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Study of Safety Investment in Mines Based on Utility Function from A Game Perspective: Experiences from China

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Abstract: Mining industry, especially coal-mining industry, is faced with many safety problems in China such as the lack of coordination between the mining enterprises and the safety administration, decision-making of production and safety investment and so on. In order to reduce costs and maximize profits, many mining enterprises are gaming in safety investment under the mining safety supervision although relative supervision provisions are strict, which results in frequent occurrence of mine accidents. In order to find out the causes that are behind the economic motivation, based on utility function with two variables, technology and cost, from a game perspective, a safety investment analysis for decision makers in coal-mining enterprises is made in this article by focusing on the technological level and production cost and presenting the gaming process during deciding safety investment among these enterprises. The result is that there is no enough incentive in short term for mining enterprises to make safety investment under the condition of low technological level and high cost in China. Therefore, it is necessary to enhance safety awareness, strengthen supervision and improve safety status during mining, which is also helpful for all mining enterprises and sustainable development.

Key words: Safety Investment; Utility Function; Game; Cost; Supervision

1. RESEARCH BACKGROUND

Coal is a basic energy and main raw material, accounting for almost 70% of all the energy in terms of consumption before 2012 and then decline, and for almost 70% of all the energy in terms of consumption in China. Considering the energy-consuming structure of China, coal was a main energy for a long time, as Fig.1 and Fig.2 show.

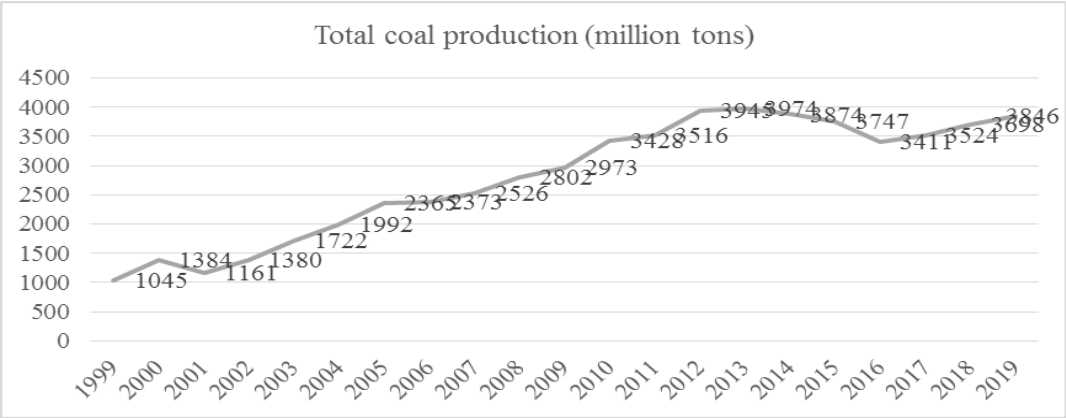

Fig.1 total coal production in China from 1999 to 2019

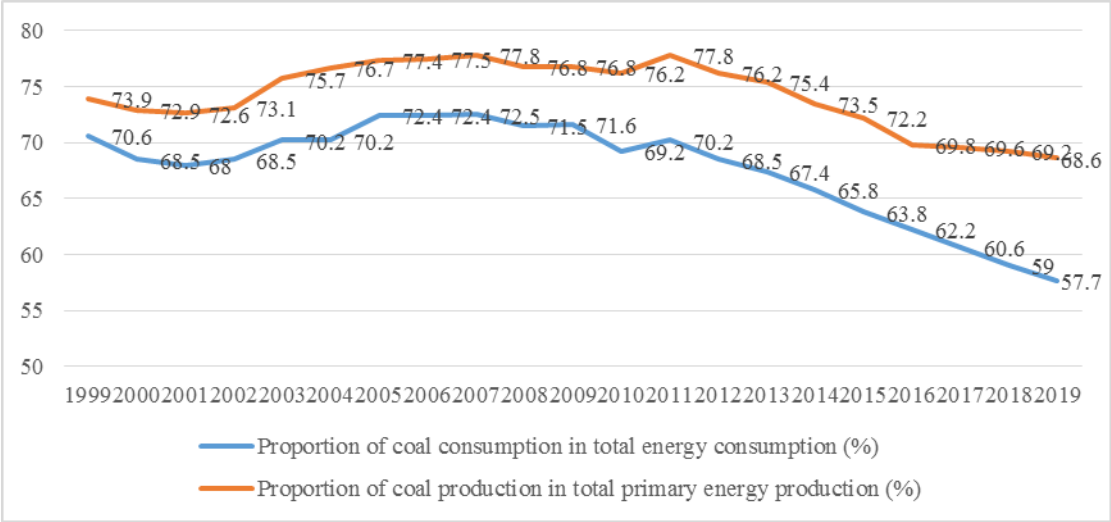

Fig.2 Percentage of coal comsuption and production in China from 1999 to 2019

Despite the fact that China is rich in coal reserves, the technology of coal production and management is at a low level, and there were nearly twenty thousand coal mining enterprises, 80% of which were small-scaled before 2012. Because of the fluctuation of coal prices, related parties gamed for maximizing profits, and many enterprises minimized their costs through minimizing the safety investments. As a result, coal-mining disasters frequently occurred because of long-term debt for safety investment. The safety investment is considerably insufficient in some Chinese coal-mining enterprises, whether they are key state-owned coal-mining enterprises or small-and-medium-scaled local ones. The burdens on some state-owned coal-mining enterprises once were heavier. So that, frequent mine disasters once were one of the most concerned issues. Table 1 lists the number of accidents in coal mines in China from 2000 to 2020.

TABLE 1 COAL-MINING ACCIDENTS IN CHINA FROM 2000 TO 2020

year	Accidents with 3-9 people dead	Increase than that in the previous year (%)	Account for all the coal mine accidents (%)	Accidents with at least 10 people dead	Increase than that in the previous year (%)	Account for all the coal mine accidents (%)	total accidents	Increase than that in the previous year (%)
1999	506	-	-	75	-	-	-	-
2000	466	-7.91	17.12	75	0.00	2.76	2722	
2001	385	-17.38	12.49	49	-34.67	1.59	3082	13.226
2002	321	-16.62	8.43	56	14.29	1.47	3806	23.491
2003	286①	-10.90	6.90	51①	-8.93	1.23	4143	8.8544
2004	247	-13.64	6.78	43	-15.69	1.18	3641	-12.12
2005	208	-15.79	6.29	58	34.88	1.75	3306	-9.201
2006	237	13.94	8.05	39	-32.76	1.32	2945	-10.92
2007	179	-24.47	7.39	28	-28.21	1.16	2421	-17.79
2008	146	-18.44	7.47	38	35.71	1.94	1954③	-19.29
2009	106	-27.40	6.56	16	-57.89	0.99	1616③	-17.3
2010	110②	3.77	7.84	24②	50.00	1.71	1403③	-13.18
2011	85	-22.73	7.08	20	-16.67	1.67	1201③	-14.4
2012	71	-16.47	9.11	15	-25.00	1.93	779③	-35.14
2013	48	-32.39	7.89	16	6.67	2.63	608	-21.95
2014	46	-4.17	9.04	14	-12.50	2.75	509	-16.28
2015	35	-23.91	9.94	5	-64.29	1.42	352	-30.84
2016	22	-37.14	8.84	9	80.00	3.61	249	-29.26
2017	26	18.18	11.87	6	-33.33	2.74	219	-12.05
2018	17	-34.62	7.59	2	-66.67	0.89	224	2.2831
2019	22④	29.41	12.94	3④	50.00	1.76	170④	-24.11
2020	10④	-54.55	8.20	3④	0.00	2.46	122④	-28.24

