Evolutionary game model of strategic transport passages in the context of Belt and Road Initiative: A case of the Strait of Hormuz

1. Introduction

International strategic passages play a vital role in transporting cargo around the world. They are not only related to the transportation of goods and energy, but also affect many aspects of a country or region including military, economy, and maritime rights, and interests. Many countries in the world need to utilize these strategic passages for the transportation of important energy sources such as oil and natural gas. However, once a certain strategic passage is blocked, the economy of the related countries, and potentially the world, can be negatively affected, such as the blocking of the Suez Canal in April 2021. When political or trade frictions occur between countries, strategic passages can be used as support for coastal countries and can even be used as transportation passages for strategic materials. Historically, there have been battles for passages to ensure the smooth passage of strategic passages.

The importance of the transport passages depends on several factors, such as its ability to transport goods to various countries in the world, the productivity of the coastal countries in the region, and the significance of military strategies for some countries[1]. In the Belt and Road Initiative, China proposes to actively promote the cooperation and development of countries along the initiative as well as realize the interconnection of development among countries, and that the strategic transport passage is an indispensable strategic fulcrum. At the mid-1980s, the US government announced to control 16 strategic passages, including the Strait of Hormuz[Error! Reference source not found.]. Along with the continuous development of the world economy, every country in the world pays great attention to strategic passages to protect its own rights and develop its own economy, thus friction between countries inevitably increases. Disputes between countries surrounding strategic passages have also intensified. In these strategic passages, the game between countries has always existed. The main reason for the game between countries is that the economic and strategic importance of these passages varies from country to country. Therefore, in order to obtain more benefits in these passages, it is necessary for each country to consider not only its own strategic choices, but also the possible reactivity of other countries.

This research proposes an evolutionary game model to analyze the game between the countries associated with strategic transport passages. The Strait of Hormuz is used as an example, and the reasons and results of several battles between the United States and Iran as well as the factors that influence their geographical location and military strength in the Strait of Hormuz are analyzed. The stabilization strategy of the two governments when the cost situation is different will also be analyzed. Due to the influence of different factors, the study analyzes the degree of influence of these factors on the participant's strategy choice. The dynamic equations of both parties' replication are obtained by calculating the constructed payoff matrix. Simultaneously the dynamic equations of the two parties are used to obtain the two-dimensional dynamic system and develop the Jacobian matrix. Through simulation under different conditions, the equilibrium point is obtained with an intuitive view of the evolutionary path in each case~~, it is simulated by MATLAB and brought into the numerical value under different conditions. Finally, each case is simulated in order to obtain~~.

2. Literature review

2.1 Geopolitical analysis of strategic transport passages

The research on strategic passages mainly involves the value identification of strategic passages, the geopolitical analysis of passages, and the cooperation and competition of passages between countries[Error! Reference source not found.-6]. The essence of geopolitics is the pursuit of geopolitical rights and interests by countries to safeguard their interests. In the modern international environment, the attention of most countries to strategic passages is by no means confined to its surroundings. Stanford (1987) compared the ideas of some major countries towards strategic passages and identified the 12 crucial strategic passages that the major powers in the world should consider. Li (2005) combined the historical factors of these passages[Error! Reference source not found.]. Through the strategic passage thinking of the major powers in the world, the geopolitics of these strategic passages are discussed in detail.

In terms of the importance of strategic corridors for each country, Katzman explored the importance of the Strait of Hormuz[8]. They mainly expanded on the status of the strait in global transportation and analyzed the political attitudes of some countries towards the strait, including the United States, Iran, Canada, and the United Kingdom. Garamond conducted research based on the example of maritime security geostrategy released in 2014[Error! Reference source not found.]. The results show that whether a strategic passage can be unblocked is directly affected by the geographical location and geopolitical factors of the strategic transportation passage. Within the context of China's Belt and Road Initiative, Blanchard summarized the content and scope of China's "One Belt One Road" Maritime Silk Road strategy and analyzed the geopolitics of some strategic passages that radiated from it[10].

The current Chinese research on strategic passages is mainly aimed at the geopolitics and transportation capabilities of the passages, discussing their value from the economic and strategic aspects[11]. In order to know the value of strategic transport passages, Lee *et al.* studied the main transport corridors in the Belt and Road Initiative and their impact on China's trade, discussing the potential and trends in the development of transport corridors[12]. In the same year Yang *et al.* conducted a study on the relative performance of two emerging trade corridors in the Belt and Road Initiative. The data therein was examined and analyzed through fuzzy multi-criteria decision analysis, exploring the development of the routes in different scenarios[13].

2.2 Evolutionary Game Theory

In the early 1970s, Smith and Price first proposed the concept of Evolutionary Stable Strategy (ESS) in evolutionary game analysis. Borges proved that the learning model converged to its replication dynamics in a continuous time through the continuous learning of the participants in the game environment[reference]. Replication dynamics and stable strategies have gradually developed into the main content of the evolutionary game theory[14].

The study of evolutionary game theory in China started late, and was not introduced by Chinese scholars until the end of the 1990s. Research on evolutionary game theory is mainly applied to related fields such as government banks and enterprises. It mainly analyzes the strategies that different groups may adopt and discusses the evolution process of their chosen strategies. Research tends to focus on the ESS of the game subject in different game situations[15]. Xu used evolutionary game theory to link three major stakeholders, namely the government, port enterprises and liner companies, to analyze their strategic choice mechanisms in the shore power system and observe the impact on the strategic choice of different subjects through numerical simulation[16]. Based on the current reality of pedestrian violations and enforcement strategies in China, a game model between pedestrian violations and enforcement strategies was developed using evolutionary game theory, and the relevant factors affecting the stability of the strategies were analyzed [17].

Boccabella, further considered the calculus model of evolutionary games. Through this model, the evolution of different populations in mixed strategies is described. The stability and the asymptotic of different strategies are analyzed in detail[18]. In terms of the objects of application of evolutionary game theory, Jian took the Chinese manufacturing industry as the subject of their study and built an evolutionary game model to analyze stabilization strategies under different stages using replicated dynamic systems. The results suggest that China need to be prepared for the expansion of the industry over time [19].

Weibull pointed out that people tended to pay more attention to the methods and instruments used in the game. Once the external environment changes, each subject will have a different probability to alter its strategy combination[reference]. Weibull further discussed how to use evolutionary games and how to learn[20-22]. In the study of replicating dynamic systems, Cheung compared replication dynamics and learning dynamics models. The results showed that only in the case of a single group game, the single belief learning dynamic model is better than the replicating dynamic model. Ozkan-Canbolat proposed a theory of strategic innovation, which determines whether other subjects are finitely rational when making strategic choices for those involved. It helps itself to choose the optimal strategy[23].

Through the above studies on the evolutionary game, it is not difficult to see that evolutionary game theory can involve many aspects. The domestic use of evolutionary games is still limited, and the theoretical understanding of evolutionary games is not mature enough. Traditional game theory regards the participants of the game as a perfectly rational economic man hypothesis. In reality, each subject is certainly finitely rational. They are affected by different circumstances and constraints. Therefore, when analyzing the game situation between the US government and the Iranian government in the Strait of Hormuz, this research takes into account the constraints of the geographic and military capabilities of the two governments during the game and establishes an asymmetric evolutionary game model. Replicated dynamic equations and the Jacobi matrices are used to determine the stability of the equilibrium point. Finally, assignment simulations are used to identify the keys influencing factors affecting the choice of strategy.

3. Analysis of U.S.-Iranian Geopolitics

3.1 The historical conflict between the United States and Iran

The Strait of Hormuz is located between the southern part of Iran and Oman, and connects the Persian Gulf and the Gulf of Oman. It is currently one of the most prosperous transportation passages in the world, through which plenty of oil shipments pass every year. The Strait of Hormuz was among the 16 strategic transportation passages announced by the US government in the 1980s. Due to the importance of this channel, its control or severance would have an immeasurable impact on the world economy. The United States has a long history of fighting with Iran in the Strait of

Hormuz region. As early as 1979, there was an international uproar when 66 US diplomats were detained in Iran during the "Islamic Revolution"[24]. In April 1980, the US government began to seek a military solution to the hostage situation by sending the aircraft carrier USS Nimitz into the vicinity of the Strait of Hormuz, sending 120 assault troops into the Iranian city of Tehran, and successfully rescuing the hostages.

