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GAME ANALYSIS AND SYSTEM DYNAMICS SIMULATION OF OIL AND GAS RESOURCES EXPLOITATION IN THE SOUTH CHINA SEA

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Abstract. *The disputes between China and Southeast Asian countries on the sovereignty of the South China Sea have been the hottest issue in the world. From an economic point of view, these disputes mainly focus on energy. And, the dispute between China and Vietnam has been the longest and the most complicated one. In this paper, we use multi-stage observable action dynamic game to analyze the best possible strategy of China and Vietnam on the exploitation of oil and gas resources in the South China Sea. And, we use system dynamics tools to simulate the results. Finally, we hope to provide a reference for the relevant decision-making issues.*
Keywords: Dynamic game, Absolute rationality, Sustainable development, Simulation

1. **Introduction.** Regardless of political factors, the economic factor behind the dispute over sovereignty of South China Sea between China and other Southeast Asian countries is the energy. Among them, the dispute between China and Vietnam is the most typical. The huge resource reserve in the South China Sea is a major cause of the Vietnam-China issue. The South China Sea is almost like the second Persian Gulf. To date, countries around the South China Sea have drilled more than 1,000 wells in the South China Sea and discovered more than 200 oil and gas fields. More than 100 oil and gas wells put into production are located in the South China Sea intermittent line. Statistics show that Vietnam's annual offshore oil production is about 30 million tons, of which 8 million tons are produced in disputed areas in the South China Sea.

The history of the South China Sea issue and other related issues has long been the focus of many scholars. For example, Zhang evaluated the strategic value of oil and gas resources in South China Sea [1]. Yan et al. confirmed that the South China Sea has an important position and incomparable strategic advantages in energy reserve [2]. Xu studied oil and gas resources development from the perspective of game theory and analyzed the main strategy of the development of South China Sea [3]. Zhang interpreted different scholar's proposition and discussed the significance of resources of South China Sea from two angles [4]. Miao and Sun studied the internationalization of the resource development in South China Sea [5].

However, most scholars only study from a single perspective and there is a lack of systematic study on strategies of energy exploration. In reality, the situation in the South China Sea is very complicated, especially in terms of energy competition. Therefore, systematically analyzing the strategies of various countries in resource competition has important theoretical and practical significance for protecting the resources of the South China Sea and maintaining our country's interests. So the innovation of this article lies

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in the following three points. Firstly, we simplified the current complex situation of the South China Sea; secondly, we discussed strategies for countries in the context of sustainable development and unsustainable development simultaneously; thirdly, we used South China Sea resources data to the game model to simulate and verify the result of the game model. In a word, we hope to provide a reference for decision-making of South China Sea energy exploitation.

2. **Game Model Establishment and Analysis.**

2.1. **Basic assumptions.**

In order to grasp the core issues and eliminate the interference of non-important factors, this paper needs to make some basic assumptions before analyzing. First, suppose there are only two game players: China and Vietnam. Second, suppose each game player is absolutely rational. Third, assuming that the opportunities and conditions for exploitation of resources are the same for every game player. Fourth, suppose the total amount of oil and gas resources in the South China Sea during the period of t is y_t, China and Vietnam are producing c_{1t} and c_{2t} respectively in the stage of t, during the period of t the utility functions of China and Vietnam are $\ln c_{1t}$ and $\ln c_{2t}$ respectively. Fifth, assuming that in the period of $t+1$ the equation is $y_{t+1} = 10\sqrt{y_t - c_{1t} - c_{2t}}$, called the state transition equation. What we concern is the resource consumption of each stage.

2.2. **Game analysis.**

2.2.1. *Not considering the sustainable development.* Under the assumption that all the players in the game are absolutely rational, all the participants were the same kind, so they will make the same decision to realize their own maximized effectiveness. The optimal strategy in this case is called balanced resource consumption. The game player's optimization problem can be expressed as:

$$\begin{cases} V_i^k(y_k) = \max \sum_{t=k}^{T} \&^{t-1} \ln c_{it} \\ c_{1k} + c_{2k} \leq y_k \end{cases} \tag{1}$$