Data source: ①China National Coal Association. Analysis Report on Coal Mine Accidents in China from 2003 to 2007 [A].China Coal Economic Research (2005 ~ 2008)

(Volume 1) [C]. China Coal Industry Association,2009:73.
②Wen Hu, Chen Bocheng, Fei Jinbiao, Jin Yunzhang, Lu Yantao. Study on Basic Characteristics and Occurrence Regularity of Accidents in Chinese Coal Mines During 2010～2014 [J].Coal Technology,2016,35(03):310-312.
③ SUN Jiping, QIAN Xiaohong. Analysis of Coal Mine Accidents in China during 2004 - 2015 [J].Industry and Mine Automation,2016,42(11):1-5.
④ Ding Baichuan. Analysis of Characteristics and Causes of Coal Mine Accidents in 2020 in China [N].China Energy News, 2021-02-22(015).
Other data is from the website of State production Safety Supervision and Management Bureau (http://www.chinasafety.gov.cn).

Debt problem in the mining safety investment is the a direct and the main reason for coal-mining accidents in China. With the deepening of coal mines, aging of equipment and backwardness technological development, severe accidents occurred frequently. However, it is not a simple technological issue that leads to mining accidents. An instinct gaming psychology, motivation for profits and lack of safe guard consciousness, is implied behind major safety accidents in China. Although there were some unavoidable accidents and the government provided safety regulations, mining enterprises would rather sacrifice safety to reduce cost. They did not have initiative to increase safety investment in order to get a maximum profit (Jiang, 2006).

Safety investment was less than 1% in China's GDP, while in some developed countries precaution investment was 3.3% in GDP, which reflects the lack of safety investment in China (Zhang & Zhang, 2002). In the long term, investment funds in production safety mainly come from the renewal and reconstruction funds. According to relative regulations, this proportion should be over 20%, while the proportion in many enterprises is far more lower than this. According to the assessment from the Research Center of National Safety Production Administration, only key coal-mining enterprises invested about 50 billion Yuan RMB in safety projects and equipment. Additionally, the direct loss from safety accidents in China reaches more than 100 billion Yuan (16.1 billion dollars), with indirect loss over 300 billion Yuan (Wang, 2005). Now, most coal-mining enterprises, especially large-scaled ones, have been fully aware of the significance of safety investment and have drafted strict production safety regulations and established complete mechanism of safety financing, so, we can find that coal mining accidents decreased a lot in recent years.

Then, what makes mining enterprises reluctant to make safety investment so long time? Is it for Government's regulation? To reduce accident occurrence and mortality in these accidents, relevant laws were enacted and some policies were issued. However, coal-mining accidents have dropped sharply until 2012. How to explain this phenomenon? The objective of this article is to analyze the phenomenon from the angle of gaming based on utility function with two variables that are technology and cost. A game model is set to analyze the gaming process of coal-mining safety investment and decisions that coal-mining enterprises choose for safety investment.

2. LITERATURE REVIEW

The reasons for coal-mining accidents are multifaceted. Andrews & Christenson (1974) divided these factors into three categories: (1) Internal factors, including the physical environment of the mine, the technology used in the mine, the scale of the operation, the characteristics of the work, and managerial forces; (2) Public factors, including state and federal government control level; public opinions about the mine operations and policies; (3) Random factors, such as human errors or equipment failure. Mine safety investment is actually a direct input into the first and the third aspects, and the second aspect is to strengthen the supervision of safety investment. Li et al. (2008) also found that coal condition, safety input, overload productivity and personnel quality are the most important factors that influence production safety in coal-mining industry in China. Lu & Fan (2013) advanced a risk control method with two factors that are physical condition failures and human errors. In addition, it is also the problem of coal-mining safety regulation standard that influences production safety in coal-mining industry (Xiao & Sun, 2006).

There are few, if any, studies on coal-mining safety investment worldwide, and relevant studies are mainly on policies and their effects. For example, Viscusi (1979, 1986, 1992), Gray & Scholz (1993), Weil (1996) and Scholz & Gray (1997) studied the effect of safety regulations established by the United States Occupation Safety and Health Administration. Stern & Holder (1999), and Stern & Cubbin (2004) analyzed the features of high-quality governance. In addition, Viscusi (1979) and Klick & Stratmann (2003) also discussed the effect of miners' behavior on the results of safety management.

The frequent occurrence of coal-mining accidents has close relationship with safety regulations in China. Regulation policies and property policies have important influence on coal-mining safety input (Bai et al., 2011). Some scholars have also analyzed supervision games under different conditions, such as Li and Mi (2007) studied the game of the local coal-mining safety supervision from information perspective; Fu & Liu (2007) and Fu & Guo (2007) explored games under a steady state and regulatory variations from an evolutionary perspective. Li et al. (2006) explained the game of safety supervision from the perspective of managers' principal-agent. Liu (2006) states that the conspiracy between local officials and the mine owners are the main reason for the frequent occurrence of coal-mining accidents.

Some scholars studied coal mine supervision problems from the perspective of investment. Chen & Lin (2006) analyzed the game between coal-mining enterprises and coal-mining supervision based on input. Liu & Qin (2006) built a safety cost minimization model, (B(S)=L(S)+C(S)), and maximum gain model of safety investment, (E(S)=F(S)-C(S)), from the principles of safety cost minimization and maximization of safety investment. The best safety degree is guaranteed by solving dB(S)/dS=0 and dE(S)/dS=0 (Dixit & Pindyck, 1994; Goeree & Holt, 2005). Similarly, Wang et al. (2009) established a safety investment decision model based on safety benefits. But in China, a lag phase in safety investments could influence the occurrence of coal-mining causality. It can also reduce accident costs to increase pre-phase safety investment (Tong, 2014). Personnel training and investment in safety technology can prevent accidents effectively (Nie et al., 2012).

However, the basic principles of both the safety cost minimization and the safety income maximization are not enough to analyze an enterprise without considering the market competition, the mutual relationship and the restriction among enterprises. They cannot reflect the real decision-making process of coal-mining safety investment. Therefore, in this article, the decision-making behavior and the game process of safety investment will be explored based on utility function with technology and cost from a game perspective.