Frequent military maneuvers between the US and Iran in the Strait of Hormuz in early 2008 led to another confrontation between the two sides. At the same time, the Iranian government has made it clear that it will act to block the Strait of Hormuz in the event of a US military strike. Iran is the closest and easiest country to control the passage, but blocking the strait is not necessarily a wise strategy. As the throat of world transportation, the Strait of Hormuz has a great economic and military value, and is one of the most important transportation passages in China's Belt and Road Initiative. There is no doubt that if the Iranian government chooses to block the strait, it will certainly have an impact on the interests of China and other relevant countries, this move would certainly not be accepted by the international community, and may even be met with countermeasures by other countries. From 2003 to 2009, Iran, in its quest for national development, tried to avoid friction with other countries and stopped threatening to block the Strait of Hormuz by following the Chinese model of development, through constant friendly contacts with Western countries[25].

Some of the major countries in the European Union have close economic ties with Iran, who had always been opposed to US's withdrawal from the nuclear deal, stressing the need to maintain stability in the Gulf and the Middle East. However, in dealing with the Iranian nuclear issue, pressure from the US did not have a clear-cut attitude to express its position. On the nuclear issue, Russia is opposed to the US government's withdrawal, as it has always taken a positive coordination attitude and maintained close cooperative relations with Iran. The US and Iran can only continue to test and pressure each other in various fields, which will only complicate the situation due to the influence of external forces. Now that stakeholder have increasingly joined in the game, the possibility of a war between the US and Iran will decrease[26]. Therefore, in modelling the evolutionary game, this paper will not consider both sides actively choosing the strategy of military strikes, but rather the strategy of mutual pressure through force deterrence and a certain degree of conflict.

3.2 Impact of relative position and geographical location

After the Cold War, the US government had always been the only superpower in the world. Its economic and military capabilities are far ahead of Iran. With the changes in the international situation, especially after the establishment of the Islamic Republic, the relationship between the United States and Iran has continued to deteriorate. The US government has been seeking to expand its influence strategically. Especially after the US government put forward the "State Participation and Expanding Security Strategy" in 1994, it paid more attention to Hormuz. From the energy point of view, non-renewable resources such as oil and gas are becoming increasingly important to all countries. Iran has always relied on its natural advantages in geographical location to obtain rich resources, and it will export a large amount of oil every year. According to statistics, Iran has the third-largest remaining recoverable oil reserves in the world. In the face of a global oil shortage, Iran's rich oil resources have also become a solid backing for its international status. From the perspective of military strength, Iran is a country where the regular army and the Revolutionary Guards coexist. Although the Iranian government's armed forces have developed considerably, on the whole, they are still backward in terms of armament and information technology[27-28].

From a geographical point of view, Iran is located in the center of the Middle East. Iran has many neighboring countries such as Turkey, Pakistan and Armenia. The southern part of the country is close to the Persian Gulf and the Gulf of Oman. At the same time, Iran holds the Strait of Hormuz, and controls the main oil export routes throughout the Middle East. It is located at the meeting point of the maritime transportation interests of Eastern and Western countries. Therefore, Iran's geographic location has an extremely important strategic position. Compared with the United States, which is far away from the Strait of Hormuz, the investment of its military forces would take a great deal of time and money. Iran's large land area and the national defense border are separated by mountains, which has a significant impact on the entry of the US mechanized army, Iran’s complex terrain is likely to trap the US military in a quagmire [29].

It can be seen from the above review that Iran and the United States have a big difference in military strengths. If a war broke out, Iran will be in a disadvantageous situation since its military strength is inferior to that of the United States. In addition to the need to invest a significant amount of manpower and material resources, the US government will also be afraid of Iran's topography and geographic location. If Iran chooses to block the Strait of Hormuz, both sides will incur huge economic losses. Therefore, although both the United States and Iran have shown tough attitudes, fundamentally speaking, neither side wants a war to break out.

3.3 The Applicability of Evolutionary Game in the U.S.-Iran Game

In evolutionary games, the object of study is the behavior of a game between one or more groups, and the strategies chosen by the groups affect each other. The game between two countries cannot necessarily be made by a single individual making strategic choices. When each country makes strategic choices, every individual in the government must study each strategy and show its own opinion. The government will consider the tactics that the other side is likely to employ when making decisions. On this basis, it will choose from its own set of strategies to respond in the best way for itself. From the point of view of an evolutionary game that allows for sudden changes in the players, each individual in the government will have their own ideas and the strategies proposed will vary. Other individuals will also analyze this strategy and make their own choices, which makes the model more relevant to the actual situation.

Considering the premise assumptions of evolutionary games, each government's choice of strategy is influenced by factors such as military capability, economic capability, and geographical location. As a result, it is not possible to directly determine which strategy will yield the greatest benefit to itself. The players participating in the game are all bounded rationally. Individuals in the government will look at the benefits of this game from a holistic perspective after making their own decisions, and make their own choices again, thus eventually tending to a stable strategy. Therefore, it is appropriate to use the evolutionary game model to play games between countries.

From the perspective of the constraints of the evolutionary game, the game between the United States and Iran has conditions that affect each other, such as military, economic, and geographical ones. Iran will have concerns due to the strong military capabilities of the United States, and the United States will also have concerns about the convenience of Iran’s geographical location. In the evolutionary game model of the US-Iran game, the key factors can be obtained for each influence by changing the numerical size of the parameters of each influence for both countries. Through the above analysis, it is possible to see whether it is the premise hypothesis of the evolutionary game, the mutual restraint between the two sides of the game, or the particularity of the research object.

4. Evolutionary game model

In the game between the US government and the Iranian government in the Strait of Hormuz, due to the different international status of the two parties, there is a big gap in economy, military, and geographic locations. Under the current international structure, the attention of both the major EU countries and major powers, like Russia, to regional issues have undoubtedly made the issues gradually more complicated. Therefore, this study uses the strategy of force deterrence to conduct game analysis without considering military strikes. Before the two governments choose their strategies, they are both in their different complex environments, and they cannot acquire complete information from the other government. In terms of keeping the Strait of Hormuz open for trade, the US government may adopt a deterrent strategy to put pressure on Iran. In this environment, the Iranian government may choose a compromise strategy or an uncompromising strategy. The Iranian government may also put pressure on the US government's tactics to interfere with transportation. Therefore, this research establishes an asymmetric evolutionary game model.

4.1 Assumptions

It is assumed that each government has incomplete information about the game and is bounded rationally. Both governments make decisions at an initial phase with a certain probability. This then allows them to learn and change their strategy after the decision has been made. The set of strategies of each subject in the game: the US government {abandon, deterrence}; the Iranian government {compromising, interference}. Both groups have their own goals to obtain more national interests and have the characteristics of an economic man.
v_1 represents the basic income obtained by the US government in the Strait of Hormuz, which refers to the basic income obtained by the US government through the passage of goods and energy transportation in the Strait of Hormuz. In the same way, v_2 represents the basic income obtained by the Iranian government in the Strait of Hormuz. Δc_1 indicates that the US government chose to abandon its strategy and its normal strategic interests in the Strait of Hormuz were affected when it was interfered with by the Iranian government. A similar Δc_2 indicates that the Iranian government chooses compromise strategy and is affected by its normal strategic interests in the Strait of Hormuz when the US government is deterred. This research refers to it as loss of equity and has $\Delta c_1 < \Delta c_2$. Taking into account the impact of the gap between the military and economic capabilities of the United States and Iran on their respective earnings, β_1 and β_2 are introduced respectively to represent the conflict losses caused by the combined deterrence and interference strategies of the United States and Iran, and $\beta_1 < \beta_2$. Given the difference in geographic location between the two countries and the different levels of dependence of the two governments on the Strait of Hormuz, use Δ_1 to denote the excess gains to the US government in the region's economy when the US government deters and the Iranian government chooses to compromise, Δ_2 indicates the excess income of the Iranian government in the region's economy when the Iranian government chooses to interfere and the US government chooses to give up. This study refers to it as excess income, and has $\Delta_1 < \Delta_2$。 Use α to indicate that when the Iranian government chooses an interference strategy, it will affect the interests of China and other related countries and cause damage to its international status. In this research, we refer to this as additional losses.

In this paragraph, there are a lot of definition of variables, which I think should not be included as assumptions, but in the model part.

