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The Research on the Competitive Advantage of Supply Chain under Demand Uncertainty

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Abstract: To reveal whether the order of supply chain competition exerts an effect on the profits of supply chains and whether the uncertainty of the market demand interferes this effect, we build a Stackelberg game model constructed by two supply chains with each containing a supplier and a retailer on the basis of previous studies. Through the comparison of revenues generated from the leading-following supply chain under the complete information game, we draw a conclusion that is different from the first-mover advantage of the traditional bertrand game; that is, the following supply chain can benefit from the later-mover advantage, which is determined by the order of decision making itself and will not change as initial market demand or the degree of product substitution varies.

Key words: Leading-following supply chain, Stackelberg game, market demand uncertainty, later-mover advantage

INTRODUCTION

Due to the development of globalization and information technology, great changes have taken place inthe present day business environment. The increasing market uncertainty and diversified demand have shortened the product life cycles and accelerated the products' updating rates. Given the increasingly fierce market competition and rapidly changing market demands, the traditional mode of running companies independently is unable to meet today's economic environment, tending to be replaced by a mode required more collaboration to reach a win-win situation. To rival against the competitors, enterprises need to develop close collaboration with partners in a supply chain and streng then their competitive advantages rather than just focusing on the competition against individual enterprises. In the real market, some leading companies in the industry often dominate in the decision making and set up the standards for the smaller companies to follow. In other words, the competition among supply chains are actually the competition among leading and following supply chains. Therefore, a clear understanding of them a in competition mechanism of the leading and following supply chain is of significant importance to companies that participate in this fierce competition, especially for those being dominated.

Research on supply chain competition can be divided into two main categories including the studies towards the game among different node companies in an internal supply chain and the studies regarding the competition among different supply chain sundervarious market demand and environment.

Abundant theoretical results of the first category of research on internal supply chain have been obtained by discussing how to use price, service and other factors or select related contracting strategies to achieve a well-coordinated supply chain. For example, (Pasternack, 1985) firstly proposed the use of the return policy contract to coordinate behavior of suppliers and vendors from news boy problem. (Bernstein and Federgruen, 2005) pointed out that if the who lesaleprice and the repurchase price satisfy a linear relationship with the retail price, the supply chain can be coordinated. Zhou (2007) compared quantity discount policy in two different stages under the randomized market demand and asymmetric information.

The second category of study has extended the research scope from single-chain to double-chain or even multi-chain, not only taking the vertical competition with in the supply chain into account but also the horizonal competition outside the supply chain. According to (Jian and Ershi, 2009) through the analysis of the effect of the product substitution degree has on the overall profit of the supply chain in the competitive environment, the extent to which this effect influences the information sharing can be assessed. Based on (Zhang and Yuan, 2010) by comparing the performance of the Bertrand game conducted among different supply chains under the market demand of power function structure, a conclusion that traditional "first mover advantage" could not hold can be drawn. Although this literature provides a good insight on analysing competition and performance in a supply chain, the authors failed to consider the fact that not all companies are doing the game at the same time because leading companies are more likely to make decisions in advance, leaving other smaller companies no choices but to follow. As such, the study still needs to be improved. A research conducted by Boxun *et al*. (2012) accentuates how to choose between centralized and decentralized strategy under the leading-following Stackelberg game and indentifies the relationships between strategy selection and product substitution degrees. This study analyzes the existing competition between the leading and following supply chains in the market place, however, it concerns more about the impact of business decisions of each node company in a supply chain has on the performance than unveiling the profit differences that result from the leading-following supply chain competition mechanism it self. Moreover, the authors also failed to discuss the consequences in the case where the market demand is uncertain.

Based on the previous studies, this study seeks to build a Stackelberg game model constructed by two supply chains with each containing a supplier and a retailer. By comparing revenues generated from the existing leading-following supply chain in a more common market, the study aim is to determine whether the competition mechanism has an effect on the supply chain revenues and whether market demand uncertainty interferes this effect. Finally, a conclusion that is different from the view that leading supply chain would take advantage of first moves in traditional Bertrand game is drawn.

