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The competitive advantages analysis of pharmaceutical industry strategic behaviors by game theory

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Abstract

Game theory is the study of mathematical models and cooperation between intelligent rational decision-makers. This paper provides a flexible model to calculate pay-off matrix based on several importance factors. This model is adapted by cooperative game and developed for some competitive advantages sections in pharmaceutical industry. An optimum solution is derived by considering Nash equilibrium method for each section. Cooperative game extended for three players in a common market. Each player is looking for increase its market share with respect to participation of other competitors. Due to factors like capability of players to perform their strategic behaviors, market share adjustment by face to face comparison, the ability of any player in defined section and the importance of competitive advantage for players is basis of the calculation. A random example has been generated that the result of which led to achieve equilibrium market share for three players.

Keywords: Competitive advantages, strategic behaviors, Nash equilibrium, cooperative game.

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1. Introduction

Game theory is the theory of independent and interdependent decision making. It is concerned with decision making in organizations where the outcome depends on the decisions of two or more autonomous players, one of which may be nature itself, and where no single decision

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maker has full control over the outcomes. Obviously, games like chess and bridge fall within the ambit of game theory, but so do many other social situations which are not commonly regarded as games in the everyday sense of the word (Kelly, 2003). The theory is concerned with optimal strategic behavior, equilibrium situations, stable outcomes, bargaining, coalition formation, equitable allocations and similar concepts related to resolving group differences. The prevalence of competition in many human activities has made game theory a fundamental modeling approach in such diversified areas as economics, political science, operations research and military planning (Lemaire, 1991). Based on the game theory framework, in many circumstances, players face a dilemma of seeking personal gain or cooperating to achieve mutual benefit (Rashedi and Kebriaei, 2014). In models based on cooperative theory, all players will coordinate to achieve an optimum or mutually desirable decision. In the literature several methods have been proposed to calculate pay-off matrix that also have access to desirable results but in these researches pay-off matrix is not obtained by a mathematical model. In this paper, the model provided based on relations among efficient factors like effectiveness and market share adjustment. This model will be applied for many other cooperative situations like business, industrial, marketing and etc. This paper constructed as follows: literature briefly reviewed in section 2, methodology defined in section 3, and an example is provided in section 4, finally in section 5 conclusions are drawn.

2. Literature review

Game theory was conceived in the seventeenth century by mathematicians attempting to solve the gambling problems of the idle French nobility, evidenced for example by the correspondence of Pascal and Fermat concerning the amusement of an aristocrat called de Mere. In these early days, largely as a result of its origins in parlour games such as chess, game theory was preoccupied with two-person zero-sum interactions. This rendered it less than useful as an application to fields like economics and politics, and the earliest record of such use is the 1881 work of Francis Edgeworth, rediscovered in 1959 by Martin Shubik (Kelly, 2003). Now many researches have done about game theory applications in different fields like industries, mathematics, business and etc. we providing a brief literature of recent studies that applied in this research. Von Stengel (2010) have studied Follower pay-off for symmetric duopoly games. Deb and Kalai (2015) have studied a class of Bayesian games in which the type and action spaces are infinite and players are not anonymous. Xiaofeng and Aiqing (2012) have prepared a construction of Shapley value for cooperative game and also provided its applications with a case study and analyzed the construction of Shapley Value based on which the rent and the efficiency of enterprise alliance are discussed. In addition Yu et al. (2012) have studied an application of computer aided game theory to automated assembly. Facing conflicts in construction managing problems due to the different involved decision makers are unavoidable. And so, analyzing this kind of problems is so different compare to the single decision maker ones, however Barough et al. (2012) have provided an application of game theory for solving the construction project conflicts. In multi-objectives optimization design a poor-competition-rich-cooperation (PCRC) evolutionary game method have provided by Biyan and Meng (2011).