In Formula (1), $V_i^k(y_k)$ represents the utility of the participants. According to the assumptions and split time by $k+1$, we can have:

$$\begin{aligned} V_i^k(y_k) &= \max \sum_{t=k}^{T} \&^{t-1} \ln c_{it} = \max \left(\&^{k-1} \ln c_{ik} + \sum_{t=k+1}^{T} \&^{t-1} \ln c_{it} \right) \\ &= \max \left[\&^{k-1} \ln c_{ik} + V_i^{k+1}(y_{k+1}) \right] \\ &= \max \left\{ \&^{k-1} \ln c_{ik} + V_i^{k+1} \left[10 * \sqrt{(y_k - c_{1k} - c_{2k})} \right] \right\} \end{aligned} \tag{2}$$

According to (2), we need to solve:

$$V_i^k(y_k) = \max \left\{ \&^{k-1} \ln c_{ik} + V_i^{k+1} \left[10 * \sqrt{(y_k - c_{1k} - c_{2k})} \right] \right\} \tag{3}$$

Assume that we are in the second stage with a resource reserve of y_2. Because the utility of the game player increases with the increase of resource consumption and the game will not stop until all the resources are consumed by the game player. According to the assumption that each game player is absolutely rational, the balanced consumption can be:

$$c_{12} = c_{22} = \frac{y_2}{2} \tag{4}$$

If there is a third stage, the game player's optimization problem is:

$$\begin{cases} \max \left[\ln c_{11} + \frac{\&}{2}\left(1 + \frac{\&}{2}\right)\ln(y_1 - c_{11} - c_{21})\right] \\ c_{11} \leq y_1 - c_{21} \end{cases} \tag{5}$$

Solve Formula (5) and we can have:

$$c_{11} = c_{21} = \frac{y_1}{2 + \frac{\&}{2} + \left(\frac{\&}{2}\right)^2} \tag{6}$$

Equation (6) is the balanced solution. We can use the above process to calculate the balanced resource consumption of each stage. The results are shown in Table 1.

Table 1. Balanced resource consumption of each stage

Stage	Balanced resource consumption
T	$\frac{1}{2}y_T$
$T-1$	$\frac{1}{2+\frac{\&}{2}}y_{T-1}$
...	...
1	$\frac{1}{2+\frac{\&}{2}+\cdots+\left(\frac{\&}{2}\right)^{T-1}}y_1$

2.2.2. *Considering the sustainable development.* Taking account of the sustainable development of society, we need to consider different types of game players. Different types of players consider the sustainable use of resources at the same time. The optimal strategy in this case is called social optimal resource consumption. The game player's optimization problem can be expressed as:

$$\begin{cases} V^k(y_k) = \max \sum_{t=k}^{T} \&^{t-1}\left(\ln c_{1t} + \ln c_{2t}\right) \\ c_{1k} + c_{2k} \leq y_k \end{cases} \tag{7}$$

In Formula (7), $V^k(y_k)$ represents the utility of the all participants. Due to space limitations, we skipped the solution process which is similar to Section 2.2.1 and get:

$$V^k(y_k) = \max\left\{\&^{k-1}\left(\ln c_{1k} + \ln c_{2k}\right) + V^{k+1}\left[10 * \sqrt{(y_k + c_{1k} + c_{2k})}\right]\right\} \tag{8}$$

When $t = T$ we can have:

$$\begin{cases} V^T(y_T) = \max \&^{T-1}\left(\ln c_{1T} + \ln c_{2T}\right) \\ c_{1T} + c_{2T} \leq y_T \end{cases} \tag{9}$$

The solution for (9) is:

$$c_{1T} + c_{2T} = \frac{y_T}{2} \tag{10}$$

When $t = T - 1$ we can have:

$$\begin{cases} \max \&^{T-2}\left[\ln c_{1T-1} + \ln c_{2T-1} + \&^1 \ln\left(y_{T-1} - c_{1T-1} - c_{2T-1}\right)\right] \\ c_{1T-1} + c_{2T-1} \leq y_{T-1} \end{cases} \tag{11}$$

The solution for (11) is:

$$c_{1T-1} = c_{2T-1} = \frac{1}{2 \times \left(1 + \frac{\&}{2}\right)} * y_{T-1} \tag{12}$$

And so, when $t = 1$ we can have:

$$c_{11} = c_{21} = \frac{1}{\left\{2 \times \left[1 + \frac{\&}{2} + \cdots + \left(\frac{\&}{2}\right)^{T-1}\right]\right\}} y_1 \tag{13}$$

(13) is the optimal resource consumption of each stage when the sustainable development is considered. The results are in Table 2.