3. A GAME MODEL FOR MINING SAFETY INVESTMENT

3.1 Utility function of coal mine safety investment

In order to study games in mining safety investment without loss of generality, the model set up in this article refers two subjects (i=1, 2), which make safety investment $a_i \geq 0$, and get their utility function u_i, and the assumptions (Meng & Sun, 2005; Lv et al., 2006) are:

- Enterprise i makes safety investment at the level of 0 and a_i >O;
- safety accident rate is p which is very small (for if it is big, the rational investors will not make investment for adventure, and the government will not allow investors to develop such high-risk projects), therefore, the aim of safety investment is to reduce accident rate to p';
- there is only price competition based on cost and profit between the two enterprises;
- The loss will be infinite once an accident occurs and the enterprise could not survive;

- The government will only punish the observed companies that do not invest in safety and will not punish those companies that are not observed by itself.

Then, the utility function of safety investment (Dong, 2004) is:

$$u_i = x_i(a_i, a_j) + y_i(a_i) - v_i(a_i) - l_i(a_i) \text{, (j=1,2; i≠j)} \qquad (1)$$

In Eq. (1), $x_i(a_i, a_j)$ is the effect value, for Enterprise i, during competition with other enterprises such as Enterprise j, and profit change exists because of changes in external competition conditions resulting from safety investment, which influences overall utilities of Enterprise i; $y_i(a_i)$ is the single utility value for an economic Subject i from safety investment; $v_i(a_i)$ is the cost that Subject i make safety investment, and $v_i(a_i)$ >0; $l_i(a_i)$ is penalty and reputation loss caused by lack of safe investment.

Thus, for Enterprise 1, as an example, $x_1(a_1, a_2) = w_1 a_1 a_2$ can be got, and $\frac{\partial^2 x_1}{\partial a_1 \partial a_2} = w_1$, which reflects the variation coefficient of Enterprise 1 because of the competition between these two enterprises, Enterprise 1 and 2, in safety investment, of which the sign is the same with $(a_2 - a_1)$ and reflects the attribution of x_i to the whole utilities of Enterprise 1. Generally, for Enterprise 1, it will increase the cost only to consider that safety investment under competition, a_1 has a negative influence, and a_2 has a positive influence.

$$y_i(a_i) = (1-p')u^c - p'u^s = [1-(p-\gamma_i a_i)]u^c - (p-\gamma_i a_i)u^s,\ \gamma_i \geq 0 \qquad (2)$$

Eq. (2) represents the influential degree of safety investment to accident rate, $(p-\gamma_i a_i) \geq 0$, in which, u^c is normal profit when there is no accident, u^s is lost profit when there are safety accidents, and $u^s \to +\infty$. When the probability p is very small, and $(p-\gamma_i a_i) \to 0$, it is hard to get a minimum or maximum value like pu^s and $(p-\gamma_i a_i)u^s$, and it is not significant for an enterprise to make decisions from an utility angle. Therefore, it can be neglected as part of the utility function, and the influence of safety investment on utility value is indicated in the value of $[1-(p-\gamma_i a_i)]u^c$.

$$v_i(a_i) = -b_i a_i + \frac{1}{2} c_i a_i^2,\ b_i > 0, c_i > 0 \quad (3)$$

Eq. (3) reflects the importance of enterprise safety investment. Then, after safety investment, the utilities of the two subjects are respectively:

$$l_i(a_i) = \begin{cases} rSF, & a_i = 0 \\ 0, & a_i > 0 \end{cases} \quad (4)$$

Eq.(4) shows the company's penalty and reputation loss caused by because of lack of safe investment. In Eq.(4), S is the probability that companies without investing in safety are observed by the government, and is in direct proportion to the government's supervision strength; F is the government's fines for companies that do not invest in safety and is inverse to the government's punishment intensity; r is the reputation factor that indicates the extent to which the impact that the company has not made safety investments on its social reputation; When $a_i > 0$, the company makes a certain safety investment. It will neither be punished, nor lose its reputation. Then, the utilities of Enterprise 1 and 2 are shown as follows:

$$u_i(a_1, a_2) = w_i a_1 a_2 + [1 - (p - \gamma_i a_i)]u^c + b_i a_i - \frac{1}{2} c_i a_i^2, \text{ (i=1,2)} \quad (5)$$

If an enterprise does not make any safety investment, a_i will be 0, while the influential value is not 0. So, in this case, it can be assumed that:

$$x_i(a_i, a_j) = z_1 a_1 + z_2 a_2 \quad (6)$$

In Eq. (5), the situation is the same with the above generality, that is, for Enterprise 1, a_1 has a negative influence while a_2 has a positive influence, therefore, $z_1 < 0$, $z_2 > 0$.

When $a_i = 0$,

$$u_i(a_1, a_2) = z_1 a_1 + z_2 a_2 + 1 - p\ \ u^c + -rSF, \mathrm{i} = 1,2 \quad (7)$$

.

3.2 Utility Matrix of Coal Mine Safety Investment

The gaming utility matrix of the two enterprises, Enterprise 1 and 2, is shown in Figure3.

Enterprise 2

0 a_2

Enterprise 1	0	$u_1(0,0)$, $u_2(0,0)$	$u_1(0,a_2)$, $u_2(0,a_2)$
	a_1	$u_1(a_1,0)$, $u_2(a_1,0)$	$u_1(a_1,a_2)$, $u_2(a_1,a_2)$

Fig.3: The Game Utility Matrix of Enterprise 1 and 2

In the above matrix, $u_1(a_1,a_2)$ and $u_2(a_1,a_2)$ are shown according to Eq. (4) as follows:

$$u_1(0,0)=u_2(0,0)=(1-p)u^c-rSF\ ;$$

$$u_1(a_1,0)=z_1a_1+[1-(p-\gamma_1a_1)]u^c+b_1a_1-\frac{1}{2}c_1a_1^2;$$

$$u_1(0,a_2)=z_2a_2+(1-p)u^c-rSF\ ;$$

$$u_2(0,a_2)=z_2a_2+[1-(p-\gamma_2a_2)]u^c+b_2a_2-\frac{1}{2}c_2a_2^2;$$

$$u_2(a_1,0)=z_1a_1+(1-p)u^c-rSF\ .$$

It needs to be emphasized that when $0<a_1<\frac{2(z_1+b_1+\gamma_1u^c)}{c_1}$, $u_1(a_1,0)>u_1(0,0)$ will be obtained. That means that when Enterprise 2 does not make safety investment, Enterprise 1 still chooses to do it, and Vice versa.

