Correlation of oilfield service companies' R&D investment on the basis of competitive speculation

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Abstract: When an oligopoly company decides how much should be invested in its R&D, in order to reap the largest profits, it considers not only what its competitors have done but also how its competitors would respond to its action. Therefore, different relationships between oligopoly companies will lead to different responses in their decisions on R&D investment. A correlation deduced from different responses of oligopoly companies in R&D investment with the complete information tactic game theory is presented, and the R&D investment of oilfield service companies was analyzed with this correlation. The correlations of Schlumberger's R&D investment, Halliburton's R&D investment and Baker Hughes' R&D investment were established and analyzed. Meanwhile, two regression models were presented. One was composed of Schlumberger's R&D investment in the previous year and Halliburton's R&D investment. The other was composed of Schlumberger's R&D investment and Baker Hughes' R&D investment in the same year. The accuracy of these two models was proved to be good.

Key words: Oilfield service companies, R&D investment, game theory, correlation analysis

1 Principle and model for determining R&D investment

1.1 The analysis method

Scholars always use game theory to analyze the R&D investment of oligopoly companies, for example, Kamien and Schwartz (1975) analyzed the allocation of innovation resources under competition with the static game model of complete information; Dasgupta and Stiglitz (1980) used the same method to study patent race; Fudenberg et al (1983) did further research in the patent race and introduced the ε -preemption and took the lag of information into consideration, by using the static game model of complete information and the dynamic game model of incomplete information; Luo and Zheng (2001) analyzed the motivation of oligopoly companies in R&D investment at a situation of patent race; Huo (2002) established profit functions in three rivalry cases; Zhang and Shi (2006) proved that dynamic game was a rational conduct of the R&D investors and analyzed the change of their R&D investment with the change of the industry. This paper analyzed the correlation of the R&D investment between oligopoly companies using the static game model of complete information.

1.2 Analysis model

Proposition: The relationship between two oligopoly companies decides the correlation of their R&D investment. Specifically, when two companies compete severely in the market, the correlation of their R&D is positive. If two companies compete but not so fiercely, the correlation is negative.

Supposition:

1) Two companies in duopoly market do R&D simultaneously and their probability of success is P_1 and P_2 respectively. And, P_1 and P_2 are the positive function of R&D investment as follows:

$$P_1 = 1 - e^{-k_1 r_1}, P_2 = 1 - e^{-k_2 r_2}$$

where, k_1 and k_2 are positive constants; r_1 and r_2 are the R&D investments of the two companies.

2) The two companies all know the distribution of the success probability and they simultaneously make decision in R&D investment.

3) Their correlation in R&D is uncertain.

4) Their marginal cost of capital is mcf_A and mcf_B respectively.

5) If both of them succeed, they both get profit π ; if one of them succeeds and the other loses, the winner gets profit π_1 and the loser gets profit π_2 ; if both of them lose, they get profit π_0 . Obviously,

$$\pi_2 < \pi_0 < \pi_1, \pi_2 < \pi$$

6) Profit π and π_k ($k=0, 1, 2$) are not the function of R&D investment.

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Table 1 Duopoly profit matrix

Companies	Profits at different probabilities			
	$P_1 \times P_2$	$P_1 \times (1-P_2)$	$(1-P_1) \times P_2$	$(1-P_1) \times (1-P_2)$
Company A	π	π	π_2	π_0
Company B	π	π_2	π_1	π_0

From Table 1, the expected profits of the two companies are as follows: (DeGroot and Schervish, 2007)

$$E\Pi_A = P_1 P_2 \pi + P_1 (1 - P_2) \pi_1 + (1 - P_1) P_2 \pi_2 + (1 - P_1) (1 - P_2) \pi_0 \quad (1)$$

$$E\Pi_B = P_1 P_2 \pi + P_1 (1 - P_2) \pi_2 + (1 - P_1) P_2 \pi_1 + (1 - P_1) (1 - P_2) \pi_0 \quad (2)$$

