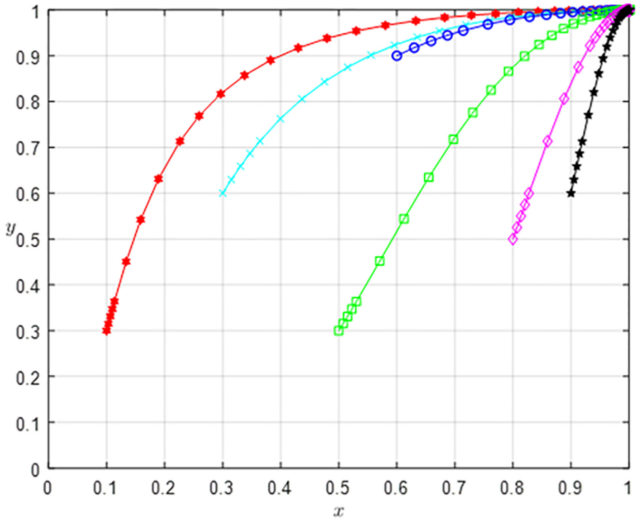

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Figure 5. Case4 evolution process

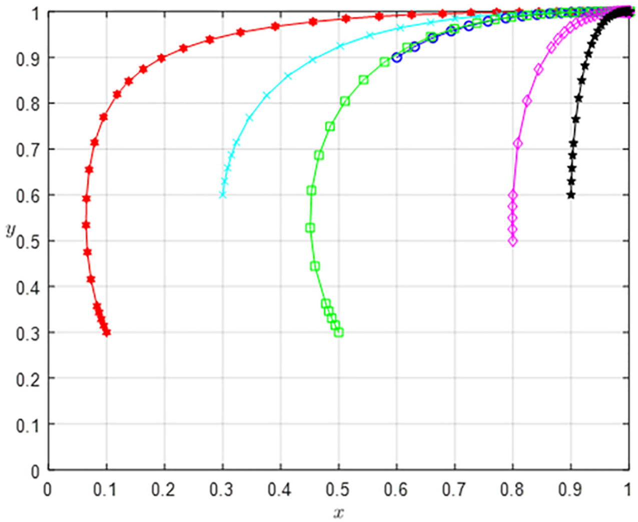

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Figure 6. Case5 evolution process

to Figure 3, so that only (0,0) is left as a stable point, that is, when the trade conflict losses between the two regions increases, the possibility of sanctions is reduced at this time, and even Region 1 and Region 2 are no longer selected a sanctions strategy.

5. Conclusion

In this paper, the game matrix of Region 1 and Region 2 is established, and the trace and determinant of the Jacobian matrix are solved by using the obtained dynamic replication

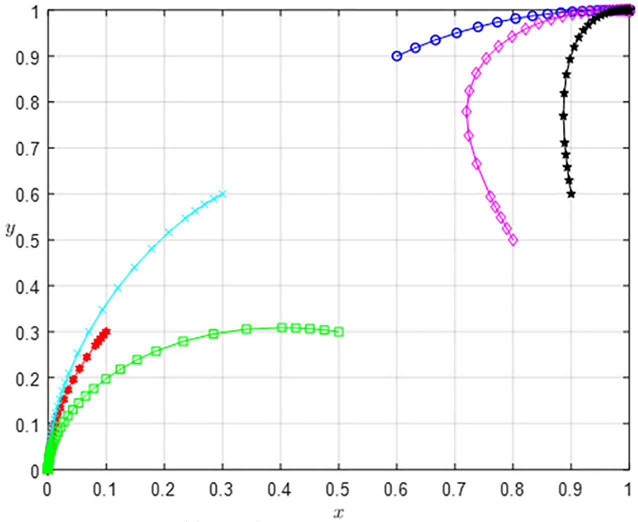

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Figure 7.
Case7 evolution process