4.2 Model

According to the definitions of the relevant variables in the previous section, a game payment matrix between the US government and the Iranian government was established as shown in Table 1. It is assumed that in the initial period of the game, the individuals in each government are bounded rationally. The probability of choosing a deterrent strategy for the US government is $x(x\epsilon(0,1))$, and the probability of choosing abandonment is $(1-x)$. The probability of choosing interference for the Iranian government is $y(y\epsilon(0,1))$, then the probability of choosing compromise is $(1-y)$.

When the combination of the two governments' strategies is (abandon, compromise), the two countries choose the way of cooperation for common development on the issue of the Strait of Hormuz. In this case both sides receive some base gain by relying on transport trade in the Strait of Hormuz. Therefore, the gain to the US government in this case is v_1, the gain to the Iranian government is v_2. When the combination of the two governments' strategies is (deterrence, compromise), the US government is not interfered by the Iranian government in this case and is able to achieve some excess income in its economy due to the Iranian government's compromise. Therefore, the gain for the US government in this case is $v_1+\Delta_1$. At the same time, the Iranian government will damage the national strategic interests and suffer a certain loss of rights and interests due to the compromise strategy. Therefore, the gain for the Iranian government at this point is $v_2-\Delta c_2$. When the strategy combination of the two governments is (abandon, interfere), the Iranian government can obtain a certain amount of excess income. However, the Iranian government will interfere with the channel and affect the interests of other countries in the Strait of Hormuz. It will be isolated by the international community and countermeasures taken by other countries and will suffer a certain degree of loss, represented by α. Therefore, the gain for the Iranian government in this case is $v_2+\Delta_2-\alpha$. The US government will suffer some loss of equity Δ_1 in this case. Therefore, the gain for the US government here is $v_1-\Delta c_1$ when the combination of the two governments' strategies is (Deterrence, Interference). This is when both governments do not want to make concessions in the Strait of Hormuz and can only put pressure on each other through force deterrence. However, due to the impact of the military and economic gap between the two governments, both sides will suffer different degrees of conflict losses in this case, represented by β_1 and β_2 respectively. Therefore, the gains for the US and Iran are $v_1-\beta_1$ and $v_2-\beta_2-\alpha$ respectively.

Table 1 US-Iran game payoff matrix

		Iranian government	
		Interference(y)	Compromise $(1-y)$
US Government	Deterrence(x)	$(v_1-\beta_1, v_2-\beta_2-\alpha)$	$(v_1+\Delta_1, v_2-\Delta c_2)$
	Abandon$(1-x)$	$(v_1-\Delta c_1, v_2+\Delta_2-\alpha)$	(v_1, v_2)

From the benefits of each case in the payoff matrix, it is possible to calculate the expected benefits to the US government. The expected revenue of the US government is denoted as $u_{11}$when choosing the deterrence strategy (Eq. 1) and u_{12} when the US government chooses the abandonment strategy (Eq. 2). Its average revenue is denoted as $\overline{u_1}$. Their expected returns and average returns are shown in Eqs. (1), (2) and (3) respectively:

$$u_{11} = y(v_1 - \beta_1) + (1 - y)(v_1 + \Delta_1) \tag{1}$$

$$u_{12} = y(v_1 - \Delta c_1) + (1 - y)v_1 \tag{2}$$

$$\overline{u_1} = xu_{11} + (1 - x)u_{12} \tag{3}$$

According to the dynamic formula of replication in the evolutionary game theory, the dynamic equation of replication of the US government can be derived as Eq. (4):

$$\frac{dx}{dt} = x(u_{11} - \overline{u_1}) = x(1 - x)[\Delta_1 - y(\Delta_1 + ß_1 - \Delta c_1)] \tag{4}$$

Similarly, the expected return is denoted as u_{21} when the Iranian government chooses the disruption strategy and u_{22} when the Iranian government chooses the compromise strategy. Its average gain is denoted as $\overline{u_2}$. Their expected returns and average returns are shown in Eqs. (5), (6) and (7) respectively:

$$u_{21} = x(v_2 - \beta_2 - \alpha) + (1 - x)(v_2 + \Delta_2 - \alpha) \tag{5}$$

$$u_{22} = x(v_2 - \Delta c_2) + (1 - x)v_2 \tag{6}$$

$$\overline{u_2} = yu_{21} + (1 - y)u_{22} \tag{7}$$

Similarly, the replication dynamic equation for the Iranian government can be derived as Eq. (8):

$$\frac{dy}{dt} = y(u_{21} - \bar{u}_2) = y(1 - y)[\Delta_2 - \alpha - x(\Delta_2 + ß_2 - \Delta c_2)] \tag{8}$$

Coupling the replicated dynamic equations of the US government with those of the Iranian government yields a two-dimensional dynamic system, as shown in Eq. (9).

$$\begin{cases} \dfrac{dx}{dt} = x(u_{11} - \overline{u_1}) = x(1 - x)[\Delta_1 - y(\Delta_1 + ß_1 - \Delta c_1)] \\ \dfrac{dy}{dt} = y(u_{21} - \bar{u}_2) = y(1 - y)[\Delta_2 - \alpha - x(\Delta_2 + ß_2 - \Delta c_2)] \end{cases} \tag{9}$$

5 Evolutionary Stability Analyses

5.1 Evolutionary Game Analysis of US-Iran Mixed Strategy

Let the two equations in the two-dimensional dynamic system associated with the replicated dynamic equations of the US government and the Iranian government be zero to find their equilibrium points. The stability of these equilibria is then determined by building a Jacobi matrix and finding the rank and trace of this matrix. According to Freidman's idea, a combination of mixed strategies is a stable strategic equilibrium when the rank of the matrix is greater than 0 and the trace of the matrix is less than 0[30]. Solving Eq. (9) to obtain the second-order differential equations, the five equilibrium points are:

$E_1(0,0)$、$E_2(0,1)$、$E_3(1,0)$、$E_4(1,1)$、$E_5\left(\frac{\Delta_2-\alpha}{\Delta_2+ß_2-\Delta c_2}, \frac{\Delta_1}{\Delta_1+ß_1-\Delta c_1}\right)$.

These equilibria vary in their stability in different situations. Their evolved positions may also change once the probability of the US government or the Iranian government's choice of strategy changes. In order to analyze the stability of these points, the Jacobian matrix is established as Eq. (10).

$$J = \begin{bmatrix} \frac{\partial \frac{d_x}{d_t}}{\partial x} & \frac{\partial \frac{d_x}{d_t}}{\partial y} \\ \frac{\partial \frac{d_y}{d_t}}{\partial x} & \frac{\partial \frac{d_y}{d_t}}{\partial y} \end{bmatrix} \tag{10}$$

Combining Eqs. (9) and (10), we have Eqs. (11)-(14):

$$\frac{\partial \frac{d_x}{d_t}}{\partial x} = (1-2x)[\Delta_1 - y(\Delta_1 + ß_1 - \Delta c_1)] \tag{11}$$

$$\frac{\partial \frac{d_x}{d_t}}{\partial y} = x(1-x)(\Delta_1 + ß_1 - \Delta c_1) \tag{12}$$

$$\frac{\partial \frac{d_y}{d_t}}{\partial x} = y(1-y)(\Delta_2 + ß_2 - \Delta c_2) \tag{13}$$

$$\frac{\partial \frac{d_y}{d_t}}{\partial y} = (1-2y)[\Delta_2 - \alpha - x(\Delta_2 + ß_2 - \Delta c_2)] \tag{14}$$

Then the Jacobian matrix can be written as Eq. (15):

$$J = \begin{bmatrix} (1-2x)[\Delta_1 - y(\Delta_1 + ß_1 - \Delta c_1)] & x(1-x)(\Delta_1 + ß_1 - \Delta c_1) \\ y(1-y)(\Delta_2 + ß_2 - \Delta c_2) & (1-2y)[\Delta_2 - \alpha - x(\Delta_2 + ß_2 - \Delta c_2)] \end{bmatrix} \tag{15}$$

Calculating the rank and trace of the Jacobian matrix in Eq. (15), Eqs. (16) and (17) are obtained:

$$\begin{aligned} Det\, J = {} & (1-2x)[\Delta_1 - y(\Delta_1 + ß_1 - \Delta c_1)](1-2y)[\Delta_2 - \alpha - x(\Delta_2 + ß_2 - \Delta c_2)] \\ & - x(1-x)(\Delta_1 + ß_1 - \Delta c_1)y(1-y)(\Delta_2 + ß_2 - \Delta c_2) \end{aligned} \tag{16}$$

$$Tr\, J = (1-2x)[\Delta_1 - y(\Delta_1 + ß_1 - \Delta c_1)] + (1-2y)[\Delta_2 - \alpha - x(\Delta_2 + ß_2 - \Delta c_2)] \tag{17}$$

Analysis of Eq. (16) shows that when the variable parameters $ß_1$ and Δc_1, α and Δ_2, α and $ß_2, \Delta c_2$ in the game payoff matrix have different relative magnitude relationships, the positive and negative rank and trace of the matrix can be determined. From this, it is possible to identify the stability of the equilibrium point in each scenario.