Then, the first-order partial derivative of r_1 and r_2 can be obtained as follows:

$$\frac{\partial E\Pi_A}{\partial r_1} = -k_1 e^{-k_1 r_1} [P_2 (\pi - \pi_2) + (1 - P_2) (\pi_1 - \pi_0)] \quad (3)$$

$$\frac{\partial E\Pi_B}{\partial r_2} = -k_2 e^{-k_2 r_2} [P_1 (\pi - \pi_2) + (1 - P_1) (\pi_1 - \pi_0)] \quad (4)$$

In Equations (3) and (4), $\frac{\partial E\Pi_A}{\partial r_1}$, $\frac{\partial E\Pi_B}{\partial r_2}$ are both positive, indicating that the expected profits of the two companies will increase with the growth of R&D investment.

Then, we can get the second-order partial derivative from Equations (3) and (4):

$$r_1 = \frac{1}{k_1} \left\{ \ln k_1 - \ln mcf_A + \ln[(1 - e^{-k_2 r_2})(\pi - \pi_2) + e^{-k_2 r_2}(\pi_1 - \pi_0)] \right\} \quad (8)$$

$$r_2 = \frac{1}{k_2} \left\{ \ln k_2 - \ln mcf_B + \ln[(1 - e^{-k_1 r_1})(\pi - \pi_2) + e^{-k_1 r_1}(\pi_1 - \pi_0)] \right\} \quad (9)$$

Then, the first-order derivative of equations (8) and (9) is obtained as follows:

$$\frac{dr_1}{dr_2} = \frac{k_2 e^{-k_2 r_2}}{k_1} \times \frac{(\pi - \pi_2) - (\pi_1 - \pi_0)}{(1 - e^{-k_2 r_2})(\pi - \pi_2) + e^{-k_2 r_2}(\pi_1 - \pi_0)} \quad (10)$$

$$\frac{dr_2}{dr_1} = \frac{k_1 e^{-k_1 r_1}}{k_2} \times \frac{(\pi - \pi_2) - (\pi_1 - \pi_0)}{(1 - e^{-k_1 r_1})(\pi - \pi_2) + e^{-k_1 r_1}(\pi_1 - \pi_0)} \quad (11)$$

$$\frac{\partial^2 E\Pi_A}{\partial r_1^2} = -k_1^2 e^{-k_1 r_1} [P_2 (\pi - \pi_2) + (1 - P_2) (\pi_1 - \pi_0)] \quad (5)$$

$$\frac{\partial^2 E\Pi_B}{\partial r_2^2} = -k_2^2 e^{-k_2 r_2} [P_1 (\pi - \pi_2) + (1 - P_1) (\pi_1 - \pi_0)] \quad (6)$$

In Equations (5) and (6), $\frac{\partial^2 E\Pi_A}{\partial r_1^2}$ and $\frac{\partial^2 E\Pi_B}{\partial r_2^2}$ are both negative, which is in accordance with the results of other scholars, that is, the marginal profit of R&D investment would be decreasing.

According to Grabowski and Baxter (1973), the optimal R&D investment of these two companies should meet such marginal conditions as follows:

$$\frac{\partial E\Pi_A}{\partial r_1} = mcf_A; \quad \frac{\partial E\Pi_B}{\partial r_2} = mcf_B \quad (7)$$

That is, the marginal profit of the R&D investment of these two companies should be equal to their marginal cost of capital.

Substituting Equations (3) and (4) into Equation (7) gives the response function of R&D investment as follows:

From Equations (10) and (11), it could be seen that $\frac{dr_1}{dr_2}$

and $\frac{dr_2}{dr_1}$ are of the same sign, all depending on the sign of

the equation $(\pi - \pi_2) - (\pi_1 - \pi_0)$.

$$(\pi - \pi_2) - (\pi_1 - \pi_0) = (\pi_0 - \pi_2) - (\pi_1 - \pi) \quad (12)$$

$(\pi_0 - \pi_2)$ is the loss of the loser.

$(\pi_1 - \pi)$ is the difference of the profits between one winner taking all and the two winners sharing the same market.