4. GAME ANALYSIS OF THE COLA MINE SAFETY INVESTMENT

4.1 Graphic analysis of Game Zone

There are two kinds of games between Enterprise 1 and 2 by analyzing the gaming zones through graphic method (Zhang, 1996; Zhang, 2007):

(1) Type 1:

When $0<a_1<\frac{t_1+\sqrt{t_1^2+2c_1rSF}}{c_1}$, $t_1=z_1+b_1+\gamma_1u^c$, $u_1(a_1,0)>u_1(0,0)$, which means that Enterprise 1 will still make safety investment when Enterprise 2 does not make any; likewise, when $0<a_2<\frac{t_2+\sqrt{t_2^2+2c_2rSF}}{c_2}$, $t_2=z_2+b_2+\gamma_2u^c$, $u_2(a_2,0)>u_2(0,0)$, which means that Enterprise 2 will still make safety investment even if Enterprise 1 does not make any safety investment. for $u_1(0,0)=u_1(a_1,0)$ and $u_2(0,0)=u_2(0,a_2)$, the zones are formed for Line

$a_1 = \dfrac{t_1 + \sqrt{t_1^2 + 2c_1 rSF}}{c_1}$, $t_1 = z_1 + b_1 + \gamma_1 u^c$ and

$a_2 = \dfrac{t_2 + \sqrt{t_2^2 + 2c_2 rSF}}{c_2}$, $t_2 = z_2 + b_2 + \gamma_2 u^c$ intersect, as Figure 4 indicates.

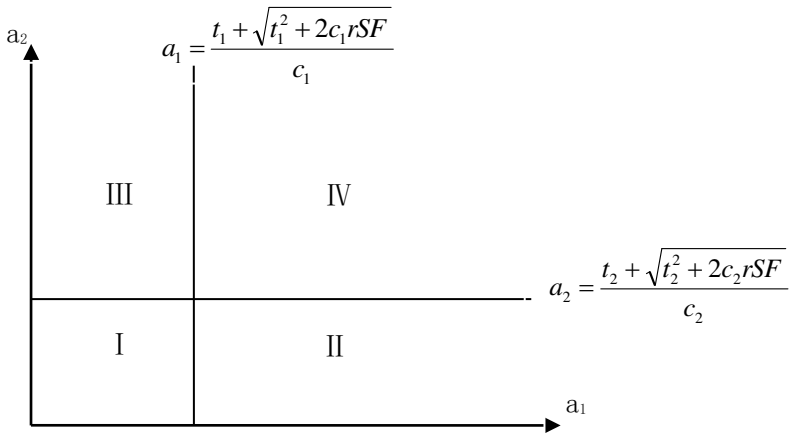

Fig.4: The Game Zone of Type 1

In Figure 4, $u_1(0,0) < u_1(a_1,0)$ and $u_2(0,0) < u_2(0,a_2)$ in Zone Ⅰ, so, the investment option group of the two enterprises is (a_1, a_2);

In the same way, in Zones Ⅱ, Ⅲ and Ⅳ, there are groups (0, a_2), (a_1, 0) and (0, 0) respectively.

(2) Type 2:

When $0 < a_2 < \dfrac{\gamma_1 a_1 u^c + b_1 a_1 - \frac{1}{2} c_1 a_1^2 + rSF}{-w_1 a_1 + z_2}$, $u_1(a_1,a_2) > u_1(0,a_2)$, which means that Enterprise 1 will also make safety investment when Enterprise 2 makes safety investment; likewise, when $0 < a_1 < \dfrac{\gamma_2 a_2 u^c + b_2 a_2 - \frac{1}{2} c_2 a_2^2 + rSF}{-w_2 a_2 + z_1}$, $u_2(a_1,a_2) > u_2(a_1,0)$, which means that Enterprise 2 will also make safety investment when Enterprise 1 makes safety investment.

For $u_1(a_1,a_2) = u_1(0,a_2)$ and $u_2(a_1,a_2) = u_2(a_1,0)$, the zones are divided for the line $a_2 = \dfrac{\gamma_1 a_1 u^c + b_1 a_1 - \frac{1}{2} c_1 a_1^2 + rSF}{-w_1 a_1 + z_2}$ and $a_1 = \dfrac{\gamma_2 a_2 u^c + b_2 a_2 - \frac{1}{2} c_2 a_2^2 + rSF}{-w_2 a_2 + z_1}$ intersect, and the figure could be like Figure 5 with application of simulation iteration to two equations. The change of specific parameters will only influence the motion of the curves but not the results.

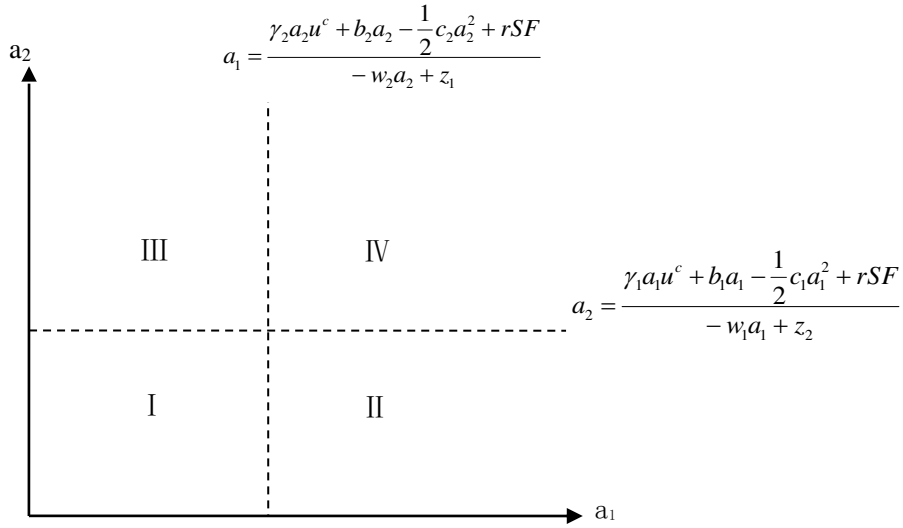

Fig.5: The Game Zone of Type 2

In Figure 5, like the above type 1, in Zones Ⅰ. Ⅱ. Ⅲ and Ⅳ, utilities of the two enterprises can be compared, and groups (0, 0), (0, a_2), (a_1,0), (a_1, a_2) can be obtained respectively.

The above two types of games can be integrated into one coordinate, in which there are four lines whose relative positions have relationship with the parameters. Here it is assumed that:

$a_2 = \dfrac{\gamma_1 a_1 u^c + b_1 a_1 - \frac{1}{2} c_1 a_1^2 + rSF}{-w_1 a_1 + z_2}$ is over $a_2 = \dfrac{t_2 + \sqrt{t_2^2 + 2c_2 rSF}}{c_2}$, $t_2 = z_2 + b_2 + \gamma_2 u^c$,

and $a_1 = \dfrac{\gamma_2 a_2 u^c + b_2 a_2 - \frac{1}{2} c_2 a_2^2 + rSF}{-w_2 a_2 + z_1}$ is on the right of $a_1 = \dfrac{t_1 + \sqrt{t_1^2 + 2c_1 rSF}}{c_1}$,

$t_1 = z_1 + b_1 + \gamma_1 u^c$.