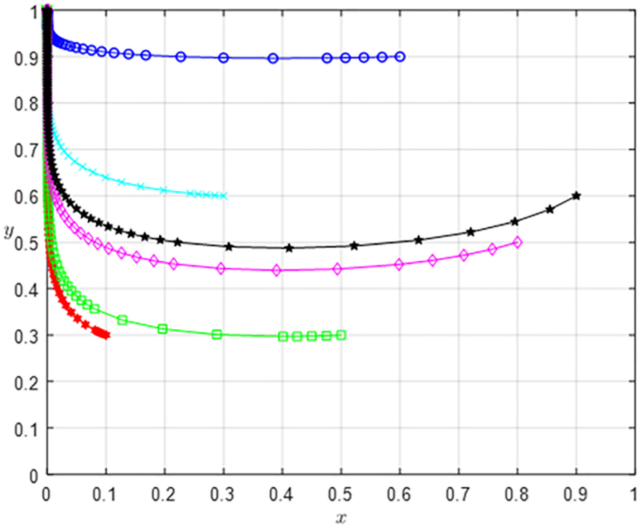

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Figure 8.
Case8 evolution process

equation, and whether the equilibrium point of the evolutionary game is an evolutionary stable point is judged according to its positive and negative. The study finds that the evolution trend of the game between the two regions mainly depends on the relationship between the net profits they obtained by adopting sanctions strategies, the losses of trade conflicts between the two regions, and the benefits of in-depth cooperation between them. It is that: (1) When the benefits of in-depth cooperation between the two regions are higher than the net profits obtained by Region 1 and Region 2 adopting sanctions strategies, the two

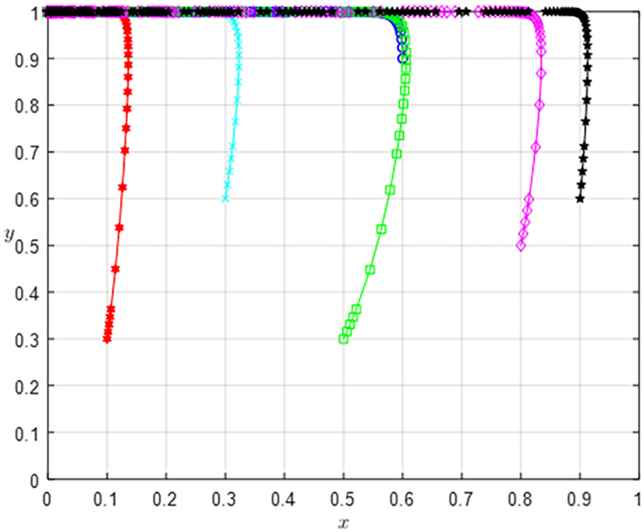

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Figure 9.
Case9 evolution process

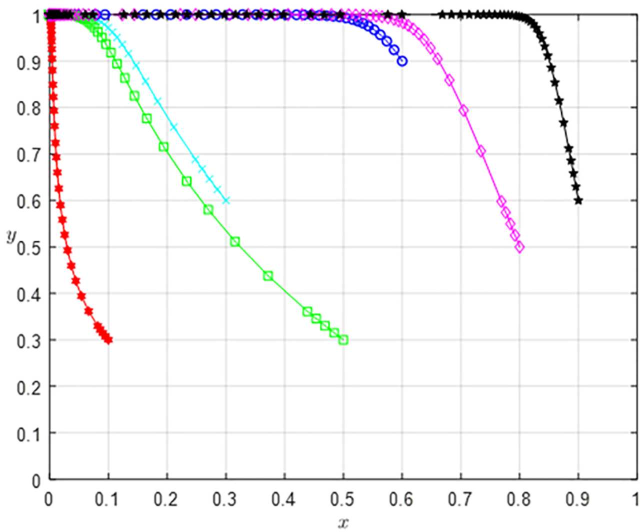

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Figure 10.
Case10 evolution process

regions will choose cooperation strategies simultaneously. (2) When the trade conflict losses between the two regions are lower than the net profits obtained by Region 1 and Region 2 adopting sanctions strategies, the two regions will choose sanctions strategies simultaneously. (3) When the net profits obtained by adopting a sanctions strategy is lower than the benefits of deep cooperation between the two regions, and while another region adopts a sanctions strategy, the net profits obtained is higher than the trade conflict losses