If, $\Delta\pi_2 = \pi_0 - \pi_2$,

Then

$$(\pi_0 - \pi_2) - (\pi_1 - \pi) = \Delta\pi_2 - (\pi_1 - \pi) \quad (13)$$

When $\Delta\pi_2 - (\pi_1 - \pi) > 0$, $\frac{dr_1}{dr_2}$ and $\frac{dr_2}{dr_1}$ are positive, which

means that the correlation of the R&D investment of the two companies is positive. There are two cases.

Firstly, $\Delta\pi_2 > (\pi_1 - \pi) > 0$. When $(\pi_1 - \pi) > 0$ or $\pi_1 > \pi$, that is, the profit of the R&D winner in the case of only one winner is larger than that in the case of two winners sharing the market, which means that the R&D of these two companies are equivalent or substitutive. And, the equation, $\Delta\pi_2 > (\pi_1 - \pi)$, means that the loss of the R&D loser is larger than the profit difference. In the case of $\Delta\pi_2 > (\pi_1 - \pi) > 0$, the two companies do the same or much similar R&D and the loss of the loser is larger than the profit difference between the case of only one winner and the case of two winners sharing the market. In such case, the correlation of the R&D investment of competitors is positive.

Secondly, $\Delta\pi_2 > 0 > (\pi_1 - \pi)$ and $(\pi_1 - \pi) > 0$. When $(\pi_1 - \pi) > 0$ or $\pi_1 < \pi$, that is, the profit of R&D winner in the case of only one winner is smaller than that in the case of two winners, which means that the R&D of these two companies are complementary to some extent. Meanwhile, $\Delta\pi_2$ is always positive. In this case, $(\pi_1 - \pi) < 0$, the R&D of the two companies are complementary, and the correlation of the R&D investment of the two companies is also positive, which is in accordance with the innovation cluster theory (Ning, 2005).

When $\Delta\pi_2 - (\pi_1 - \pi) < 0$ or $\Delta\pi_2 < (\pi_1 - \pi)$, the correlation of the R&D investment of the two companies is negative. As $\Delta\pi_2$ is always positive, $(\pi_1 - \pi)$ is also positive, which means that the two companies compete in their R&D. However, $\Delta\pi_2 < (\pi_1 - \pi)$, means that the loss of the R&D loser is not so large as the profit difference between the case of only one winner and the case of two winners sharing the market. Therefore, when the two companies compete in R&D but their competition is not so fierce that the loss of the loser is smaller than the profit difference between the case of only one winner and the case of two winners sharing the market, the correlation of the R&D investment of the two companies will be negative.

2 Market structure of oil-field service companies

In the 1980s, the world oil-field service market was mainly occupied by three giant companies, i.e. Schlumberger, Halliburton and Baker Hughes. They all have their own core fields. Schlumberger's strong points lie in well logging, geophysical exploration and drilling-production technology. Halliburton's strong points lie in well logging, drilling-production technology and engineering construction. Baker

Hughes' strong points lie in well logging, geophysical exploration, drilling tools and drill bits.

The present world market structure of oil-field service is as follows:

2.1 Geophysical exploration

Geophysical exploration is a high-technology task. Only a few companies worldwide have the capacity of doing research work, manufacturing apparatus and providing technology services for oil-field companies. Presently, the geophysical exploration market is mainly shared by three companies, namely, Western Geophysical owned by Baker Hughes, Geco-Prakla owned by Schlumberger, and Compagnie Générale de Géophysique (CGG), with more than 75% market share of geophysical exploration of the world. The services provided by Prakla and CGG are numerous, from seismic data acquisition and processing and interpretation to research and manufacture of apparatus for geophysical exploration. Geoquest owned by Schlumberger and Landmark owned by Halliburton have great power in the software market of geophysical exploration (Wang, 2001).

2.2 Well-logging

In the 1980s, the well-logging market worldwide was mainly shared by three companies, i.e. Schlumberger, Atlas and Gearhart, with a total market share more than 85%. Thereafter, Atlas was annexed by Baker Hughes and Gearhart annexed by Halliburton (Wang and Zhou, 2002). Now, 90% market share of well-logging market was occupied by these three companies, i.e. Schlumberger, Baker Hughes and Halliburton, of which, Schlumberger shares 60%-70%, Baker Hughes 13%-15%, Halliburton 13%-14% (Yang, 2004). The three companies all provide services in well-logging, data processing and interpretation, and in research and manufacture of equipment.