Table 2. Optimal resource consumption of each stage

Stage	Optimal resource consumption
T	$\frac{1}{2} y_T$
$T-1$	$\frac{1}{2\left(1 + \frac{\&}{2}\right)} y_{T-1}$
...	...
1	$\frac{1}{2\left(1 + \frac{\&}{2} + \cdots + \left(\frac{\&}{2}\right)^{T-1}\right)} y_1$

It can be seen from the above game model, whether to consider sustainable development makes the game result completely different. All players want to maximize their own interests when the sustainable development does not be considered. And they often do the same decision. According to Table 1 and Table 2 we can obviously find that the consumption of balanced resources is greater than the optimal resource consumption. Combined with the actual situation, we can see that, in order to maximize the effectiveness of their own country, all countries will inevitably over-consume public resources whether or not sustainable development is considered. However, when considering sustainable development, all countries will appropriately reduce the amount of exploitation. In other words, the result of the South China Sea oil and gas exploitation dispute is "the tragedy of the commons".

3. **Simulation.**

3.1. **Modeling.**

According to the above conclusions, as well as the balanced exploitation strategy and optimal exploitation strategy of China and Vietnam shown in Table 1 and Table 2, we can set the variables and model system parameters of simulation model in Table 3.

Simulation model flow chart is shown in Figure 1.

According to the above analysis, both sides of the game will over-exploit the oil and gas resources. Therefore, in the next simulation, the consumption of both players is always

Table 3. Model variables

Variable type	Variable meaning	Variables
Horizontal variables	Total storage for each period (Billion tons)	Y
	Consumption of both players (Billion tons)	c
Rate variable	Discount rate	$\&$
Auxiliary variables	Each period of the game (month)	T
	Current storage of oil and gas resources (Billion tons)	y_0
	Oil and gas consumption ratio of each period (Billion tons)	b

