Pricing Mechanism Design of Supply Chain under Game Theory

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Abstract. Within the framework of game theory, through building model of game theory, this paper starts from the perspective of supply chain's systematic coordination, emphasizes the needs of cooperative partners' coordination and the equilibrium strategy of price, and regards both parties of supply chain enterprises with close interaction, game and coordination relationship. Under the decision-making objective of maximum profit in supply chain system, this paper takes supply chain cost as basis and cooperative relationship as bond, studies the issues of needs and price decision of manufacturers and distributors, and makes reasonable distributions of the profit in supply chain system, to make price-making and capital flow change in coordination with logistics and information flow, so as to elevate the overall operation efficiency of the cooperative partnership of supply and requistioning parties in supply chain, and to reach the goal of rational configuration and optimization of resources in supply chain.

1. Introduction

Rapid development of information technology has greatly accelerated the global economic integration, and the market competition shows the trend of internationalization [1，2]. Traditional "vertical integration" management model cannot adapt to the changes in market as a result of disadvantages in the model. As enterprises need to seek for a new kind of operation and management model-- supply chain management emerges at the right moment. Under this model, cooperation among enterprises has become competition among supply chains [3，4]. To coordinate the relationship among joint enterprises is the critical path to enhance enterprise profit in supply chain. As a theory to study the decision-making at the time of direct interactions among decision-making behaviors and the equilibrium issue at the time of decision-making, game theory has important realistic significance on the choice of studying supply chain strategy.

Within the framework of game theory, through building model of game theory, this paper starts from the perspective of supply chain's systematic coordination, emphasizes the needs of cooperative partners' coordination and the equilibrium strategy of price, and regards both parties of supply chain enterprises with close interaction, game and coordination relationship. Under the decision-making objective of maximum profit in supply chain system, this paper takes supply chain cost as basis and cooperative relationship as bond, studies the issues of needs and price decision of manufacturers and distributors, and makes reasonable distributions of the profit in supply chain system, to make price-making and capital flow change in coordination with logistics and information flow, so as to elevate the overall operation efficiency of the cooperative partnership of supply and requisitioning parties in supply chain, and to reach the goal of rational configuration and optimization of resources in supply chain.

2. Game theory and game equilibrium

2.1 Definition of game thoery

Till now, there is no unanimous conclusion for the definition of game theory. Harsanyi, Nobel Prize Winner in 1994, defines game theory as the theory about strategy interaction. It means that game theory is about rational behaviors in the society, where people's choices on behaviors should be based on the others' reactions. It can be understood this way: it's about making decisions according to every participant's behaviors in the cooperative environment of many people. In this way, 4 factors are included in a game issue, as is shown in Figure 1.

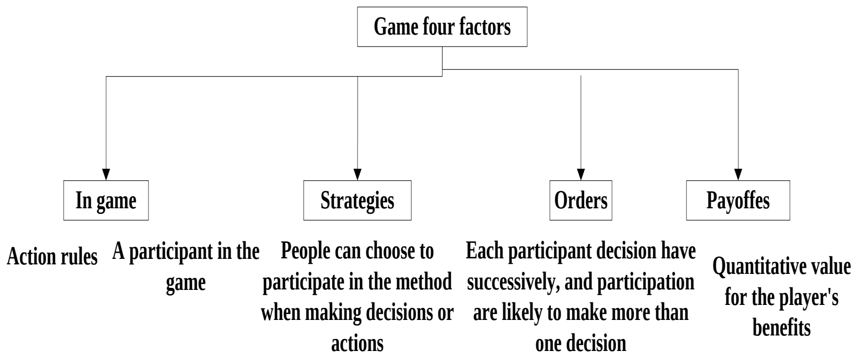

Figure 1: Game four factors

After the game rules are decided, every participant is equal and has to behave strictly according to rules. In the game, different participants have different strategies and contents to choose, several or infinite. The order should be stipulated in a game; if the order is different, the game is different even thought the other aspects are the same. To stipulate a game, payoffs should be decided beforehand, which can be of positive or negative value , and it is the standard and basis to analyze game.