MODEL ASSUMPTIONS

This study analysez the leading-following supply chain competition in the real market. To further discuss the main impact of the supply chain competitive mechanism has on the profits and to eliminate the interference of corporate decision-making in the supply chain such as information sharing, the study is under the condition of complete information where the game between leading-following supply chains takes place; this means that retailers would alway faithfully report the market demand to the suppliers. Ideally, each supply chain includes a supplier S and a retailer R. As such, we assume that supply chain i (SCi) is the leading supply chain that dominates the market to make the first move, while supply chain j (SCj) is the following supply chain that observes and follows the trend accordingly. In other words, both of them are participating in the Stackelberg game. Hypothetically, suppliers on these two supply chains offer products to the retailers with price w_i, w_j, respectively and accordingly their retailers provide consumers with the retailling price p_i, p_j while the market demands present q_i, q_j correspondingly. The structures of these two supply chains are shown below:

$$S_i \xrightarrow[q_i]{w_i} R_i \xrightarrow[q_i]{p_i} C$$
$$S_j \xrightarrow[q_j]{w_j} R_j \xrightarrow[q_j]{p_j} C$$

Based onthe principles of economics (Choi, 1991), we assume that the basic needs of the market are corresponding to a linear uncertain demand:

$$q_i = \alpha_D - p_i + \gamma^* p_j,\ q_j = \alpha_D - p_j + \gamma^* p_i \tag{1}$$

Where γ represents the alternative coefficient of the two price supply chains while α_D acts as the initial needs of the market (that is, all prices were zero). There are α_H (high initial demand) and α_L (low initial demand) in both cases whereby the probabilities of each are b and (1-b), respectively scilicet:

$$\alpha_D = \begin{cases} \alpha_H,\ P(\alpha_H) = b \\ \alpha_L,\ P(\alpha_L) = 1 - b \end{cases} \tag{2}$$

Recording Π as the revenues that correspond to each part, as such the retailer'searnings are as follows:

$$\Pi_{Ri} = (p_i - w_i) * q_i,\ \Pi_{Rj} = (p_j - w_j) * q_j$$

Suppliers' earnings are:

$$\Pi_{Si} = w_i * q_i,\ \Pi_{Sj} = w_j * q_j$$

Supply chain over all revenues are:

$$\Pi_{SCi} = \Pi_{Si} + \Pi_{Ri},\ \Pi_{SCj} = \Pi_{Sj} + \Pi_{Rj}$$

The expected revenues of supply chain are:

$$\begin{aligned} &E(\Pi_{Ri}) = P(\alpha_H)*\Pi_{(Ri,\alpha_H)} + P(\alpha_L)*\Pi_{(Ri,\alpha_L)},\ E(\Pi_{Rj}) = P(\alpha_H)*\Pi_{(Rj,\alpha_H)} + P(\alpha_L)*\Pi_{(Rj,\alpha_L)} \\ &E(\Pi_{Si}) = P(\alpha_H)*\Pi_{(Si,\alpha_H)} + P(\alpha_L)*\Pi_{(Si,\alpha_L)},\ E(\Pi_{Sj}) = P(\alpha_H)*\Pi_{(Sj,\alpha_H)} + P(\alpha_L)*\Pi_{(Sj,\alpha_L)} \\ &E(\Pi_{SCi}) = E(\Pi_{Si}) + E(\Pi_{Ri}),\ E(\Pi_{SCj}) = E(\Pi_{Sj}) + E(\Pi_{Rj}) \end{aligned} \tag{3}$$

MODEL SOLUTION

After observing the pricing and sales of leading supply chain i, supply chain j will make the decisions correspondingly; later in the supply chain i/j, given the whole sale price of supplier i/j, the retailer i/j then will make the decisions accordingly.