So, the lines in the two types of games are drawn within the first quadrant, as Figure 6 shows.

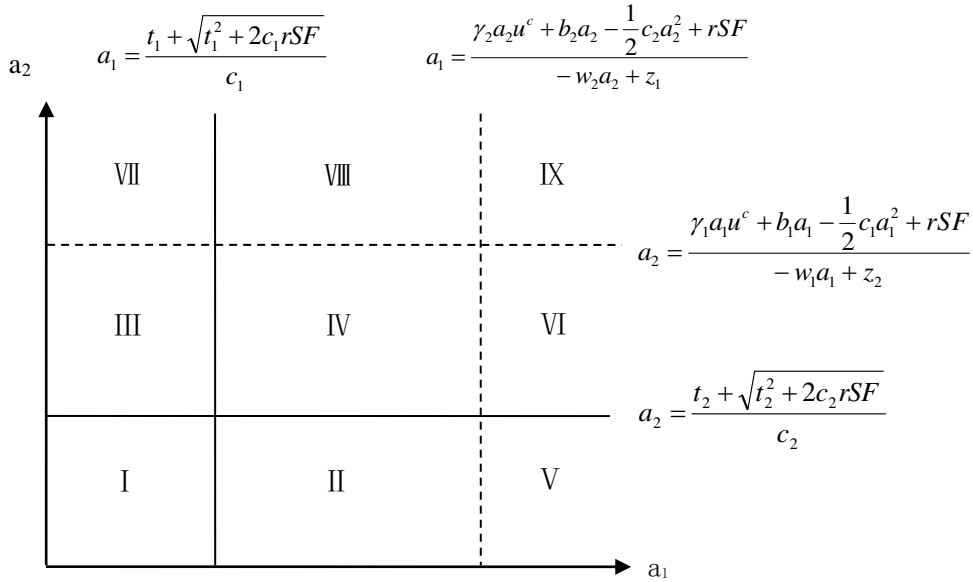

Fig.6: Comprehensive Game Zone

In Figure 6, in Zone Ⅰ and Ⅸ, no matter what types the games are, the results are the same, which are (a_1, a_2) and (0,0) respectively. The results in other zones differ with different types of games. In Figure 6, Zones Ⅰ and Ⅸ correspond to two different situations:

i. when $0 < a_1 < \frac{t_1 + \sqrt{t_1^2 + 2c_1 rSF}}{c_1}$, $t_1 = z_1 + b_1 + \gamma_1 u^c$ and $0 < a_2 < \frac{t_2 + \sqrt{t_2^2 + 2c_2 rSF}}{c_2}$, $t_2 = z_2 + b_2 + \gamma_2 u^c$, the safety investment options of Enterprise 1 and 2 are (a_1, a_2);

ii. when $a_1 > \frac{\gamma_1 a_2 u^c + b_2 a_2 - \frac{1}{2} c_2 a_2^2 + rSF}{-w_2 a_2 + z_1}$ and $a_2 > \frac{\gamma_1 a_1 u^c + b_1 a_1 - \frac{1}{2} c_1 a_1^2 + rSF}{-w_1 a_1 + z_2}$, the safety investment options of Enterprise 1 and 2 are (0,0).

4.2 The game analysis for enterprises without making safety investment

According to the above analysis of the game model and game zones, it can be noted that many parameters are related to enterprises' choice of whether to invest in safety or not. But in reality, the tendency is unidirectional. The following game is explained from an enterprise's point of view.

Obviously, the choices of Enterprise 1 are properly (0, 0), (a_1, 0), (0, a_2), (a_1, a_2). By comparison, $u_1(0,0)$ and $u_1(a_1,0)$, and $u_1(0,a_2)$ and $u_1(a_1,a_2)$ decide the strategies of Enterprise 1, these four groups are put into the expression and the following equations can be obtained:

$$u_1(a_1,0) - u_1(0,0) = z_1 a_1 + \gamma_1 a_1 u^c + b_1 a_1 - \frac{1}{2} c_1 a_1^2 + rSF \quad (8)$$

$$u_1(a_1,a_2) - u_1(0,a_2) = w_1 a_1 a_2 - z_2 a_2 + \gamma_1 a_1 u^c + b_1 a_1 - \frac{1}{2} c_1 a_1^2 + rSF \quad (9)$$

In Eq.(8), $z_1 a_1$ <0; based on the assumption that for Subject i, safety cost $v_i(a_i)$ >0 and $b_1 a_1 - \frac{1}{2} c_1 a_1^2$ <0; under certain safety investment a_1, $\gamma_1 a_1 u^c$ depends on γ_1 and u^c, and γ_1 is decided by the technological level of Enterprise 1. The higher the level is, the bigger γ_1 is; u^c is related to the cost, and the lower the cost is, the bigger u^c is. The value of rSF is related with r, S and F, in which, r, as a reputation factor, is influenced by reputation mechanism. The greater the reputation effect is, the less inclusive the market is, and the bigger r is; S and F are

influenced by the extent of the government's regulation and punishment, The stricter the government is, the heavier the punishment is, and the bigger S and F are.

In view of the current technological level, the reputation mechanism of the market, the regulatory system of the government and the cost constitution of China's coal-mining enterprises, the lower the technological level is, the higher the safety investment is. Thus, the value of $\gamma_1 a_1 u^c$ is not big. If there is not a sound regulatory system for the government to supervise the safety investment behavior of the coal-mining enterprises, supervision forces will not be strong, the market will be more inclusive, the economic and reputation losses will be very low for those enterprises. As a result, rSF will be not big. Therefore, it can be found that $(rSF + \gamma_1 a_1 u^c)$ in Eq.(8) can be neglected compared with $(z_1 a + b_1 a_1 - \frac{1}{2} c_1 a_1^2)$, and $u_1(a_1,0) - u_1(0,0) < 0$. In the strategies of (0, 0) and (a_1, 0), Enterprise 1 chooses not to make safety investment. It depends on the improvement of the future technological level, the soundness of the reputation mechanism and the supervision system, and the profit increase for Enterprise 1 to decide whether to invest or not.

In Eq. (9), there will be $b_1 a_1 - \frac{1}{2} c_1 a_1^2 < 0$ and $w_1 a_1 a_2 - z_2 a_2 = (w_1 a_1 - z_2) a_2$. Generally, for Enterprise 1, (0, a_2) is better than (a_1, a_2) in improving competition conditions if the utility changes with the change of competition conditions. Compared with the influential value brought to the whole utilities of Enterprise 1 because Enterprise 1 does not make safety investment but its competitors do, the influential value will be bigger under the condition that both Enterprise 1 and its competitor, Enterprise 2, make safety investment, $w_1 a_1 a_2 - z_2 a_2 < 0$, and $(rSF + \gamma_1 a_1 u^c)$ will be small and can be neglected compared with $z_1 a_1$ and $w_1 a_1 a_2 - z_2 a_2$. So, $u_1(a_1, a_2) - u_1(0, a_2) < 0$. Between the strategies (0, a_2) and (a_1, a_2), Enterprise 1 chooses not to invest in safety facilities. This also depends on the improvement of the future technological level, the soundness of reputation mechanism and the supervision system, and the profit increase for Enterprise 1 to decide whether to invest or not.