2.2 Game equilibrium

Game theory supposes that participants are rational and wise; among all the strategy space at choice of every participant, this participant is independent, not threatened by other participants in any form. In the typical payment structure, the payoff of a participant is not only related to the strategy he chooses, but also is the function of strategies chosen by other participants. It means that the benefits among people are involved and controlled by each other. Under the presupposition that participants pursue the maximum personal profits, game theory studies the behavioral choice of these rational individuals. The “solution” to a game, the most likely outcome for a game, is “equilibrium”. Game theory includes following contents, as is shown in Figure 2; general equilibrium reflects the relationship of price and supply and demand of all the commodities in the market. Nash equilibrium is composed of optimal strategies of individuals, but it doesn’t mean that it’s the best result for the whole. Under the circumstance where individual rationality and collective rationality are conflicting, the end resulted from pursuing egoism is a nash equilibrium, which maybe unfavorable for all the people. Therefore, basically speaking, nash equilibrium is a kind of non-cooperation game state. Bayesian nash equilibrium is an equilibrium of incomplete information static game, but it can correctly prospect the relationship between the choices of other participants and their related types. Pareto optimal is in this state, and any change cannot make more than one person’s state better or anyone’s state worse. All in all, nash equilibrium is just a kind of equilibrium, not necessarily pareto optimal or perfect end.

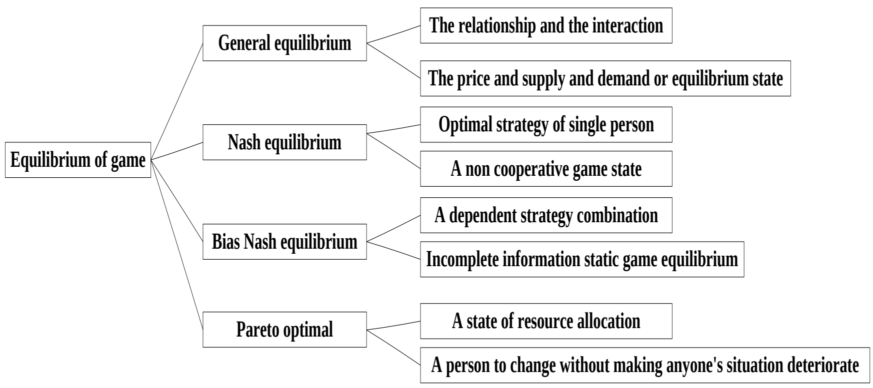

Figure 2: Expression of game equilibrium

3. Construction of supply chain pricing model based on game theory

3.1 Game theory analysis of behavior characteristics of enterprises in supply chain

Suppose the excessive effectiveness (remove cooperation cost) brought by manufacturers and distributors is a and b, and as manufacturers play the leading role, the gained profit is high, which is a>b; the effects brought through gaining the shared information of the opposite party are equal, which are p; the effects produced by the unilateral information published by enterprises on the chain are equal, which is c; x and y stand for the probabilities of distributors and manufacturers to choose cooperation strategies, from which game strategic space and payoff matrix of enterprises in the supply chain can be showed in Table 1:

Table 1: Matrix of game strategy space and payoff in enterprises of supply chain

Strategies		Manufacturers	
		Cooperation （y）	Non-cooperation（1-y）
Distributors	Cooperation （x）	a+p，b+p	-c，p
	Non-cooperation（1-x）	P，c	0，0

For manufacturers, when mixed strategy is adopted, the effects of choosing cooperation strategies and noncooperation strategies are the same:

$$x(b+p)+(1-x)(-c)=xp \qquad (1)$$

For distributors, it is in the same way:

$$y(b+p)+(1-y)(-c)=yp \qquad (2)$$

It can be gained:

$$\begin{cases} x = c/(b+c) \\ y = c/(a+c) \end{cases} \qquad (3)$$

When two enterprises are in a game, manufacturers choose cooperation strategies at the probability of y=c/(a+c), and distributors choose cooperation strategies at the probability of x=c/(b+c), which means that if the probability for manufacturers to choose cooperation strategies is greater than y=c/(a+c), the optimal strategy of distributors is to choose cooperation strategy, whereas to choose noncooperation strategy; if the the probability for distributors to choose cooperation strategies is greater than x=c/(b+c), the optimal strategy is to choose cooperation strategy, whereas to choose nonstrategy. As a>b, x>y, which means the probability for distributors to choose cooperation is relatively high; this is because manufacturers are active in supply chain and distributors have to passively accept cooperation strategy to gain more profit.

For any enterprise, its behavior characteristics are not always the same in supply chain; when the outer conditions change, certain evolution happens.