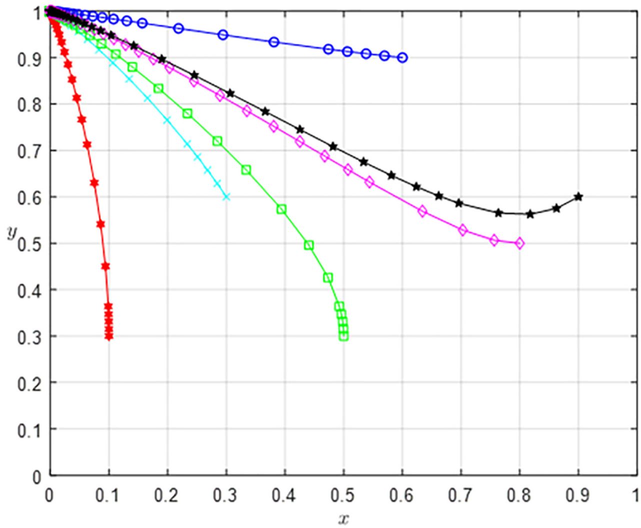

Figure 11. Case14 evolution process

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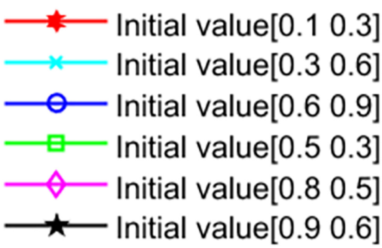

Figure 12. Legend

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between the two regions, there will be unilateral sanctions where one side sanctions and the other side does not.

Based on the above evolutionary results, several meaningful insights can be drawn: (1) Participation in the oil game between the two regions should prioritize the long-term benefits of deep cooperation. Policy makers should focus on long-term benefits rather than just short-term gains. When the benefits of in-depth cooperation between the two regions are greater than the net profits obtained from sanctions strategies, it will give the two regions a greater incentive to choose oil cooperation trade. Therefore, policy makers need to conduct a comprehensive threat and risk assessment, considering the possible long-term impact of cooperation, such as sustainable profit growth and more opportunities for deeper cooperation. (2) The oil game between regions should weigh the benefits and risks. Policy makers need to fully consider the potential trade conflict losses. For example, oil cooperation projects that have been signed and oil-related industrial chain cooperation will collapse with the implementation of sanctions strategies. As the losses of trade conflicts between the two regions increase, the cost of choosing a sanctions strategy increases, thereby reducing the likelihood of both parties choosing sanctions strategies. (3) Flexible response to the possibility of unilateral sanctions in the

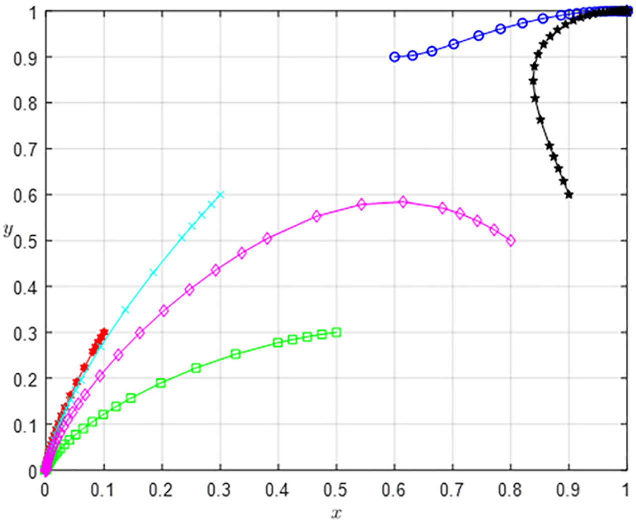

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Figure 13.
Evolution process after
F increases

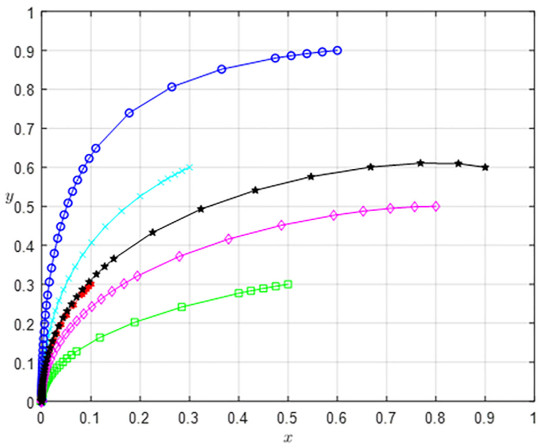

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Figure 14.
Evolution process after
C increases