According to the above analysis of Eq. (8) and (9), Enterprise 1 would believe that there is little utility in the short term to make safety investment and won't have much punishment from the government under the condition that technological level is low, supervision is not strong and profits are increased while the cost of safety investment is high in China. It would also hold that it may not be necessary to make safety investment. As a result, it will wait and see until the future technological level is improved, the reputation mechanism and the supervision system are sound and profits are increased. So, under such macro-situation, such game will be repeated for Enterprise 1, which finally results in unwillingness of safety investment and falls into a continuous cycle, leadsing to frequent accidents.

Similarly, this holds true for Enterprise 2 and the results will be the same. If we examine Figure 6 closely, it is likely that the situation of the coal-mining industry makes the combination of the parameters in Zone Ⅸ. Enterprise 1 and 2 will choose the combination, (0, 0), and the result is that both enterprises will not make any safety investment.

5. CONCLUSION AND SUGGESTIONS

5.1 Conclusion and Discusion

In accordance with the above assumptions and analysis process, under some safety regulations and mechanism for coal-mining safety investment, in the gaming process of coal-mining safety investment in China, the enterprises, based on its utilities and according to the gaming results, will choose the dominant strategy of not investing in production safety whatever the choices of other enterprises, which will eventually lead to a “Nash equilibrium”. That is, every enterprise has its own dominant strategy to reach the balance between profits and safety investment and will not invest in production safety. Under the existing assumptions, for all the enterprises, among all the optimal strategies of combination, there is not any individual enterprise intending to choose other strategies. Yet no initiative has been found to break this balance. Actually, the phenomena are popular in other mine industry, so, it is significant to reveal the inside reasons.

However, if the institutional arrangement or balance is changed, such as reducing the costs of safety investment, including safety equipment and personnel training, the balance is no longer a Nash Equilibrium. That is, it is not an optimal combination strategy of all participants, which will

not be able to persist to make it possible that the enterprises begin to choose safety investment, to realize the purpose of reducing safety accidents by increasing the safety investment. This kind of institutional arrangement may come from the government which changes enterprise operation rules, maybe from the society in which consumers will choose not to buy coal from the coal-mining enterprises with high safety accidents, or from the enterprise itself for better vision and image, which will change the utility function of the enterprise to form a new equilibrium in the games. Therefore, the outside incentive and pressure, a better institutional arrangement, could be a better approach to change the utility functions of mining enterprises and form a reasonable "Nash Equilibrium", which will reduce the costs of safety investment so as to increase the profits brought from the investment.

5.2 Suggestions

The reasons why mining enterprises do not choose to invest in safety can be explained by several factors: low technological level, high cost and weak administration, among which the shortage of safety investment and inadequate attention paid to it might be two main factors. Weak administration and pursuit of maximum profits are also important factors that result in unwillingness to make safety investment. In order to break the above-analyzed "balance" and build a new "equilibrium" that makes it possible for enterprises to choose safety investment, some suggestions are put forward here as follows:

(1) The government needs to quicken the steps of introducing internationally advanced safety technology and increase the R & D investment on safety technology so as to improve the technological level of production safety in China.

(2) The fund channel of safety investment should be confirmed, including government allowance and requisite funds for production safety in the enterprises. What's more, enterprises should also be confirmed, and active investment mechanism, risk avoidance and safety system of risk fee mortgage should be set up.

(3) To solve the problems of the shortage of safety investment funds, the government should develop flexible policies, such as adjusting fiscal policy and taxation policy timely, and increase safety investment subsidy to assist enterprises to increase safety investment.

(4) It is necessary to make reasonable accounting framework of mining cost to ensure a virtuous circle of regular fund for safety investment and to invest direct funds in theoretical research in the field of safety investment.

(5) Production safety administration and supervision should be strengthened. In the tide of the market economy, some local governments and enterprises' thought of maximizing benefits leads to shortage of safety investment and weak administration and supervision. In pursuit of GDP growth and political achievements, some local governments do cooperative games illegally and unreasonably at the expense of the interests of the third parties, which results in corruption occurs, finally leading to the serious safety problems which cannot be reversed. All of these should be prevented and "safety economy" should be set up. That is, the more developed the a society is, the more importance is attached to safety production.