So reverse induction is used to calculate the maximum benefits of the retailer j, that is Π_{Rj}, we can get:

$$p_j = \frac{\alpha_D + \gamma * p_i + w_i}{2} \tag{4}$$

To maximize the benefits of supplier j, that is when Π_{Sj}, we can get:

$$w_j = \frac{\alpha_D + \gamma * p_i}{2} \quad (5)$$

Substituting Eq. 4 in to Eq. 5 we can obtain that:

$$p_j = \frac{3}{4}(\alpha_D + \gamma * p_i),\ q_j = \frac{1}{4}(\alpha_D + \gamma * p_i) \quad (6)$$

Therefore, the revenues of each part of the supply chain j are:

$$\Pi_{Rj} = \frac{1}{16}(\alpha_D + \gamma * p_i)^2,\ \Pi_{Sj} = \frac{1}{8}(\alpha_D + \gamma * p_i)^2,\ \Pi_{SCi} = \frac{3}{16}(\alpha_D + \gamma * p_i)^2 \quad (7)$$

For retailers I, given that:

$$q_i = \alpha_D - p_i + \gamma * p_j = (1 + \frac{3}{4}\gamma)\alpha_D - (1 - \frac{3}{4}\gamma^2)p_i \quad (8)$$

In order to maximize the benefits of retaileri, that is when Π_{Ri}, it can be obtained that:

$$p_i = \frac{(1+\frac{3}{4}\gamma)\alpha_D + (1-\frac{3}{4}\gamma^2)w_i}{2(1-\frac{3}{4}\gamma^2)},\ q_i = \frac{(1+\frac{3}{4}\gamma)\alpha_D - (1-\frac{3}{4}\gamma^2)w_i}{2} \quad (9)$$

Based on the results summarized above in reverse order, we forward projected and substituted Eq. 9 in to supplier i's revenue equation expression. According to the principle of maximizing the interests of supplier j, that is when Π_{Si}, it can be obtained that:

$$w_i = \frac{(1+\frac{3}{4}\gamma)\alpha_D}{2(1-\frac{3}{4}\gamma^2)} \quad (10)$$

Substituting Eq. 10 in to Eq. 9, it can be obtained that:

$$p_i = \frac{3(1+\frac{3}{4}\gamma)\alpha_D}{4(1-\frac{3}{4}\gamma^2)},\ q_i = \frac{(1+\frac{3}{4}\gamma)\alpha_D}{4} \quad (11)$$

Therefore, the revenues of each part of the supply chain i are:

$$\Pi_{Si} = \frac{(1+\frac{3}{4}\gamma)^2\alpha^2_D}{8(1-\frac{3}{4}\gamma^2)},\ \Pi_{Ri} = \frac{(1+\frac{3}{4}\gamma)^2\alpha^2_D}{16(1-\frac{3}{4}\gamma^2)},\ \Pi_{SCi} = \frac{3(1+\frac{3}{4}\gamma)^2\alpha^2_D}{16(1-\frac{3}{4}\gamma^2)} \quad (12)$$

Substituting the result of Eq. 11 in to Eq. 6, it can be obtained that:

$$p_j = \frac{3}{4}\frac{(1+\frac{3}{4}\gamma)\alpha_D - \frac{3}{16}\gamma^2\alpha_D}{(1-\frac{3}{4}\gamma^2)},\ q_j = \frac{1}{4}\frac{(1+\frac{3}{4}\gamma)\alpha_D - \frac{3}{16}\gamma^2\alpha_D}{(1-\frac{3}{4}\gamma^2)},$$
$$w_j = \frac{1}{2}\frac{(1+\frac{3}{4}\gamma)\alpha_D - \frac{3}{16}\gamma^2\alpha_D}{(1-\frac{3}{4}\gamma^2)} \quad (13)$$

Therefore, the revenues of each part of the supply chain j are:

$$\Pi_{Sj} = \frac{1}{8}\left[\frac{(1+\frac{3}{4}\gamma)\alpha_D - \frac{3}{16}\gamma^2\alpha_D}{(1-\frac{3}{4}\gamma^2)}\right]^2,\ \Pi_{Rj} = \frac{1}{16}\left[\frac{(1+\frac{3}{4}\gamma)\alpha_D - \frac{3}{16}\gamma^2\alpha_D}{(1-\frac{3}{4}\gamma^2)}\right]^2,$$
$$\Pi_{SCi} = \frac{3}{16}\left[\frac{(1+\frac{3}{4}\gamma)\alpha_D - \frac{3}{16}\gamma^2\alpha_D}{(1-\frac{3}{4}\gamma^2)}\right]^2 \quad (14)$$