Suppose the expected benefits for manufacturers to adopt “cooperation” and “noncooperation” are u1 and u2, and their average benefit is u3:

$$u1=x(a+p)+(1-x)(-c) \qquad (4)$$

$$u2=xp+(1-x)0=xp \qquad (5)$$

$$u3=y[x(b+p)+(1-x)(-c)]+(1-y)xp \qquad (6)$$

The replicator dynamic equation of manufacturers is:

$$Dy/dt=u(u1-u3)=y(1-y)[(b+c)x-c] \qquad (7)$$

The replicator dynamic equation shows that, the dots crossing with horizontal axis and whose intersection point’s tangent slope are negative, are evolutionarily steady strategies for corresponding game replicator dynamics. For the perspective of the whole supply chain, the replicator dynamics of both parties in the game can be showed in a coordinate plane figure, as is shown in Figure 3.

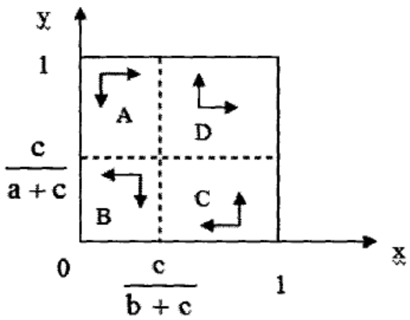

Figure 3 Relational graph of replicator dynamics of both parties in the game

In asymmetrical game, x*=0，y*=0，and x'=1，y'=l, are the evolutionarily stable strategy in this game. In the evolutionary game of replicator dynamics of this game, when the initial situation falls over B section, it will restrain to evolutionarily steady strategy of x*=0，y*=o, which means both parties of enterprises adopt noncooperation strategy; when the initial situation falls over D section, it will restrain to evolutionarily steady strategy of x*=1，y*=1, which means both parties of enterprises adopt cooperation strategy; when the initial situation falls over A and C sections, to gain more profits, both parties of bounded rationality game will most likely restrain to evolutionarily steady strategy of x*=1，y*=1 through long-term learning and strategy adjustment. Therefore, under most circumstances, it will finally restrain to the situation that both parties of enterprises adopt cooperation strategy to reach equilibrium.

3.2 Studies on pricing model improvement of two-stage supply chain based on cooperation

Under the circumstance of cooperation game, the pricing structure of supply chain is shown in Figure 4, the idea of cooperation game is applied; two parties can be regarded as a unity and all the parties of game master information of supply and demand information; the profit maximization of the whole supply chain system is regarded as the goal and manufacturers coordinate profit distribution; the equilibrium prices of manufacturers and distributors are finally defined.

Objective function:

$$\max \prod = \prod_M + \prod_D = (p - c_M - c_d) \bullet (a - bp) + w_M + w_D \quad (8)$$

Manufacturers and distributors are two parties of game; manufacturers and distributors fix a price dispersely; the prices made by manufacturers and distributors are PM and P respectively; cM is the average cost per unit, cd is second incremental cost of distributors, and the market demands at all the nodes are the same, which is Q.

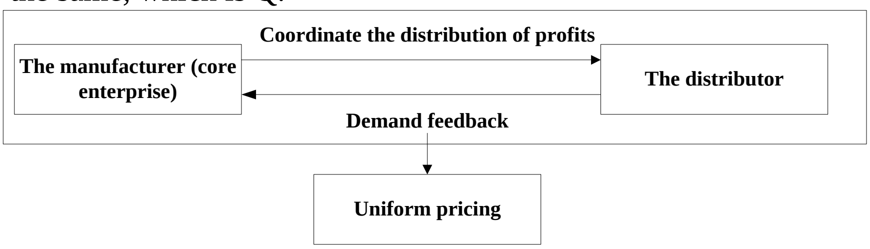

Figure 4: Structure chart of supply chain

In the pricing of cooperation game, although the maximum benefit in supply chain system is satisfied, two parties’ benefits are not maximized; therefore, through designing a pricing scope with definite profit distribution, the optimal pricing can be decided according to the bargaining power. The quantity demand is random; it is too ideal to restrict market demand function as linear function and it cannot ensure whether different demand functions exert influence on the equilibrium results. Therefore, a profit distribution factor θ (0<θ<l) is designed, in which θ is the distribution ratio of manufacturers and 1-θ is the distribution ratio of distributors, so as to make the profits of manufacturers’ and distributors’ profits are no less than the profits gained under the circumstance of noncooperation, which is,

$$\begin{cases} \theta\prod \geq \prod_M \\ (1-\theta)\prod \geq \prod_D \end{cases} \qquad (0<\theta<1) \qquad (9)$$

A section of 0 can be gained through solving the system of inequalities, and the pricing value interval is p， ， p”]， and taking values in this section can make manufacturers and distributors get better profits than noncooperation.