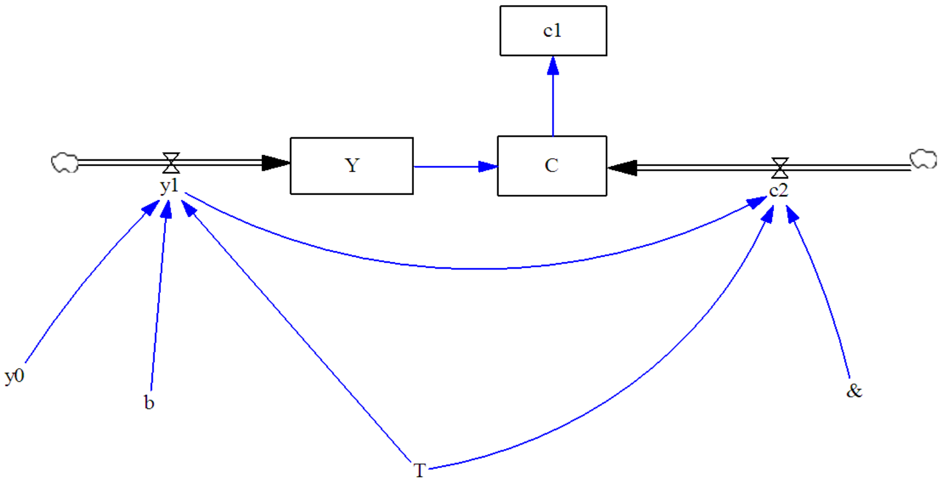

Figure 1. Flow chart of the model

Table 4. Resource consumption comparison table

Stage	O	B	Stage	O	B	Stage	O	B
0	1.649 M	3.3 M	31	52.79 M	105.6 M	62	103.94 M	207.9 M
1	3.3 M	6.6 M	32	54.44 M	108.9 M	63	105.59 M	211.2 M
2	4.949 M	9.9 M	33	56.09 M	112.2 M	64	107.24 M	214.5 M
3	6.599 M	13.2 M	34	57.74 M	115.5 M	65	108.89 M	217.8 M
4	8.249 M	16.5 M	35	59.39 M	118.8 M	66	110.54 M	221.1 M
5	9.899 M	19.8 M	36	61.04 M	122.1 M	67	112.19 M	224.4 M
6	11.54 M	23.1 M	37	62.69 M	125.4 M	68	113.84 M	227.7 M
7	13.19 M	26.4 M	38	64.34 M	128.7 M	69	115.49 M	231 M
8	14.84 M	29.7 M	39	65.99 M	132 M	70	117.14 M	234.3 M
9	16.49 M	33 M	40	67.64 M	135.3 M	71	118.79 M	237.6 M
10	18.14 M	36.3 M	41	69.29 M	138.6 M	72	120.44 M	240.9 M
11	19.79 M	39.6 M	42	70.94 M	141.9 M	73	122.09 M	244.2 M
12	21.44 M	42.9 M	43	72.59 M	145.2 M	74	123.74 M	247.5 M
13	23.09 M	46.2 M	44	74.24 M	148.5 M	75	125.39 M	250.8 M
14	24.74 M	49.5 M	45	75.89 M	151.8 M	76	127.04 M	254.1 M
15	26.39 M	52.8 M	46	77.54 M	155.1 M	77	128.69 M	257.4 M
16	28.04 M	56.1 M	47	79.19 M	158.4 M	78	130.34 M	260.7 M
17	29.69 M	59.4 M	48	80.84 M	161.7 M	79	131.99 M	264 M
18	31.34 M	62.7 M	49	82.49 M	165 M	80	133.64 M	267.3 M
19	33 M	66 M	50	84.14 M	168.3 M	81	135.29 M	270.6 M
20	34.64 M	69.3 M	51	85.79 M	171.6 M	82	136.94 M	273.9 M
21	36.29 M	72.6 M	52	87.44 M	174.9 M	83	138.59 M	277.2 M
22	37.94 M	75.9 M	53	89.09 M	178.2 M	84	140.24 M	280.5 M
23	39.59 M	79.2 M	54	90.74 M	181.5 M	85	141.89 M	283.8 M
24	41.24 M	82.5 M	55	92.39 M	184.8 M	86	143.54 M	287.1 M
25	42.89 M	85.8 M	56	94.04 M	188.1 M	87	145.19 M	290.4 M
26	44.54 M	89.1 M	57	95.69 M	191.4 M	88	146.84 M	293.7 M
27	46.19 M	92.4 M	58	97.34 M	194.7 M	89	148.49 M	297 M
28	47.84 M	95.7 M	59	98.99 M	198 M	90	150.14 M	300.3 M
29	49.49 M	99 M	60	100.6 M	201.3 M	91	151.79 M	303.6 M
30	51.14 M	102 M	61	102.2 M	204.6 M	92	153.44 M	306.9 M

the same. The time span of this simulation is discredited into 10 periods by 1 interval. The endpoint value of discount rate is the highest and lowest one-year interest rates of the LIBOR in recent 10 years which are discredited into 7 periods by 0.1% interval. Finally, through querying the relevant literature, this paper finds that the current storage capacity of the South China Sea oil and gas resources is about 33 billion tons and the consumption ratio is about 100,000 tons a month.

3.2. **Simulation results.** We can get the resource consumption map through the simulation system.

The "stage" is a relative concept; it can be any time unit. According to the actual crude oil production cycle, one stage in this article represents one month. In Table 4, O represents the optimal resource consumption and B represents the balanced resource consumption. Figure 2 and Figure 3 show that the optimal resource consumption is much