5.2 Evolutionary Stability Strategies in Different Scenarios

From the perspective of the US government, when <, the US military strength is far stronger than that of Iran. After the conflict between the two sides and no other country may intervene in the event of a conflict between the two sides. The losses to the US government in this situation are not very large. At the same time, the losses in terms of strategic and economic benefits are not very significant. In terms of the Iranian government's choice of interference strategy, the US government suffers less conflict loss than its equity loss. For Iran, in this case, the relationship between the magnitude of the Iranian government's conflict losses and equity losses is not determinable. It is necessary to conduct a detailed analysis of the two situations of $\Delta c_2 < \alpha + ß_2$ and $\Delta c_2 > \alpha + ß_2$, analyze the rank and trace of the Jacobian matrix, and get the stable strategy after evolution.

Similarly, when $ß_1 > \Delta c_1$, and the two sides conflict, there may be interference from other countries and the loss to the US government is within its acceptable range. It is important to note that in the above scenario the Iranian government must consider the impact on the interests of the countries concerned, such as China when choosing its disruption strategy and the additional losses it suffers as a result. Therefore, the relative magnitude of Δ_2 and α needs to be discussed further.

In terms of the relative size of the Iranian government's losses, it may be subject to intervention by other countries when the US and Iran play. The conflict losses suffered by the Iranian government in choosing the disruption strategy are small when compared to the equity losses. At this time, when the US government chooses an abandonment strategy, it can obtain a certain amount of excess income, that is, $\Delta c_2 > \alpha + ß_2$.

Similarly, when $\Delta c_2 < \alpha + ß_2$, in the absence of intervention by other countries following a conflict between the two sides, the Iranian government will suffer more if it chooses an interference strategy than if it chooses a compromise strategy.

In summary, the above scenarios are all possible ones that could occur in the Strait of Hormuz. It can be more comprehensively analyzed that in different game conditions, the loss caused by different factors will affect the choice of the two governments' strategies. Similarly, the size relationships of the parameters of the variables in the model can be combined into eight different scenarios.

Scenario 1

When $ß_1 < \Delta c_1$, $\Delta_2 < \alpha$ and $\Delta c_2 < \alpha + ß_2$, the system has four equilibria $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$ and $E_4(1,1)$. The stability of each equilibrium point is shown in Table 2.

Table 2 Stability of equilibrium point when $ß_1 < \Delta c_1$, $\Delta_2 < \alpha$ and $\Delta c_2 < \alpha + ß_2$.

Equilibrium	$\boldsymbol{Det\,J}$	$\boldsymbol{Tr\,J}$	Stability
E_1(0,0)	−	±	Saddle
E_2(0,1)	+	+	Unstable
E_3(1,0)	+	−	Stable
E_4(1,1)	−	±	Saddle

At this point, when the US government chooses the deterrence strategy, the losses from conflict are less than the losses from compromise. Once the two sides conflict, Iran suffers higher conflict losses and some additional losses when it chooses to interfere. In the system, only $E_3(1,0)$ is the stable point, $E_2(0,1)$ is an unstable point, and $E_1(0,0)$, $E_4(1,1)$ are saddle points. Therefore, in this scenario, the system will gradually converge to the $E_3(1,0)$ point over time. This strategic combination of the United States and Iran is (deterrence, compromise). The dynamic evolution phase diagram is shown in Figure 1.

Scenario 2

When $ß_1 > \Delta c_1$, $\Delta_2 < \alpha$, $\Delta c_2 > \alpha + ß_2$, there are five equilibrium points $E_1(0,0)$、$E_2(0,1)$、

$E_3(1,0)$、$E_4(1,1)$、$E5(\frac{\Delta_2-\alpha}{\Delta_2+ß_2-\Delta c_2}, \frac{\Delta_1}{\Delta_1+ß_1-\Delta c_1})$ in the system at this time, and the stability of each equilibrium point is shown in Table 3.

Table 3 Stability of equilibrium point when $ß_1 > \Delta c_1$, $\Delta_2 < \alpha$ and $\Delta c_2 > \alpha + ß_2$.

Equilibrium	$\boldsymbol{Det\,J}$	$\boldsymbol{Tr\,J}$	Stability
E_1(0,0)	−	±	saddle
E_2(0,1)	−	±	saddle
E_3(1,0)	−	±	saddle
E_4(1,1)	−	±	saddle

All equilibrium points in the system do not satisfy the stability condition, so there is no evolutionary stability strategy in this scenario. The dynamic evolution phase diagram is shown in Figure 2.

Scenario 3

When $ß_1 < \Delta c_1$, $\Delta_2 < \alpha$and $\Delta c_2 > \alpha + ß_2$, in this case the system has four equilibria E_1(0,0), E_2(0,1), E_3(1,0) and E_4(1,1). The stability of each equilibrium point is shown in Table 4.

Table 4 Stability of equilibrium point when $ß_1 < \Delta c_1$, $\Delta_2 < \alpha$ and $\Delta c_2 > \alpha + ß_2$

Equilibrium	$\boldsymbol{Det\,J}$	$\boldsymbol{Tr\,J}$	Stability
E_1(0,0)	−	±	Saddle
E_2(0,1)	+	+	Unstable
E_3(1,0)	−	±	Saddle
E_4(1,1)	+	−	Stable

In this case, the conflict loss when the US government chooses the deterrence strategy is less than the loss of rights when it chooses the abandon strategy. At the same time, the Iranian government's gains when choosing an interference strategy will not change its strategy due to differences in military strength and considers its own interests in the Strait of Hormuz to be more important. In this case, only E_4(1,1) is the stable point in the system, E_2(0,1) is the unstable point, E_1(0,0), E_3(1,0) is the saddle point. Therefore, in this scenario, the system will gradually converge to E_4. This strategy combination of the US and Iran is (deterrence, interference). The dynamic evolution phase diagram is shown in Figure 3.

Scenario 4

When $ß_1 < \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 < \alpha + ß_2$, in this case the system has four equilibria E_1(0,0), E_2(0,1), E_3(1,0) and E_4(1,1). The stability of each equilibrium point is shown in Table 5.

Table 5 Stability of equilibrium point when $ß_1 < \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 < \alpha + ß_2$.

Equilibrium	***Det J***	***Tr J***	Stability
E_1(0,0)	+	+	Unstable
E_2(0,1)	−	±	saddle
E_3(1,0)	+	−	stable
E_4(1,1)	−	±	saddle

At this point, the U.S. government's loss of conflict when it chooses the deterrence strategy is still less than the loss of equity when it chooses the abandonment strategy. As the Iranian government chooses to interfere in the Strait of Hormuz at this time, the loss is less than the gain obtained in equilibrium at the E_2 point. Therefore, there will be fluctuations in the E_2 situation, which eventually tend to evolve to a stable point. In this case, only E_3(1,0) is the stable point, E_1(0,0) is the unstable point, E_2(0,1), and E_4(1,1) is the saddle point in the system. Therefore, in this scenario, the system will gradually converge to the E_3 point, that is, the strategic combination of the United States and Iran is (deterrence, compromise). The dynamic evolution phase diagram is shown in Figure 4.