There is competitive conflicts among manufacturers and repeated game can be applied to coordinate the pricing decisions of two parties; now, the pricing range is divided into three small sections; every section is set to have uniform distribution to the prices of provided products, and the prices can be marked as H, M and L; both parties decide price together; when the prices are equal, the profit is divided evenly and when unequal, the profit is enjoyed exclusively by the lower price. Suppose in the circumstance of H, the total profit for both parties is 2a, in the circumstance of M, the total profit for both parties is 2b, and in the circumstance of L, the total profit for both parties is 2c, and 2c<b<a<2b, the choice on price of both manufacturers forms a static game problem, and the payoff matrix is shown in Table2.

Table 2: Table of payoff matrix

Pricing strategy		New manufacturers		
		H	M	L
Former manufacturers	H	a， a	0， 2b	0， 2c
	M	2b， 0	b， b	0， 2c
	L	2c， 0	2c， 0	c， c

Through streaking, two pure strategy nash equilibriums of (M，M) and (L，L) can be gained, and (H，H) is not nash equilibrium, in which, however, the total profit for both parties of the game is the largest and it suits their individual profits. To elevate the result efficiency of both parties' game, repeated game can be considered. Suppose two parties cooperate for the first time, they adopt low-price strategy to revenge as long as they find the other party uncooperative; therefore, in two times of repeated games, former manufacturer chooses H first, and if the result is (H，H), they choose M for the second time; if the result for the first time is any other strategy profile, they choose L for the second time; the strategies of new manufacturers are the same as former manufacturers. Under the strategy profile above, two paths of repeated games are surely (H，H) in the first stage and (M，M) in the second stage, which is a nash equilibrium path with perfect subgames.

On the premise of not considering government's abrupt policies, market demand can judge the increase or decrease in specific periods; these specific periods can be seen as the demand cycle of products. Suppose the initial market demand is Q。, the demand is QT after T time, and Q is the instantaneous demand at the time of t, in the time of T, $Q=\int_0^T Q_t dt$

With the knowledge of stochastic analysis, it can be gained:

$$Q_T = Q_0 e^{[(u-\frac{1}{2}\sigma^2)t+\sigma W(t)]} \qquad (10)$$

The price of distributors is:

$$P_T = \frac{a - Q_0 e^{[(u-\frac{1}{2}\sigma^2)t+\sigma W(t)]}}{b} \qquad (11)$$

The profit of supply chain system is:

$$\prod = (P_T - c_M - c_d)Q_T + w_M + w_D \qquad (12)$$

The profit of manufacturers is:

$$\prod_M = \frac{5}{7}\prod \qquad (13)$$

The price made by manufacturers is

$$P_M = \frac{5\prod - w_M}{Q_r} + c_M \qquad (13)$$

As certain supply-demand relationship may influence corresponding price levels, the main market direction can be found through previous demand fluctuation trend and the present price of manufacturers at present can be evaluated further.

4 Empirical study on the financing of small and medium technology-based enterprises

The relevant parameters of dedicated device and parts of machine building industry in supply chain are as followings: cM=8 yuan per unit，cD=2 yuan per unit，wM=900 yuan, wD=600yuan, market demand Q=1500-25p，and p is the price made by distributors. Through matlab simulating and forecasting of the demand fluctuation circumstance with period of T, price can be made according to market demand. If the initial market demand is Q0=625, the expected growth rate of demand is the fluctuation rate of demand, n is simulation times, the fluctuation trend of market demand can be observed through assigning different values for parameters, so as to define the market demand at this time and to get the rational price in the market. If there are two situations of T=1,n=1,σ=0.1,u=0.16, and T=1,n=1, σ=0.1,u=-0.16, simulation calculations can get what is in Figure 4.