2.3 Oil-drilling

The oil-drilling market is full of a large number of small drilling contractors, drilling technology service companies, drilling equipment and tool manufacturers, drilling mud companies. Most of them own 1-2 drilling rigs and only about ten firms have more than 100 drilling rigs. In the field of drilling technology, Anadrill owned by Schlumberger, Sperry-Sun owned by Halliburton, Drillex owned by Baker Hughes, and Smith Co. have great power in technology innovation. In the manufacture of drilling rigs and drilling equipment, Baker Hughes and Valco are two large companies. The roller cone bits and diamond bits manufactured by Baker Hughes play a leading role in the world. Baroid owned by Halliburton, M-I and Anchor are engaged in producing drilling muds.

2.4 Oil-production service

In this market, Schlumberger, Halliburton, Baker Hughes and Dresser occupy 80%-90% market shares and provide such technique services as well completion, work-over, fracturing, plugging and sand control.

3 Analysis of the correlation of oil-field service companies' R&D investment

3.1 Correlation coefficient of oil-field service companies' R&D investment

According to the above analysis of oil-field service market structure, it is clear that this market is highly monopolized by oligopoly. Three giant companies, i.e. Schlumberger, Halliburton and Baker Hughes, control about 90% market shares and their competition mainly focus on their technical service, with low cost and less time for oil companies.

Among these three oil-field service companies, the R&D intensity of Schlumberger is the highest and more than the sum of the other companies' R&D intensity (Fig. 1). Besides, Schlumberger has research centers mostly engaged in basic research. Therefore, Schlumberger plays the leading role in R&D investment. Hence, the correlation coefficients of R&D intensities of Halliburton and Baker Hughes versus Schlumberger in the same year and in the previous year were calculated in this paper, according to the data from Baker Hughes Annual Reports(1997-2003), Halliburton Annual Reports(2000-2004) and Schlumberger Annual Reports (1997-2004).

Fig. 1 R&D intensity of three companies

The correlation coefficient of Halliburton's R&D intensity versus Schlumberger's in the same year is 67.9% (Fig. 5), not reaching significance level. Whereas, the correlation coefficient of Baker Hughes' R&D intensity versus Schlumberger's in the same year is -74.94%, reaching significance level (Fig. 2).

The correlation coefficient of Halliburton's R&D intensity versus Schlumberger's one-year-lagged R&D intensity is 90.34% (Fig. 4), reaching significance level. The correlation coefficient of Baker Hughes' R&D intensity and Schlumberger's one-year-lagged R&D intensity is -38.98%, not reaching significance level (Fig. 3).

Fig. 2 R&D intensities of Baker Hughes and Schlumberger in the same year

Fig. 3 R&D intensities of Baker Hughes and R&D intensity of Schlumberger in the previous year

3.2 Analysis of correlation coefficients

From Fig. 2 and Fig. 4, it could be seen that the responses of Halliburton and Baker Hughes to Schlumberger' R&D investment were different in this period of time.

The correlation between the R&D intensity of Halliburton and that of Schlumberger was positive, which means that if Schlumberger increased its R&D investment Halliburton would do the same. Besides, when Halliburton decided its R&D intensity, it would take Schlumberger's R&D intensity of last year into consideration. Whereas the correlation between the R&D intensity of Baker Hughes and that of Schlumberger was negative, which means if Schlumberger increased its R&D investment, Baker Hughes would reduce its R&D investment. And Baker Hughes decided its R&D intensity according to Schlumberger's R&D intensity in the same year. Such phenomena could be explained with the theory above. That is, when two companies compete fiercely or are substitutive in the market, correlation of their R&D investment will be positive. While when two companies

Fig. 4 R&D intensity of Halliburton and R&D intensity of Schlumberger in the previous year

Fig. 5 R&D intensities of Halliburton and Schlumberger in the same year

compete in R&D but the loss of the loser is smaller than the profit difference between the case of only one winner and the case of two winners sharing the market, the correlation will be negative.