Also Marianthi et al. (2015) have researched an application of game theory in irrigation systems. Yongshi et al. (2011) have discussed about the effective approach of constructing multi-interests balanced mechanism under the new nested relationship of decision-making on large public engineering projects. Jorgensen and Zaccour (2014) have researched the literature on cooperative advertising in marketing channels (supply chains) using game theoretic methods. As well Rashidi and Kebriaei (2014) have studied non-cooperative Nash equilibrium strategy and cooperative Nash bargaining solution were utilized to study the competitive and collusive behavior of suppliers in an oligopolistic market based on linear supply function equilibrium game model. The constant and price sensitive demand conditions are analyzed in both competitive and cooperative games. The Nash equilibrium point of the non-cooperative SFE game was achieved analytically. Two-person zero sum game approach for fuzzy multiple attribute decision making problems have provided by Chen and Larbani (2006), also Xu et al. (2015) have incorporated the effects of punishment into the N-person evolutionary snowdrift game and studied the effects in a well-mixed population. Tao et al. (2015) have researched a group decision making with fuzzy linguistic preference relations via cooperative games method. Kishimoto (2013) provided a stable bargaining outcomes with a cooperative approach without side payments. Alvarez-Mozos et al. (2013) have studied share functions for cooperative games levels structure of cooperation. In the literature several methods have been proposed to calculate pay-off matrix that also have access to desirable results but in these researches pay-off matrix is not obtained by a mathematical model.

3. Methodology

3.1 model importance

Several studies have been done in game theory that have been similar methods to achieve pay-off matrix based on expert's comments. In other words, pay-off matrix directly derived with methods like brain storming and Delphi method. Although these methods access to desirable results but relations among effective factors not considered and in fact, there is not a defined framework to derive pay-offs. In this paper, the model provided based on efficient factors like effectiveness and market share adjustment. This model will be applied for different cooperative situations like economic, industries, supply chain, marketing systems.

3.2 Strategic Behaviors

Strategic behavior is the general term for actions taken by firms which are intended to influence the market environment in which they compete. Strategic behavior includes actions to influence rivals to act cooperatively so as to raise joint profits, as well as non-cooperative actions to raise the firm's profits at the expense of rivals (Khemani and Shapiro, 1993). In this paper, most important strategic behaviors detected in pharmaceutical industry.

3.3 Competitive Advantages

Basically, competitive advantages are achieved through the capability of an organization to create value for costumers. Competitive advantages are created through lower costs from competitors or unique services against competitors' products and services, in fact it enables firms to create more economic value. Pharmaceutical industry have many competitive advantages but our emphasis in this paper is on the most effectiveness of them along the most relevant with customers.

3.4 Sections of therapeutic

In general, drugs have the most comprehensive section of health benefits, which are divided into 44 categories. We stress on top five of the most effective sections on mortality in recent years including anti-bacterial, anti-neoplastic, cardio vascular, neurotic and respiratory drugs.

3.5 Market share

The share of an industry or market's total sales that is earned by a particular company over a specified time period. This metric is used to give a general idea of the size of a company to its market and its competitors. Market share is calculated by taking the company's sales over the period and dividing it by the total sales of the industry over the same period.

3.6 Nash equilibrium

In game theory, the Nash equilibrium is a solution concept of a non-cooperative game involving two or more players, in which each player is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing only their own strategy (Osborne and Rubinstein, 1994).

3.6.1 Nash equilibrium method

Follow equation describes Nash equilibrium for static games with complete information:

$$h_i(s_i^*, s_{-i}^*) \geq h_i(s_i, s_{-i}^*) \quad \forall s_i \in S_i \quad \forall i \in N$$

That, h_i shows player "i" and "s_i" shows player i strategy and "s_i^*" shows the best strategy for player i.