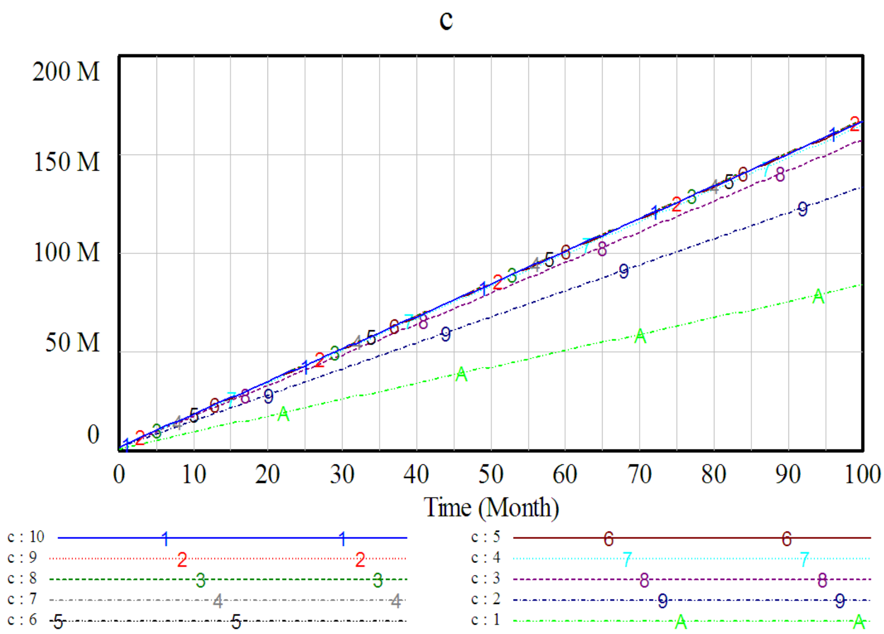

FIGURE 2. Balanced resource consumption

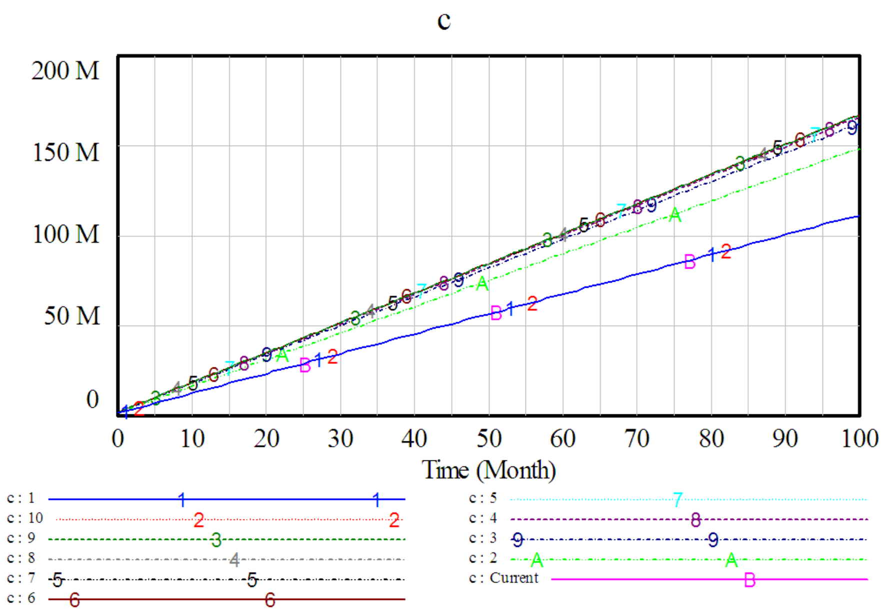

FIGURE 3. Optimal resource consumption

less than the balanced resource consumption. The resource consumption comparison in Table 4 shows more specific verification conclusions. This proves the rationality of the conclusion of the multi-stage observable action dynamic game model in the second part of this paper.

4. **Conclusions and Recommendations.** Since ancient times, the South China Sea has been an inalienable part of China, so China has the right to fully exploit it. However, the international situation in the South China Sea is very grim at present, and the model in this paper shows that all countries will over-exploit resources of South China Sea and cause the resources to drain quickly. Therefore, we should develop offshore oil and gas resources exploitation technology, and immediately put deep-sea oil and gas exploration technology into production. Gradually promote the South China Sea oil and gas exploration, resulting in the fact that "the first station should be exploited first" in order to substantively occupy all sea areas. The occupied islands and reefs will gradually lose occupation value. Maintain our territorial integrity and economic interests.

In the case of scarce resources, there are many factors that countries need to consider in formulating their own resource development plans. Especially in a complex international environment, countries often cannot fully consider the sustainable development. Our study shows that in the South China Sea resource issue, China will inevitably face the problem of excessive exploitation of resources by other countries. If all countries in the South China Sea only consider their own interests, the South China Sea resources will soon be depleted. However, if China cooperates with other countries around the South China Sea, the tragedy of the commons can be avoided to some extent. In subsequent studies, we will consider multi-stage repeated games and cooperative games to better describe the changes of strategies of different countries in different stages. Calculate optimal resource consumption when countries around South China Sea considered sustainable development and cooperated with each other.

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