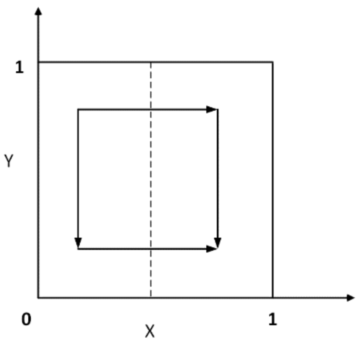


Figure 1 Evolution phase diagram of case (1)

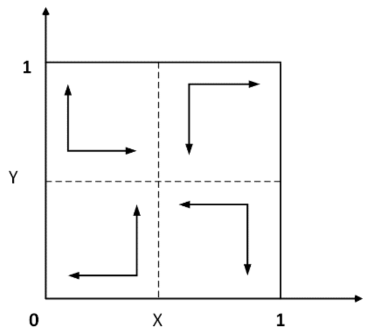


Figure 2 Evolution phase diagram of case (2)

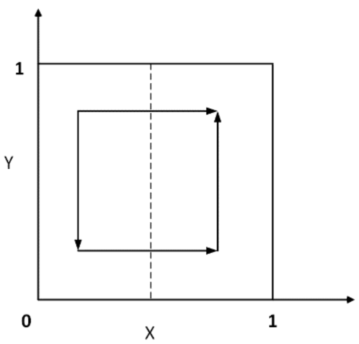


Figure 3 Evolution phase diagram of case (3)

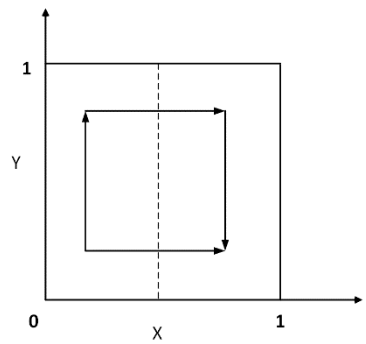


Figure 4 Evolution phase diagram of case (4)

Combine figure 1-4 into one figure with four parts, Figure 1 a,b,c,d

Scenario 5

When $ß_1 < \Delta c_1$, $\Delta_2 > \alpha$and $\Delta c_2 > \alpha + ß_2$, in this case the system has four equilibria $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$ and $E_4(1,1)$. The stability of each equilibrium point is shown in Table 6.

Table 6 Stability of equilibrium point when $ß_1 < \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 > \alpha + ß_2$

Equilibrium	$\boldsymbol{Det\,J}$	$\boldsymbol{Tr\,J}$	Stability
E_1(0,0)	+	+	Unstable
E_2(0,1)	−	±	saddle
E_3(1,0)	−	±	saddle
E_4(1,1)	+	−	stable

In this case, the conflict losses of the United States and Iran are both less than their respective equity losses. In this system, $E_4(1,1)$ is the stable point, $E_2(0,1)$, $E_3(1,0)$ is the saddle point, and $E_1(0\ ,0)$ is the unstable point. Therefore, in this scenario, the system will gradually converge to E_4, that is, the strategic combination of the United States and Iran is (deterrence, interference). The dynamic evolution phase diagram is shown in Figure 5.

Scenario 6

When $ß_1 > \Delta c_1$, $\Delta_2 < \alpha$and $\Delta c_2 < \alpha + ß_2$, in this case the system has four equilibria $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$ and $E_4(1,1)$. The stability of each equilibrium point is shown in Table 7.

Table 7 Stability of equilibrium point when $ß_1 > \Delta c_1$, $\Delta_2 < \alpha$ and $\Delta c_2 < \alpha + ß_2$

Equilibrium	$\boldsymbol{Det\,J}$	$\boldsymbol{Tr\,J}$	Stability
E_1(0,0)	−	±	saddle
E_2(0,1)	−	±	saddle
E_3(1,0)	+	−	stable
E_4(1,1)	+	+	Unstable

In this case, in the system, $E_3(1,0)$ is the stable point, $E_4(1,1)$ is the unstable point, $E_1(0,0)$, $E_2(0,1)$ is the saddle point. The system will gradually converge to the E_3 point, that is, the strategic combination of the United States and Iran is (deterrence, compromise). The evolutionary game phase diagram is shown in Figure 6.

Scenario 7

When $ß_1 > \Delta c_1$, $\Delta_2 > \alpha$and $\Delta c_2 < \alpha + ß_2$, in this case the system has four equilibria $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$ and $E_4(1,1)$. The stability of each equilibrium point is shown in Table 8.

Table 8 Stability of equilibrium point when $ß_1 > \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 < \alpha + ß_2$

Equilibrium	$\boldsymbol{Det\,J}$	$\boldsymbol{Tr\,J}$	Stability
E_1(0,0)	+	+	Unstable
E_2(0,1)	+	−	Stable
E_3(1,0)	+	−	Stable
E_4(1,1)	+	+	Unstable

In this case, there are two stable points E_2(0,1) and E_3(1,0) in the system, and E_1(0,0) and E_4(1,1) are unstable points. It shows that the loss of the system when conflict occurs for both the United States and Iran currently is very huge, and the system gradually converges to E_2(0,1) or E_3(1,0). Affected by different factors and different initial states gradually converge to a certain stable point. The phase diagram of the evolution game is shown in Figure 7.

Scenario 8

When $ß_1 > \Delta c_1$, $\Delta_2 > \alpha$and $\Delta c_2 > \alpha + ß_2$, in this case the system has four equilibria E_1(0,0), E_2(0,1), E_3(1,0) and E_4(1,1). The stability of each equilibrium point is shown in Table 9.

Table 9 Stability of equilibrium point when $ß_1 > \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 > \alpha + ß_2$

Equilibrium	$\boldsymbol{Det\,J}$	$\boldsymbol{Tr\,J}$	Stability
E_1(0,0)	+	+	Unstable
E_2(0,1)	+	−	stable
E_3(1,0)	−	±	saddle
E_4(1,1)	−	±	saddle

For the Iranian government, the conflict loss caused by its interference strategy is relatively small compared with the loss of rights and interests. At the same time, when the US government chooses to give up, it can obtain a certain amount of excess income. The system has only one stable point E_2(0,1), where E_1(0,0) is the unstable point and E_3(1,0) and E_4(1,1) are the saddle points. The system will eventually converge at point E2. The phase diagram of the evolution game is shown in Figure 8.

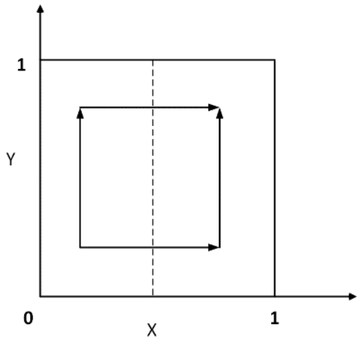


Figure 5 Evolution phase diagram of case (5)

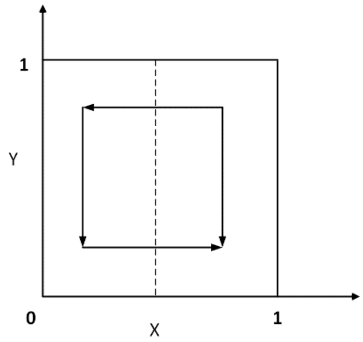


Figure 6 Evolution phase diagram of case (6)

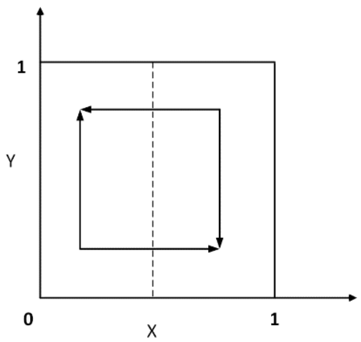


Figure 7 Evolution phase diagram of case (7)

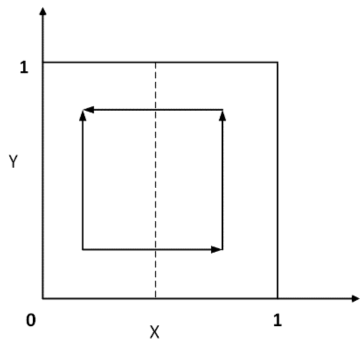


Figure 8 Evolution phase diagram of case (8)

The same as figure 1-4, 5-8---figure 2 a, b, c, d

6 Simulation and Discussion

6.1 Numerical simulation

The evolutionary path of the game is obtained by using numerical simulation of the probability of the game subject's choice of strategy in each case, based on the relationship between the magnitude of each parameter in the payoff matrix in the previous section for the eight scenarios, with different game conditions. This gives a more intuitive view of the degree of influence of each factor on the game.