In addition based on the best response function, Nash equilibrium is:

$$s_i^* \in Best\ Response(s_{-i}^*) = \{s_i \in S_i: h_i(s_i^*, s_{-i}^*) \geq h_i(s_i, s_{-i}^*) \quad \forall s_i \in S_i \} \qquad (1)$$

3.7 Pay-off model

3.7.1 Model notations

PO: pay-off

i: players (i=1, 2, 3)

k: strategy behavior of players (k=1,2,…r) p: competitive advantage (p=1, 2, …, q)

j: h_1 player strategic behavior (j=1, 2, …, m)

g: h_2 player strategic behavior (g=1, 2, …, n)

c: h_3 player strategic behavior (c=1, 2, …, z)

e_{hik}: the effectiveness of strategic behavior for player h_i (based on percentage of market share)

y_{hik}: h_i player performance in selected strategic behavior (based on percentage of market share)

$m_{h_i k, h_{i'} k}$: h_i player market share adjustment rate if select k^{th} strategy and $h_{i'}$ ($i' \neq i$) player select k^{th} strategy (based on percentage; $-1 < m_{h_i k, h_{i'} k} < 1$)

I_i: the importance of competitive advantage for player h_i in pharmaceutical industry

W_{hip}: h_i player relative ability in p^{th} competitive advantage

$[X_{j,g,c}]$: pay-off value for h_i player when h_1 selected j^{th} strategic behavior, h_2 selected g^{th} strategic behavior and h_3 selected k^{th} strategic behavior.

3.7.2 pay-off values Modeling

By considering cooperation game with three players:

$$x_{h_i k} = e_{h_{ik}} y_{h_i k}(1 + m_{h_i k, h_{i'} k} y_{h_{i'} k} + m_{h_i k, h_{i''} k} y_{h_{i''} k}) \quad (2)$$

$$\forall \begin{cases} i = 1,2,3 \\ k = 1,2,3, \dots, l \\ i \neq i' \neq i'' \end{cases}$$

$$e_{hi} = I_i \times W_{hi,p} \quad (3)$$

Thus

$$x_{h_i k} = (I_i \times W_{hi,p}) \times y_{h_i k} \times (1 + m_{h_i k, h_i k} y_{h_i k} + m_{h_i k, h_{i''} k} y_{h_{i''} k}) \quad (4)$$

4. Numerical Example

Now, we provide a numerical example for model validation. In this simulation consider three players that have static games and complete information about themselves. We consider the most important competitive advantages and focused on one of the most important drugs sections.

Summary of assumptions:

- Consider three players (i=3).
- Number of competitive advantages is four including quality, cost, deliver time, innovation (p=4).
- Among the most effective sections of therapeutic, focused on cardio vascular drugs.

Other data are simulated in following tables.

Table1. h_i player relative ability in p^{th} competitive advantage

p \ h_i	I	II	III
Quality	0.261	0.616	0.106
Cost	0.429	0.143	0.429
Deliver time	0.634	0.106	0.261
Innovation	0.261	0.106	0.634

Data in table 1 show hi player relative ability in p competitive advantage. The numbers are without scale. In other words factor like and deliver time cost is not negative and same to innovation and quality.

Table2. The importance of competitive advantage for player h_i

p \ Drug sections	cardio vascular	anti-neoplastic	anti-bacterial	respiratory	neurotic
Quality	0.365	0.295	0.166	0.273	0.157
Cost	0.172	0.163	0.499	0.410	0.231
Deliver time	0.099	0.303	0.242	0.169	0.073
Innovation	0.365	0.240	0.119	0.096	0.583

The importance of competitive advantage for player hi show in table 2. Note that the larger number shows better answer.

Table3. Strategic behaviors in pharmaceutical industry

strategic behaviors	**code**
ISO9001, ISO14001	(quality-1)
Good manufacturing practice (GMP)	(quality-2)
Health Safety Environment (HSE)	(quality-3)
Maintenance	(cost-1)
Risk Based and reliability Maintenance (RBM, RCM)	(cost-2)

strategic behaviors	code
Reorder point modeling	(delivery time-1)
Supply Chain Maintenance (SCM)	(delivery time-2)
Transport Management	(delivery time-3)
Portfolio planning	(innovation-1)
Generic production	(innovation-2)
Branding	(innovation-3)

Strategic behaviors in pharmaceutical industry show in table 3. Any of strategic behaviors categorized in related competitive advantage.