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Figures

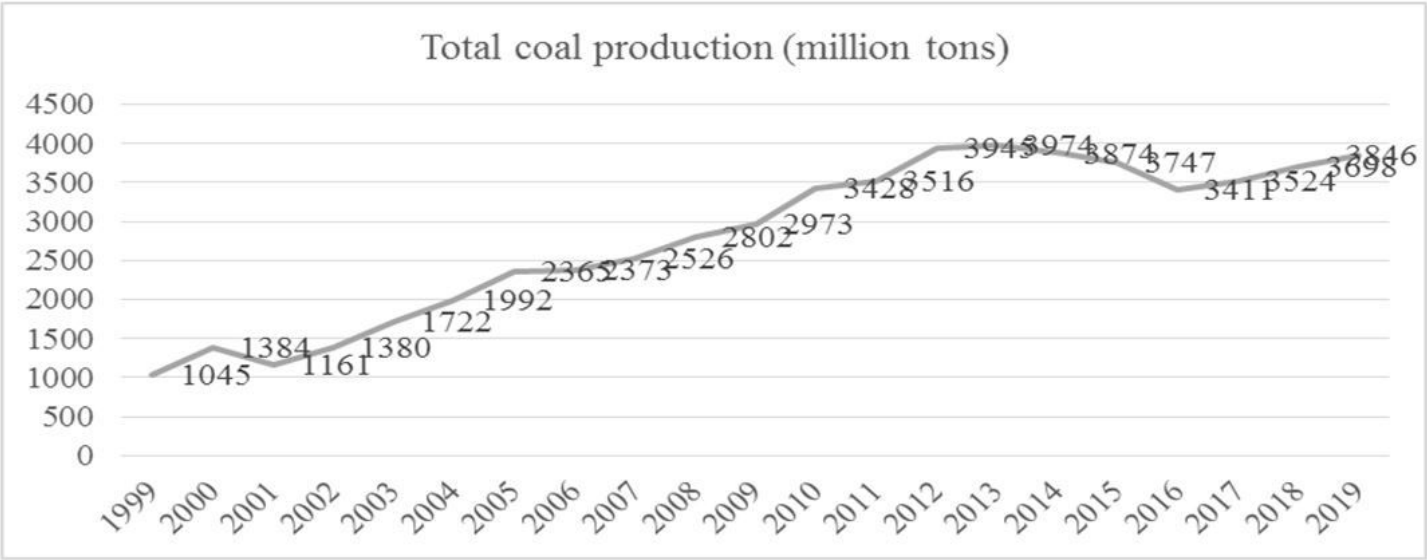

Figure 1

total coal production in China from 1999 to 2019

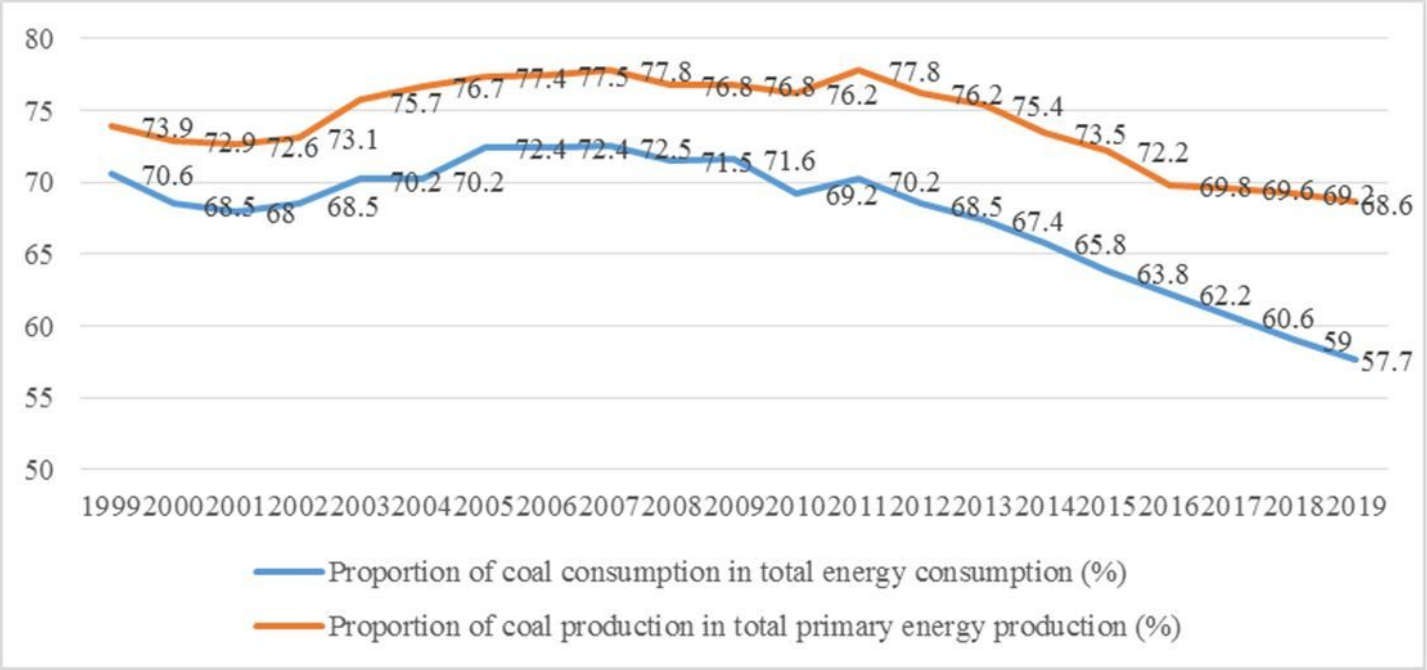

Figure 2

Percentage of coal comsuption and production in China from 1999 to 2019

		Enterprise 2	
		0	a_2
Enterprise 1	0	$u_1(0,0)$, $u_2(0,0)$	$u_1(0,a_2)$, $u_2(0,a_2)$
	a_1	$u_1(a_1,0)$, $u_2(a_1,0)$	$u_1(a_1,a_2)$, $u_2(a_1,a_2)$