Particularly, although three oil-field service companies compete with each other fiercely, they have different correlations among them.

Firstly, Schlumberger and Halliburton are very similar, not only in their business scale but in their business fields. The R&D of the two companies is highly substitutive and influences their market shares greatly. Thus, they compete fiercely in R&D and the correlation of their R&D investments is positive.

Secondly, because Schlumberger and Baker Hughes compete in well-logging and geophysical exploration market, their R&D is somewhat substitutive. On the other hand, two companies differ in core competence. Schlumberger started with well-logging which is still one of its core fields up to now. Baker Hughes is the combination of two companies, Baker and Hughes. Baker and Hughes both started with oil

tools. The core fields of Baker Hughes lie in drill bit and oil tools manufacturing (An and Gao, 2005). Therefore, in view of core competence, two companies have different emphasis on R&D and their R&D will not do great harm to each other. More importantly, there is cooperation between Schlumberger and Baker Hughes. The biggest seismic company, WesternGeco, is the joint venture of these two companies. So in such case, furious competition will do harm to both of them and the correlation of their R&D investment is negative.

Since the correlation coefficients of the three companies' R&D intensity are very significant, we established two univariant linear regression models, with Schlumberger's R&D intensity as independent variable. One model is as follows:

$$R_H = -0.0068 + 0.4591R_{S-1} \quad (14)$$

where, R_H represents Halliburton's R&D intensity; R_{S-1} represents Schlumberger's R&D intensity in the previous year.

The t-test statistics, which tests the significance level of the model (Wei, 2001) is as follows:

$$|t| = 4.7100, |t_{0.05,5}| = 2.571, |t_{0.01,5}| = 4.032, |t| > |t_{0.01,5}|$$

The t-test result indicates that the model passes the t-test at the significance level of 1% and 5%, respectively. Therefore, according to the model (13), when Schlumberger's R&D intensity increases by 1% Halliburton's R&D intensity will correspondingly increase by 0.4591% next year.

The other model is as follows:

$$R_B = 0.0655 - 0.80078R_S \quad (15)$$

where, R_B represents Baker Hughes' R&D intensity; R_S represents Schlumberger's R&D intensity in the same year.

The t-test statistics is as follows:

$$|t| = 2.77200, |t_{0.05,6}| = 2.447, |t| > |t_{0.05,6}|$$

The t-test result indicates that the model passes the t-test at the significance level of 5% and when Schlumberger's R&D investment increases by 1% Baker Hughes' R&D investment will correspondingly increase by 0.80078% in the same year.

4 Conclusion

Different relations among oligopoly companies would lead to different correlations in their R&D investment. The authors presented a correlation which was deduced from different responses of oligopoly companies on R&D investment with the complete information tactic game theory. That is, when two oligopoly companies do the same or much similar R&D and the loss of the loser is larger than the profit difference between the case of only one winner and the case of two winners sharing the market, the correlation of their R&D investment will be positive. Otherwise, when the loss of the loser is smaller than the profit difference between

the case of only one winner and the case of two winners sharing the market, the correlation of their R&D investment will be negative. The R&D investment of oilfield service companies was also analyzed with this correlation. In oil field service market, there are three leading companies, Schlumberger, Halliburton and Baker Hughes. According to the analysis of this market, Schlumberger and Halliburton are very similar in their business fields and compete with each other fiercely. However, although Schlumberger and Baker Hughes also compete with each other, their competition is not very serious and both of them have quite different core competence. Thus, the correlations of Schlumberger's R&D investment, Halliburton's R&D investment and Baker Hughes' R&D investment should be different. The correlation of Schlumberger's R&D investment lagged one year and Halliburton's R&D investment was positive from 1998-2004 and the correlation of Schlumberger's R&D investment and Baker Hughes' R&D investment in the same year was negative from 1996-2003.

Additionally, the relation between companies will change with time, which will lead to the change in the correlation of their R&D investment. When two oligopoly companies that had once competed only slightly with each other became fierce competitors, the correlation of their R&D investment would become positive.

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