Table4. h_i player performance in selected strategic behavior

strategic behaviors \ h_i	I	II	III
ISO14001 , ISO9001 (quality-I)	0.70	0.65	0.60
GMP (quality-II)	0.50	0.42	0.30
HSE (quality-III)	0.65	0.54	0.65
Maintenance (cost-I)	0.50	0.50	0.50
RBM , RCM (cost-II)	0.35	0.45	0.22

strategic behaviors \ hi	I	II	III
Reorder point modeling (delivery time-I)	0.65	0.66	0.55
SCM (delivery time-II)	0.53	0.50	0.55
Transport management (delivery time-III)	0.66	0.68	0.71
Portfolio planning (innovation-I)	0.63	0.70	0.50
Generic production (innovation-II)	0.30	0.31	0.18
Branding (innovation-III)	0.35	0.40	0.21

Now in table 4 performance in selected strategic behavior shown for all players.

Table 5.1. hi player market share adjustment rate if select k^{th} strategy and $h_{i'}$ $(i' \neq i)$ player select k^{th} strategy (quality)

Quality		h2		
		I	II	III
h1	I	0.20	0.30	0.30
	II	-0.20	0.20	0.20
	III	-0.30	-0.20	0.20
Quality		h3		
		I	II	III
h1	I	0.20	0.40	0.40
	II	-0.20	0.20	0.20
	III	-0.40	0	0.20
Quality		h3		
		I	II	III
h2	I	0.20	0.30	0.30
	II	-0.20	0	0
	III	-0.30	0	0

Player market share adjustment rate shown in table 5.1. Binary comparison is done between companies. If the number is positive, increasing market share shows and if the number is negative, declining market share shows.

In follow, market share adjustment rate are shown for other competitive advantages.

Table 5.2. hi player market share adjustment rate if select kth strategy and hi̇́ (i̇́ ≠ i) player select kth strategy (cost)

cost		h2	
		I	II
h1	I	0.20	0
	II	0.20	0
cost		h3	
		I	II
h1	I	0.20	0
	II	0.20	0.20
cost		h3	
		I	II
h2	I	0.20	0
	II	0.30	0

Table 5.3. hi player market share adjustment rate if select kth strategy and hi̇́ (i̇́ ≠ i) player select kth strategy (delivery)

Delivery time		h2		
		I	II	III
h1	I	0.20	-0.20	-0.30
	II	0.20	0.20	-0.20
	III	0.30	0.20	0.20
Delivery time		h3		
		I	II	III
h1	I	0.20	0	-0.20
	II	0.30	0.20	0
	III	0.40	0.20	0.20
Delivery time		h3		
		I	II	III
h2	I	0.20	-0.20	-0.20
	II	0.20	0	-0.20
	III	0.30	0.20	0

Table 5.4. hi player market share adjustment rate if select k^th^ strategy and hi΄(i΄≠ i) player select k^th^ strategy (innovation)

innovation		h2		
		I	II	III
h1	I	0	0.30	0.40
	II	-0.20	0	0.20
	III	-0.30	0.20	0
innovation		h3		
		I	II	III
h1	I	0.20	0.40	0.30
	II	-0.20	0.20	0
	III	-0.30	0.20	0
innovation		h3		
		I	II	III
h2	I	0	0.30	0.30
	II	-0.20	0	-0.20
	III	-0.20	0.20	0

Firstly by using of equation (4) values of pay-off matrix are calculated and then by Nash equilibrium method solved.