Scenario 1

When $ß_1 < \Delta c_1$, $\Delta_2 < \alpha$, $\Delta c_2 < \alpha + ß_2$, the evolutionary equilibrium result is (deterrence, compromise). Subject to the above conditions, assuming that the combination of strategies is (deterrence, compromise), the US government obtains excess income $\Delta_1 = 20$, Due to the difference in the dependence of the two countries on this passage, there is $\Delta_1 < \Delta_2$, assume $\Delta_2 = 25$. In terms of conflict losses, assume that the loss suffered by the US government $\beta_1 = 10$, Since the difference in military power between the two sides there is $ß_1 < ß_2$, assuming that $ß_2 = 20$. In terms of equity loss, it is assumed that the US government suffers an equity loss of $c_1 = 15$ as the importance of the corridor to both sides differs in terms of their respective strategies with $\Delta c_1 < \Delta c_2$, assuming $\Delta c_2 = 20$. Furthermore, based on the constraint on α in this scenario, assuming $\alpha = 30$, the evolutionary path diagram in this scenario is shown in Figure 9. The diagram shows that both subjects involved in the game eventually converge to the equilibrium point (1,0). In this scenario, both sides end up with a combination of decisions to exert pressure on each other, regardless of the initial states of *x* and *y*. This is because the US government's conflict losses in this scenario are lower than its equity losses and the conflict losses incurred by the Iranian government in choosing the intervention strategy are higher than its equity losses.

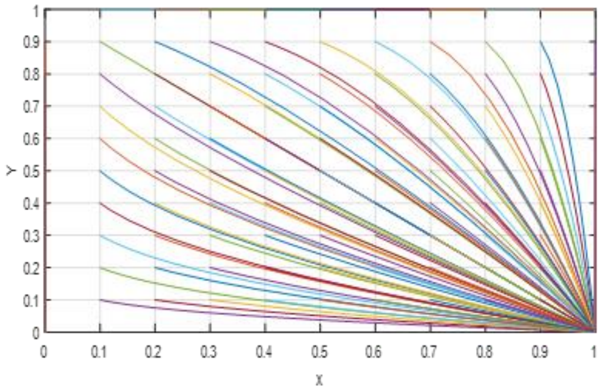


Figure 9 Evolutionary path diagram when $ß_1 < \Delta c_1$, $\Delta_2 < \alpha$, $\Delta c_2 < \alpha + ß_2$ (deterrence, compromise).

Scenario 2

When $ß_1 > \Delta c_1$, $\Delta_2 < \alpha$ and $\Delta c_2 > \alpha + ß_2$, the two sides of the game cannot form a stable combination of strategies. The same as above, assign each parameter and satisfy its corresponding condition, assuming that each parameter is: $\Delta_1 = 10$, $ß_1 = 15$, $\Delta c_1 = 10$, $\Delta_2 = 15$, $\alpha = 20$, $ß_2 = 20$, $\Delta c_2 = 45$. The simulation diagram in this case is shown in Figure 10. The graph shows that the probability of the US and Iran choosing each strategy changes over time, eventually forming a wavy curve. This indicates that the probability size of each party's choice of strategy is dependent on the other party's choice, which affects each other and ultimately does not lead to a stable strategy.

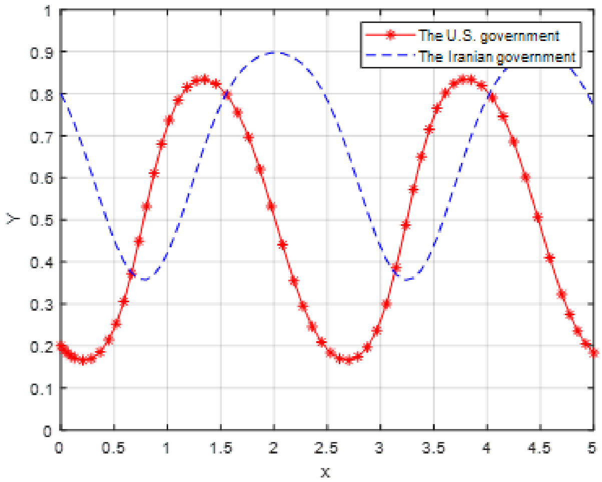
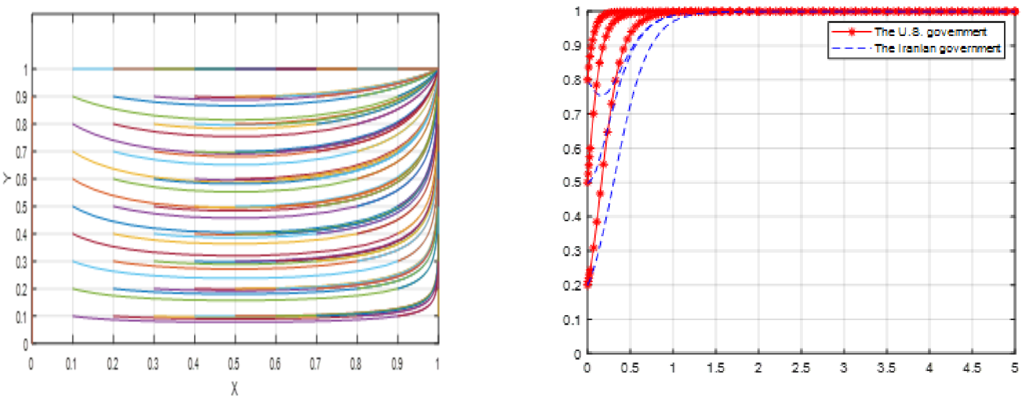


Figure 10 Evolutionary path diagram when $ß_1 > \Delta c_1$, $\Delta_2 < \alpha$, $\Delta c_2 > \alpha + ß_2$ (no evolutionary stability).

Scenario 3

When $ß_1 < \Delta c_1$, $\Delta_2 < \alpha$ and $\Delta c_2 > \alpha + ß_2$ the result of the evolutionary equilibrium in this scenario is (deterrence, interference). Assigning each parameter and satisfy its corresponding condition, assuming that each parameter is: $\Delta_1 = 20$, $ß_1 = 10$, $\Delta c_1 = 15$, $\Delta_2 = 25$, $\alpha = 30$, $ß_2 = 15$, $\Delta c_2 = 50$. The simulation diagram in this case is shown in Figure 11. The graph shows that no matter how the values of x and y change, they eventually converge on the strategy combination (deterrence, interference). When the probability of Iran's initial state is 0.8, the probability of disruption decreases during the first period of the game and then gradually starts to increase, as the Iranian government's equity loss is lower than the conflict loss, which makes the Iranian government prefer a compromise strategy.

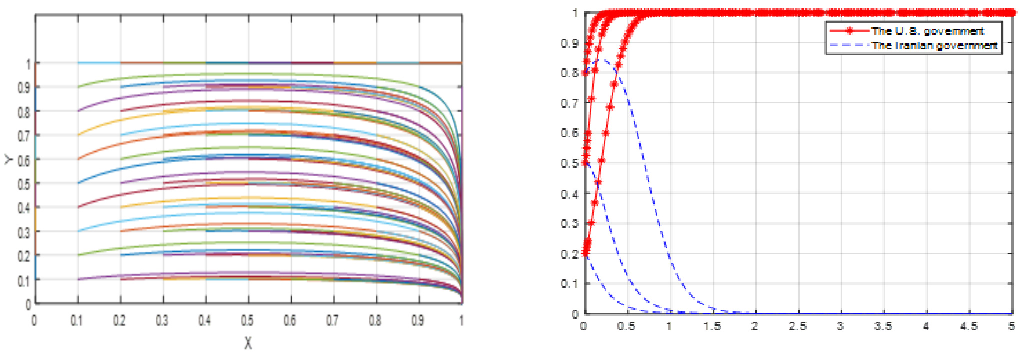


(a) (b)

Figure 11 Evolutionary path diagram when $ß_1 < \Delta c_1$, $\Delta_2 < \alpha$, $\Delta c_2 > \alpha + ß_2$ (deterrence, interference).