ANALYSIS

By comparing the revenues of each part of leading and following supply chains, a result can be achieved through subtracting Eq. 14 and 12:

$$\Pi_{Rj} - \Pi_{Ri} = \left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_D^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2},\ \Pi_{Sj} - \Pi_{Si} = 2\left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_D^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2},$$
$$\Pi_{SCi} - \Pi_{SCi} = 3\left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_D^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2} \quad (15)$$

Revenue expectations for each part of both supply chains can be acquired by substituting the Eq. 12 and 14 in to Eq. 3 that:

$$E(\Pi_{Rj}) - E(\Pi_{Ri}) = b\left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_H^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2} + (1-b)\left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_L^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2},$$
$$E(\Pi_{Sj}) - E(\Pi_{Si}) = 2b\left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_H^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2} + 2(1-b)\left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_L^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2},$$
$$E(\Pi_{SCi}) - E(\Pi_{SCi}) = 3b\left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_H^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2} + 3(1-b)\left(\frac{117}{256}\gamma^2 + \frac{3}{8}\right)\frac{\alpha_L^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2} \quad (16)$$

It is obvious that $b \geq 0$, $1-b \geq 0$,

$$\frac{117}{256}\gamma^2 + \frac{3}{8} \geq \frac{3}{8},\ \frac{\alpha_H^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2} \geq 0,\ \frac{\alpha_L^2\gamma^2}{(1-\frac{3}{4}\gamma^2)^2} \geq 0$$

Therefore:

$$E(\Pi_{Rj}) \geq E(\Pi_{Ri}),\ E(\Pi_{Sj}) \geq E(\Pi_{Si}),\ E(\Pi_{SCj}) \geq E(\Pi_{SCi}),$$
$$\Pi_{Rj} \geq \Pi_{Ri},\ \Pi_{Sj} \geq \Pi_{Si},\ \Pi_{SCj} \geq \Pi_{SCi}$$

CONCLUSION

By comparing the revenues of the game between leading and following supply chains under the condition of complete information, we can reach the following conclusions:

- Conclusion 1 Unlike the first-mover advantage of leading supply chain inthe traditional Bertrande game, the later-mover advantage of the following supply chain has been seen in the leading-following supply chain competition. This is mainly because the following supply chain is able to observe the outcomes of the decisions and actions made by the leading supply chain, thereby reducing the market uncertainty to gain more revenues
- Conclusion 2 When the market demand is uncertain, the following supply chain will always be more profitable regardless of the changes with respect to the value of market demand α_D and product alternative coefficient γ. This means that the later-mover advantage is determined by the order of decision-making itself and is not likely to change asinitial market demand or the degree of product substitution varies

The above conclusions provide a theoretical verification for some economic theories such as freebie and sunk costs and also offer inspiration for specific companies to make decisions. For those followers who face the difficultities in entering or surviving in a industry dominated by a certain number of leading companies with technological advantages, they can manage to reduce the market uncertainty through observing the consequences of the first moves taken by leading companies and hence take advantages of appropriate later moves in order to develop the capabilities to catch up.

Thru the comparison of revenues generated from the leading-following supply chain in the complete information game, a profound finding that the following supply chain can take advantages of the later moves, which will not vary in relation to the changes in market demand, can be acquired. This can provide references for the further research regarding the competition among the supply chains and for those followers that urge to gain footholds in the target market. However, there are still a number of incomplete information and multi-chains games in the real world that need to be taken into consideration in the future studies. Addtionally, for further research it should also be interesting to investigate how to adjust the contracts offered by suppliers reasonably, how to boost the competitive advantages of a supply chain and how to coordinate effectively within a supply chain.

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