interregional oil game. If one of the two parties involved in the oil trade is a strong party that can make huge profits through the sanctions strategy, and the other is a weak party that is highly dependent on each other's products or have difficulty in improving the competitiveness of its own products, the situation will evolve into a unilateral sanctions situation where only one party adopts the sanctions strategy. At this time, the weak party should flexibly adopt measures to get rid of unilateral sanctions. For example, a weak party can give up some of its current interests in exchange for opportunities for in-depth cooperation in the future. Besides, it should endeavor to expand its trade cooperation relations and establish a more stable cooperative relationship with the strong party. (4) Policy makers can strengthen regional risk response capabilities. Participating regions in the game pay close attention to the possibility of sanctions and cooperation between the two regions in real time by establishing corresponding management organizations and formulate different response methods. Assessing the possibility of current sanctions and cooperation in a quantitative way and considering the risks and benefits that different strategies may bring will help regions adjust decision-making choices and response methods in real time.

This paper analyzes the relationship between cooperation and sanctions in oil trade between the two regions, and future research can be further explored. First, this paper only considers the oil game between the two regions. In fact, in the oil game between the two regions, there are often the participation and constraints of third-party organizations, which makes the game complicated. Therefore, future research can build a tripartite evolutionary game model in which two regions and a regulator coexist to further explore the interregional oil game. Besides, this paper considers the influence of various parameters on the current evolutionary game. In fact, there are often disturbances from emergencies in the oil game. In the future, it can also be expanded to study the decision-making of participating in games under emergencies. Finally, the game in this paper only involves the impact on oil interests. In fact, there are also cooperation with other products, the intervention of competitors, and the emergence of alternative products, these parameters may dynamically influence the evolutionary pathways over time, and such issues will provide ample challenges for further research.

Notes

1. https://www.jsskgh.com.cn/shekedongtai/202307/t20230714_8010133.shtml
2. www.sinopecnews.com.cn/xnews/content/2023-08/15/content_7073372.html
3. https://www.thepaper.cn/newsDetail_forward_3498959
4. https://www.thepaper.cn/newsDetail_forward_16583535
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8. www.sic.gov.cn/News/456/8931.html
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Appendix

Proof of equilibrium solutions of replicated dynamic equations.

Let $F(x) = (F + g_2 - t_2 + u_2 + cy - Fy)(x-1)x = 0$, which can be solved:

$$x_1^* = 0\ ,\ x_2^* = 1\ ,\ y^* = \frac{g_2 - t_2 + u_2 + F}{F - C}$$

Let, $F(y) = (F + g_1 - t_1 + u_1 + cx - Fx)(y-1)y = 0$, which can be solved:

$$y_1^* = 0\ ,\ y_2^* = 1\ ,\ x^* = \frac{g_1 - t_1 + u_1 + F}{F - C}$$

Proof completed.

Proof of partial derivatives of replicated dynamic equations.

The replication dynamic equation when selecting sanctions for Region 1 is:

$$F(y) = \frac{dy}{dt} = y\left(U_{11} - \overline{U_1}\right)$$

$$= (F + g_1 - t_1 + u_1 + cx - Fx)(y-1)y$$

The replication dynamic equation when selecting sanctions for Region 2 is:

$$F(x) = \frac{dx}{dt} = x\left(U_{21} - \overline{U_2}\right)$$

$$= (F + g_2 - t_2 + u_2 + cy - Fy)(x-1)x$$

Partial derivatives can be obtained respectively from the replication dynamic equation in Region 1 and Region 2 when sanctions are selected

$$\frac{\partial F(x)}{\partial x} = (2x - 1)(F + g_2 - t_2 + u_2 + Cy - Fy)$$

$$\frac{\partial F(y)}{\partial y} = (2y - 1)(F + g_1 - t_1 + u_1 + Cx - Fx)$$

$$\frac{\partial F(x)}{\partial y} = (C - F)(x - 1)x$$

$$\frac{\partial F(y)}{\partial x} = (C - F)(y - 1)y$$

Therefore, the corresponding Jacobian matrix can be constructed:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix}$$

$$= \begin{bmatrix} \left\{ \begin{array}{l} (2x - 1)(F + g_2 - t_2 \\ +u_2 + Cy - Fy) \end{array} \right\} & (C - F)(x - 1)x \\ (C - F)(y - 1)y & \left\{ \begin{array}{l} (2y - 1)(F + g_1 - t_1 \\ +u_1 + Cx - Fx) \end{array} \right\} \end{bmatrix}$$

Proof completed.

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