Scenario 4

When $ß_1 < \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 < \alpha + ß_2$the result of the evolutionary equilibrium in this scenario is (deterrence, compromise). Same as above, assign each parameter and satisfy its corresponding condition, assuming that each parameter is: $\Delta_1 = 20$, $ß_1 = 10$, $\Delta c_1 = 15$, $\Delta_2 = 25$, $\alpha = 20$, $ß_2 = 15$, $\Delta c_2 = 30$. The simulation diagram in this case is shown in Figure 12. The system converges gradually towards (1,0) in this scenario, as shown in Figure 12a. For the US government there is a convergence towards a deterrence strategy regardless of the initial probability x. For the Iranian government there is a tendency for the probability to increase for a period when the initial value is larger, after which it will gradually converge towards a compromise strategy.



(a) (b)

Figure 12 Evolutionary path diagram when $ß_1 < \Delta c_1$, $\Delta_2 > \alpha$, $\Delta c_2 < \alpha + ß_2$ (deterrence, compromise).

Scenario 5

When $ß_1 < \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 > \alpha + ß_2$ the result of the evolutionary equilibrium in this scenario is (deterrence, interference). Same as above, assign each parameter and satisfy its corresponding condition, assuming that each parameter is: $\Delta_1 = 20$, $ß_1 = 10$, $\Delta c_1 = 15$, $\Delta_2 = 25$, $\alpha = 20$, $ß_2 = 15$, $\Delta c_2 = 40$. The simulation diagram in this case is shown in Figure 13. In this scenario, the conflict loss of both parties is less than the loss of equity. Evolutionary paths do not fluctuate over time when the initial probability varies. When the initial probability of the US government is low, it can converge to the deterrence strategy at a rapid rate. For the Iranian government, although it converges to the interference strategy in the end, it needs to consider the magnitude of the loss, α. Therefore, its convergence rate is slower than that of the US government.

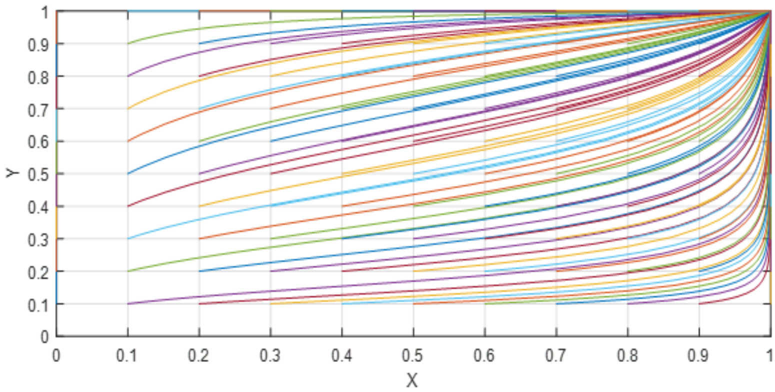


Figure 13 Evolutionary path diagram when $ß_1 < \Delta c_1$, $\Delta_2 > \alpha$, $\Delta c_2 > \alpha + ß_2$ (deterrence, interference).

Scenario 6

When $ß_1 > \Delta c_1$, $\Delta_2 < \alpha$ and $\Delta c_2 < \alpha + ß_2$. The result of the evolutionary equilibrium in this scenario is (deterrence, interference). In a similar way, assign each parameter and satisfy its corresponding condition, assuming that each parameter is $\Delta_1 = 20$, $ß_1 = 15$, $\Delta c_1 = 10$, $\Delta_2 = 25$, $\alpha = 30$, $ß_2 = 20$, $\Delta c_2 = 30$. The simulation diagram in this case is shown in Figure 14. The graph shows that there are significant fluctuations when the initial probabilities of both sides are high. As time progresses, *y* gradually converges to the compromise strategy, and *x* will give up the strategy first. As the probability of *y* gradually decreases, *x* will eventually converge to the deterrence strategy. The situation arises because the US government's conflict losses are higher than its equity losses. When the Iranian government has a high probability of choosing an interference strategy, the US government will give priority to choosing the abandonment strategy. The Iranian government will also suffer from greater conflicts, which will gradually reduce the probability of interference. In the end, both parties will converge to (1,0).

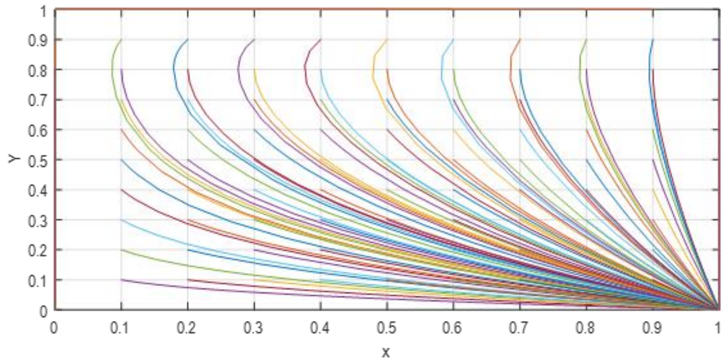


Figure 14 Evolutionary path diagram when $ß_1 > \Delta c_1$, $\Delta_2 < \alpha$, $\Delta c_2 < \alpha + ß_2$ (deterrence, interference).

Scenario 7

When $ß_1 > \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 < \alpha + ß_2$ there are two equilibrium points. Its evolutionary equilibrium results are (deterrence, compromise) and (abandonment, interference). Assigning each parameter, satisfying its corresponding condition, thus it is assumed that each parameter is $\Delta_1 = 20$, $ß_1 = 15$, $\Delta c_1 = 10$, $\Delta_2 = 25$, $\alpha = 30$, $ß_2 = 20$, $\Delta c_2 = 30$. The simulation diagram in this case is shown in Figure 15. From table (8) it is known that (0,0) as well as (1,1) are its instability points and that different initial values eventually converge to (1,0) or (0,1) after evolution. In this scenario, the system evolves to continue to converge to its chosen strategy only when its initial probability is high for both sides. As conflict losses are relatively large for both parties, the United States and Iran are trying to avoid conflicts as much as possible. Only when one party is more determined and has a higher probability of choosing a strategy can the game eventually converge on a combination of strategies in its favor after repeated play.

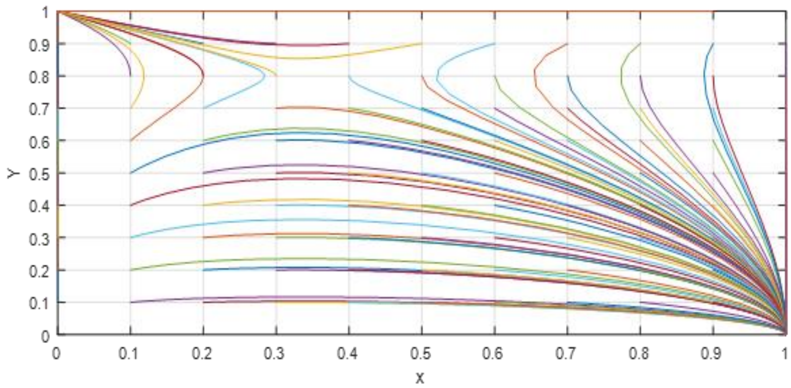


Figure 15 Evolutionary path diagram when $ß_1 > \Delta c_1$, $\Delta_2 > \alpha$, $\Delta c_2 < \alpha + ß_2$ (deterrence, compromise) and (abandonment, interference).

Scenario 8

When $ß_1 > \Delta c_1$, $\Delta_2 > \alpha$ and $\Delta c_2 > \alpha + ß_2$ the result of the evolutionary equilibrium in this scenario is (abandonment, interference). Same as above, assign each parameter and satisfy its corresponding condition, assuming that each parameter is $\Delta_1 = 20$, $ß_1 = 15$, $\Delta c_1 = 10$, $\Delta_2 = 25$, $\alpha = 30$, $ß_2 = 20$, $\Delta c_2 = 45$. The simulation diagram in this case is shown in Figure 16. The probability of the US government's strategy choice in this scenario is more volatile for two reasons.

On the one hand, the US government's own conflict losses are higher than its equity losses. On the other hand, there are larger excess returns of the Iranian government in this scenario, which can influence its strategy choice to gradually move towards an interference strategy.