Figure 3

The Game Utility Matrix of Enterprise 1 and 2

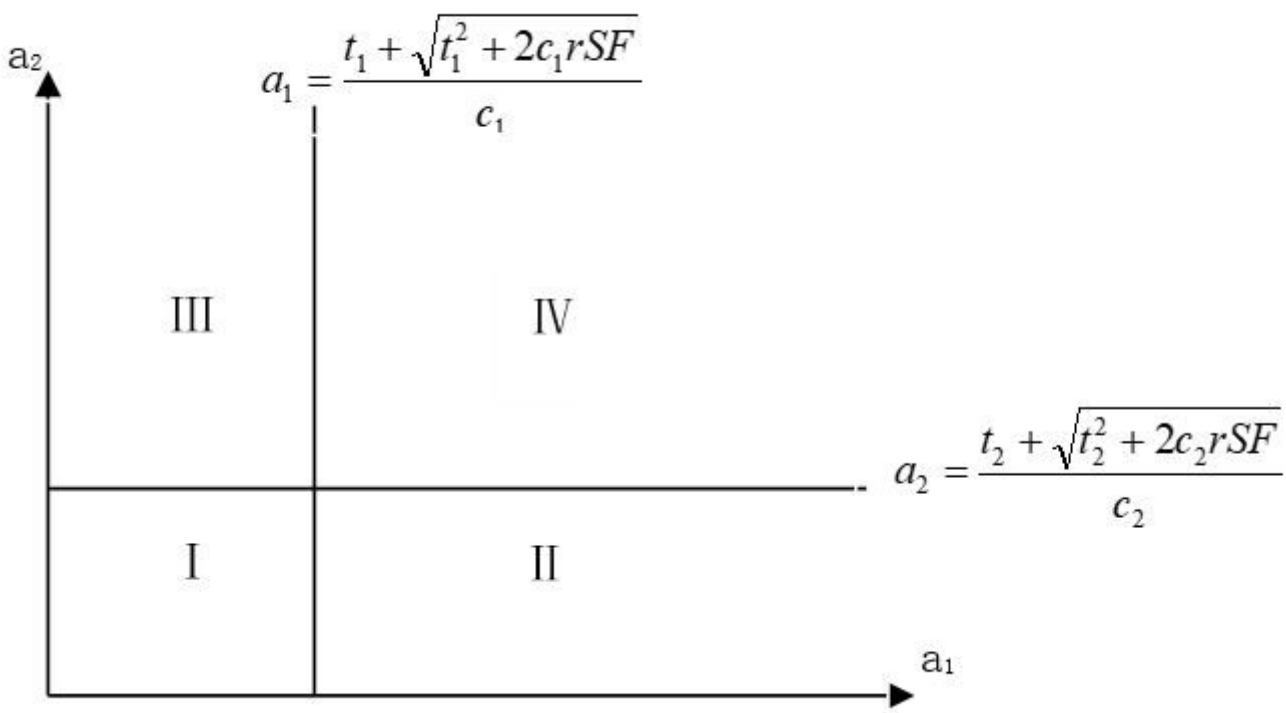

Figure 4

The Game Zone of Type 1

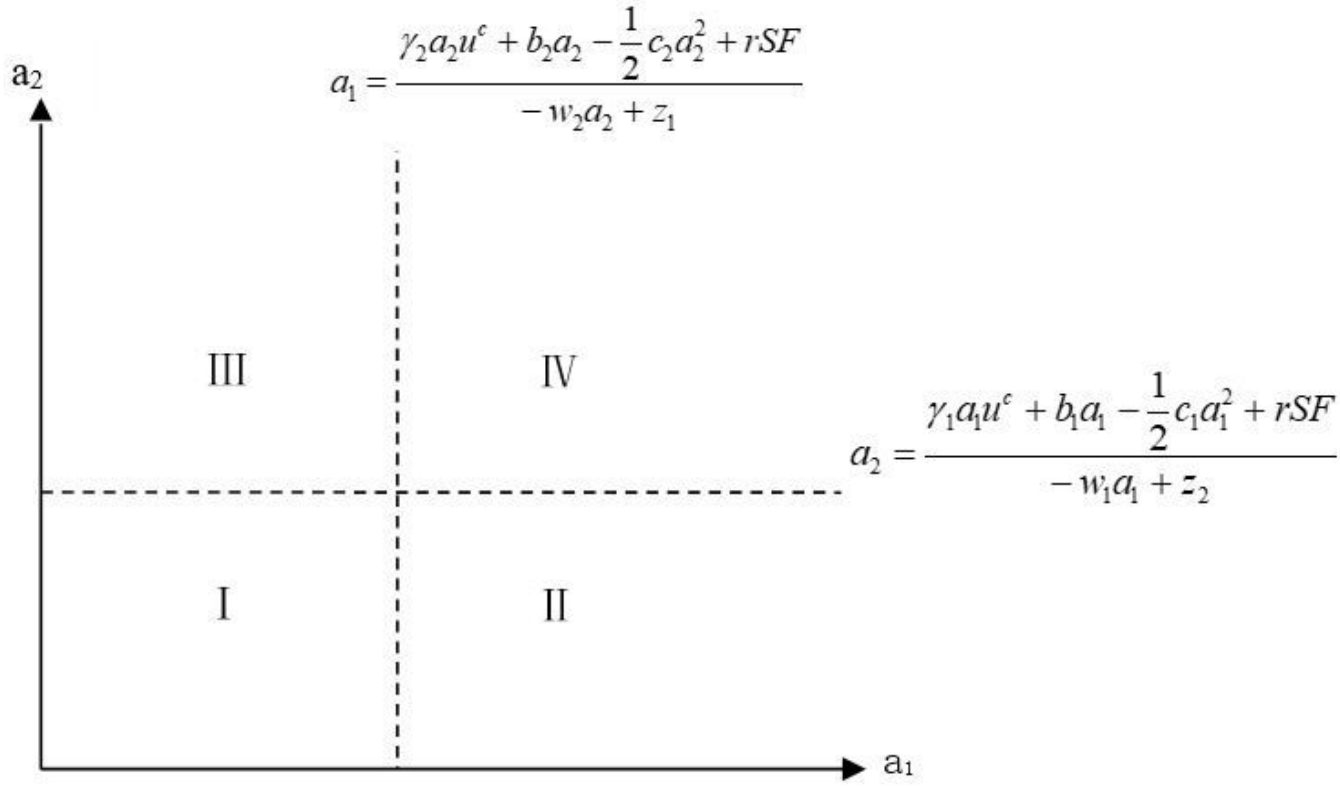

Figure 5

The Game Zone of Type 2

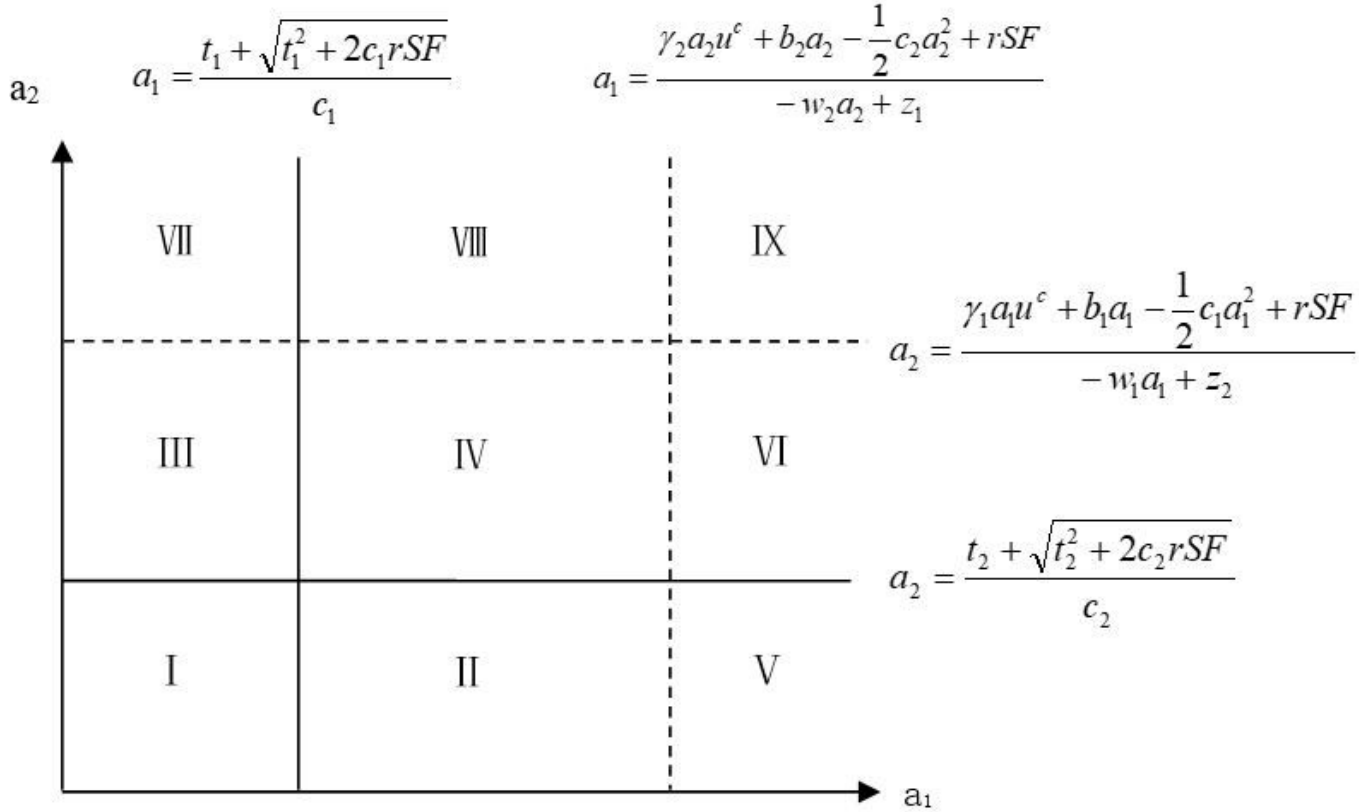

Figure 6

Comprehensive Game Zone