Table6. Pay-off matrix for quality

quality		**h3 selected I**		
		h2		
		I	II	III
h1	I	**(80,126,20)**	(69,125,17)	**(83,116,20)**
	II	(68,124,19)	(63,102,16)	(68,124,19)
	III	(54,165,23)	(54,130,20)	(70,127,23)
quality		**h3 selected II**		
		h2		
		I	II	III
h1	I	(71,158,15)	(57,113,12)	(71,113,15)
	II	(60,133,9)	(54,110,9)	(60,111,15)
	III	(28,156,15)	(49,113,19)	(64,114,16)
quality		**h3 selected III**		
		h2		
		I	II	III
h1	I	(83,126,18)	(68,123,15)	(83,126,18)
	II	(67,124,17)	(14,100,14)	(67,80,18)
	III	(61,165,18)	(61,128,16)	77,127,18)

Pay-off matrix concluded by using of equation (4); for example

$$x_{h_1 1} = (0.365 \times 0.261) \times 0.7(1 + 0.2 \times 0.65 + 0.2 \times 0.60) = 0.08$$

Consider a coefficient (1000) for simplification of calculation

$$0.08 \times 1000 = 80$$

According to equation (1), there are two Nash equilibrium points in this section, the first point when three players selecting ISO 9001, 14001 strategic behavior and secondly when player 1 and 3 selecting ISO 9001, 14001 strategic behavior and player 2 selecting HSE strategic behavior.

Table7. Pay-off matrix for innovation

innovation		**h3 selected I**		
		h2		
		I	II	III
h1	I	**(67,162,17)**	(62,92,15)	(71,90,15)
	II	(40,147,17)	(34,82,15)	(39,91,15)
	III	(41,151,18)	(34,90,16)	(37,102,16)
innovation		**h3 selected II**		
		h2		
		I	II	III
h1	I	(58,156,9)	(54,81,8)	(63,78,8)
	II	(36,142,8)	(30,72,7)	(34,78,7)
	III	(36,145,9)	(27,79,8)	(32,89,8)
innovation		**h3 selected III**		
		h2		
		I	II	III
h1	I	(60,155,9)	(56,85,7)	(65,81,8)
	II	(33,145,9)	(30,76,7)	(35,81,7)
	III	(38,144,9)	(30,84,7)	(33,93,8)

When three players selecting Portfolio planning is reached the Nash equilibrium point.

Table8. Pay-off matrix for delivery time

Deliver time		**h3 selected I**		
		h2		
		I	II	III
h1	I	(51,17,4)	(41,16,4)	(37,24,4)
	II	(43,17,4)	(43,13,4)	(34,22,4)
	III	(59,16,3)	(50,13,4)	(56,18,3)
Deliver time		**h3 selected II**		
		h2		
		I	II	III
	I	(46,13,7)	(35,20,6)	(32,23,5)
	II	(41,13,6)	(40,12,5)	(32,21,4)
h1	III	(54,12,6)	(50,13,4)	(52,17,4
Deliver time		**h3 selected III**		
		h2		
		I	II	III
h1	I	(42,13,7)	(32,13,7)	(28,21,7)
	II	(38,13,7)	(37,10,6)	(29,19,6)
	III	(54,13,6)	(50,10,6)	**(52,15,5)**

The Nash equilibrium point in this section is reached when three players selecting Transport management strategic behavior.

Table9. Pay-off matrix for cost

cost		**h3 selected I**	
		h2	
		I	II
h1	I	(44,37,10)	**(41,38,9)**
	II	(31,38,10)	(28,38,10)
cost		**h3 selected II**	
		h2	
		I	II
h2	I	(41,33,5)	(40,33,5)
	II	(30,34,5)	(27,33,5)

Finally, when player 1 and 3 selecting maintenance strategic behavior and player 2 selecting RBM, RCM strategic behavior the Nash equilibrium point is reached.

5. Conclusions

In this paper, we analyzed competitive advantages of pharmaceutical industry strategic behaviors with providing a new pay-off model that including the most importance market share factors. We have derived Nash equilibrium for model by a simulated example. The results have shown optimum answer is not the best answer for each player but in a cooperative game with regard to benefit of all players the answers are satisfactory. This methodology will assist managers to reach collectivity with their counterparts and will be developed to other industries. Future researches can modify and develop modeling by considering other importance factors like resources, scheduling, affordability and etc.

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