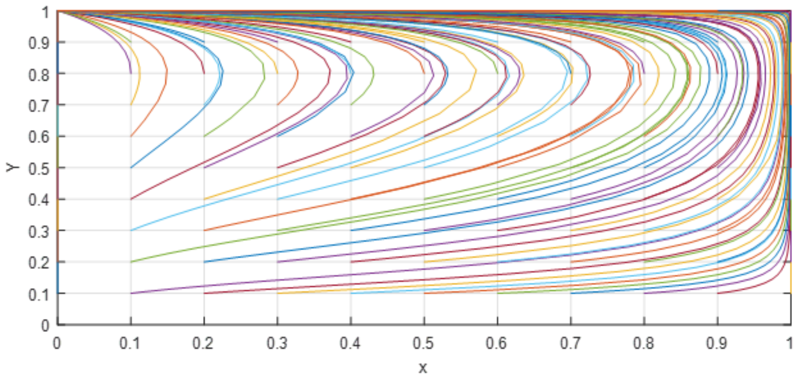


Figure 16 Evolutionary path diagram when $ß_1 > \Delta c_1$, $\Delta_2 > \alpha$, $\Delta c_2 > \alpha + ß_2$ (abandonment, interference).

6.2 Parameter sensitivity analysis

From the analysis in the previous section, it is known that the US government and the Iranian government differ in the combination of their stabilization strategies under different conditions. The relative sizes of the parameters of the variables in the model are key to their choice of strategy. Since the changes in the size of each parameter in each scenario will not affect the final stable equilibrium point and the way it changes, this section adopts the variable parameters $ß_1$, Δc_1, Δ_2, α to take different values. Thus, the impact on the convergence speed of the evolutionary path will be analyzed.

Sensitivity analysis of $ß_1$, Δc_1

Take the conditions of situation (4) in the previous section as an example. When other parameters are fixed, the value range of $ß_1$ is (0,15). Take the values of $ß_1$ as 5, 10, and 13, respectively. Take the initial state as (0.2, 0.8), as shown in Figure 17. It can be seen from Figure 17 that as the value of the variable parameter gradually increases, the color of the curve gradually becomes lighter. When the value of $ß_1$ is 5, the US government converges to 1 when the time is 0.5. As the value of $ß_1$ increases, the convergence time becomes longer. When $ß_1$ and other parameters are fixed, the value range of Δc_1 is (10, 30). Take the values of Δc_1 as 15, 20, and 25 respectively. As shown in Figure 18. When the value of Δc_1 is 15, the convergence time is around 0.3. As the value of Δc_1 gradually increases, it has a certain inhibitory effect on the US government. As for the Iranian government, its convergence time has not changed significantly. It shows that when the conflict loss or loss of rights and interests of the US government gradually increases, it will restrain the US government from making decisions, so that the US government will try to avoid conflicts and protect its rights and interests in the Strait of Hormuz. Similarly, $ß_2$ and Δc_2 can also inhibit the Iranian government's selection of interference strategies, however this study will not further elaborate on this situation.

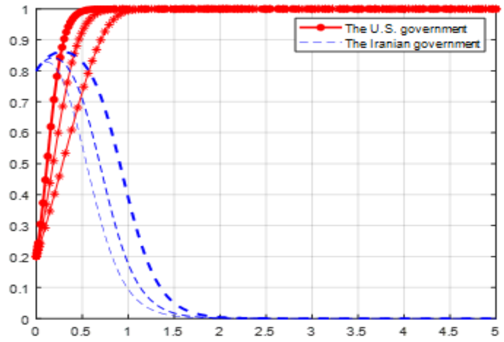


Figure 17 Evolution simulation diagram with different values of $ß_1$

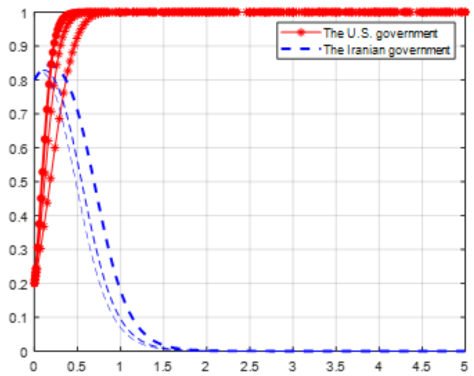


Figure 18 Evolution simulation diagram with different values of Δc_1

Combine 18 and 19 to one figure.

Sensitivity analysis of Δ_2， α

Take the conditions of situation (4) in the previous section as an example. When other parameters are fixed, the value range of Δ_2 is (20, +∞), take the values of Δ_2 as 25, 30 and 35, , and take the initial state as (0.2, 0.8), respectively. As shown in Figure 19, when the value of Δ_2 is 25, the Iranian government converges to 0 when the time is 1.6. As the value of Δ_2 increases, the convergence time becomes longer. This indicates that the increase or decrease in excess revenue acts as a disincentive for the Iranian government to choose a compromise strategy. Similarly, the value range of α is (15, 25). Take the values of α as 17, 20, and 23, respectively. As shown in Figure 20, it can be seen that as the value of α increases it has a clear promotion effect on the Iranian government's choice of compromise strategy. It shows that when the Iranian government chooses the interference strategy, it will affect the interests of other relevant countries in the Strait of Hormuz, thus making itself isolated by the international community and even subject to countermeasures by other countries, which will have a greater impact on its own losses.

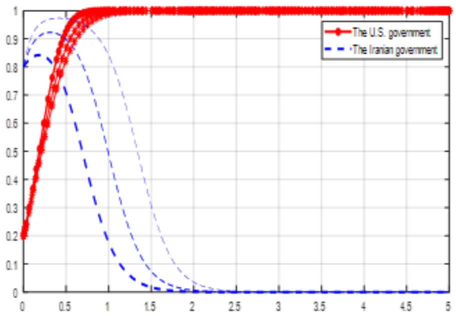


Figure 193 Evolution simulation diagram with different values of Δ_2

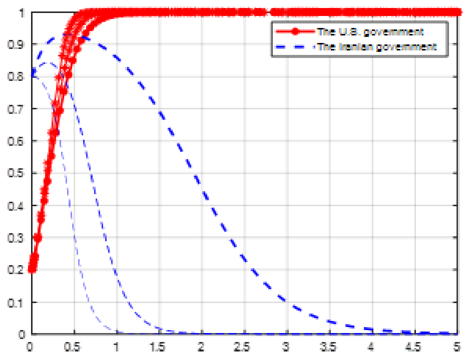


Figure 20 Evolution simulation diagram with different values of α

Combine 20 and 21 to one figure.

7 Conclusion

Whether the strategic transportation channel can maintain normal transportation involves the interests of many related countries. In the context of China's Belt and Road Initiative, cooperation among countries along the initiative has gradually increased. As one of the important transportation channels, the Strait of Hormuz is the subject of close attention of many countries. This paper uses the evolutionary game theory method to establish an evolutionary game model for the Strait of Hormuz with the US and Iranian governments as the main players in the game. The model in this paper analyzes the possible strategies that the United States and Iran may adopt in the game model as well as the conflicts between the United States and Iran surrounding the Strait of Hormuz. The payment variables are specifically divided into strategic equity losses, economic excess gains, conflict losses caused by different military forces, and additional losses incurred by the Iranian government when choosing interference strategies. By establishing the Jacobian matrix and analyzing the rank and trace of the matrix, the presented model is divided into eight different game scenarios. The game results show that the stability strategy in most scenarios is (deterrence, compromise), and the stability strategy in a small number of scenarios is (deterrence, interference) and (abandonment, interference). It is shown that under the assumption that other countries intervene in the US-Iran dispute, losses incurred by the US can become quite large, and the evolutionary outcome will change significantly if the initial attitude of the Iranian government is very firm. Furthermore, the US government's deterrence strategy can be inhibited when its conflict losses gradually increase or get closer to its equity losses. Similarly, as the Iranian government's additional losses incurred gradually increases, regardless of its initial state, it can effectively inhibit its choice of interference strategy. Finally, an in-depth analysis of the sensitivity of the variable parameters in the model shows that the size of the additional losses for the Iranian government has a greater impact on the choice of its strategy. When the economic interests of various countries are getting closer, the friction between them increases. Therefore, to safeguard the smooth passage through the Strait of Hormuz and the interests of the various countries involved in the Strait of Hormuz, it is necessary to establish early warning of political frictions in a timely manner, as well as gradually improve the international coordination and punishment mechanism to avoid possible conflicts.

Disclaimer

The authors are solely responsible for the analysis in this paper, which is largely based on hypothetical and judgmental data. This paper is the opinion of the authors and does not represent the belief and policy of their employers.

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