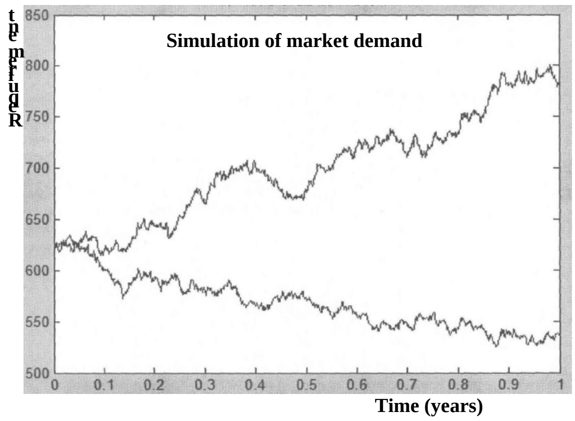

Figure 4: Simulation graph of market demand fluctuation

As is shown, as the growth rate of market demand can increase or decrease, if the expected growth rate is positive, it shows the overall trend of demand increases; otherwise, it decreases. If T=l,n=100, σ=0.1,u=0.16, the simulation calculation gets Figure 5.

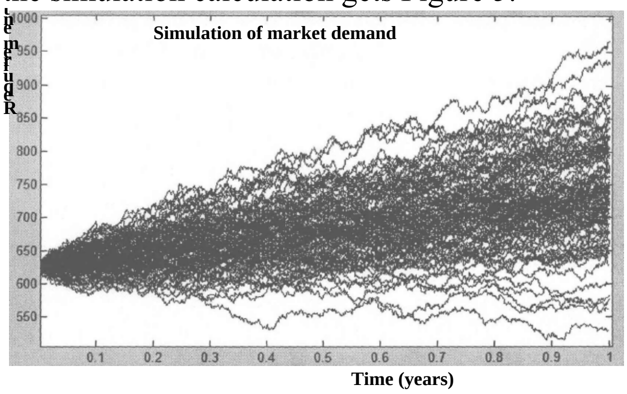

Figure 5: Simulation graph of market demand fluctuation

The density of lines shows the market demand’s randomness; the more loose it is, the more random it is. From Figure 5, it shows that with the increase of simulation times, the randomness of market demand gradually decreases, cycle length shortens and demand fluctuation range shrinks.

5 Conclusions

Manufacturers should have macroscopical understanding on the market changes and highlight the leading role in supply chain; therefore, manufacturers can make targeted pricing according to market demand; using the fluctuation relationship of demand can reflect the relationship of rise and fall of prices, and it can show the optimal pricing at certain time; but as there are a lot of uncertain factors, only short-term forecast demand can be made; long-term estimation should follow short-term expected value to make tracking prediction on market demand, so as to define rational price; it means that it’s a dynamic price-making and the demand on every period is random and supply chain enterprises may need make decisions according to the market demands of former periods continuously, so as to define the best price in this period, which is a repeated decision-making process.

References

[1] Zhang Jingmin. On the paths of elevating supply chain’s coordination [J]. Beijing Technology and Business University Journal (Social sciences), 2005,2:8-88

[2] Zhang Liming. Studies on harmonious supply chain construction based on multi-dimensional game [D]. Wuhan, Wuhan University, 2008 [3]

[3] Jeremy Shapiro. Modeling of supply chain [M]. Beijing, CITIC Publishing House, 2002:3~25

[4] Xu Ying. Studies on supply chain cooperation relationship based on game theory [D]. Guangdong, Wuyi University, 2008.

[5] Gu Qiaolun, Gao Tiegang. Analysis on the reverse supply chain pricing strategy based on game theory [J]. Theory and practice of systems engineering, 2005,3:23-36.

[6] Hou Yunzhang et al. Studeis on unite pricing and profit allocation strategy in closed-loop supply chain [J]. Logistics Technology,2004,6:50-52.

[7] Ma Zujun. Pricing model of supply-demand coordination and quantity discount in supply chain [J] Journal of Southwest Jiaotong University, 2004,39(2):185-188

[8] Yangcheng, Tong Lizhong. Chain main mode under supply chain environment [J]. Business management 2009,(l).

[9] Zhu Qinghua. Game model of evolution of government and core enterprises in green supply chain [J]. Theory and practice of systems engineering ,2007' 27(12) : 85-89...

[10] Hou Linna, Wang Haiyan. Analysis on evolutionary game of enterprise sustaibable development in green supply chain and traditional supply chain [J]. Technology and innovation management, 2010,31(6) ; 677-680.