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Research on Quality Management of Supply Chain with Multi Manufacturer Competition

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The paper considers a supply chain contain two competing manufacturers with different market share and a retailer, examines the impact of different market share on product quality level and supply chain profits while two manufacturers competition and cooperation. The conclusions show that: from the market share point of view, whether the two manufacturers are competing or cooperation, the greater the market share of the manufacturers, product quality level, market demand and profits of manufacturers and retailer are higher, and they increasing with the increase of the market share. Under the condition of cooperation, the wholesale price, retail price, product quality level and the profits of manufacture are higher than those of the competition, but the market demand and the profits of the retailer are lower. For the same market share gap, the gap between the two manufacturers' demand and the profits in cooperation model are greater than that of the competition model, while the gap of quality level in the cooperation model is the same as that of the competition model, and they all increase with the increase of the market share gap.

1. Introduction

With the increasingly fierce market competition, the competition between enterprises gradually changed into the competition between supply chain and supply chain, in this context, frequently outbreak product quality problems have increasingly become the focus of people's attention, such as Sanlu milk powder incident, Toyota recall event and KFC crash chicken events. The research of product quality management system began in the beginning of twentieth Century, and produced a series of quality management theory and methods, including six sigma method, comprehensive quality management theory, etc.. However, most of these traditional theories and methods focus on the quality improvement of a single enterprise, and seldom take into account the quality control of the upstream and downstream enterprises.

In recent years, the quality management of supply chain has received the attention of many scholars. From a supply chain perspective, a non-cooperative dynamic game is formulated (El-Ouardighi and Kim, 2010) in which a single supplier collaborates with two manufacturers on design quality improvements for their respective products and the manufacturers with same initial market demand compete for market demand both on price and design quality. (Xie et al., 2011) considered quality improvement in a given segment of the market, shared by two supplier–manufacturer supply chains which offer a given product at the same price but compete on quality. (Xie et al., 2011) considered the risk-averse behaviour of the players about quality investment and price decision in three different supply chain strategies: Vertical Integration (VI), Manufacturer’s Stackelberg (MS) and Supplier’s Stackelberg (SS). (Lee and Rhee, 2013) tested the two most widely examined coordination schemes, buybacks and revenue-sharing, and find that these two contracts have critical drawbacks in the presence of quality uncertainty. (Ma et al., 2013) investigated the issue of channel coordination for a two-stage supply chain with one retailer and one manufacturer, analyzed the equilibrium behaviors of a two-stage supply chain (SC) under different supply chain structures. (El-Ouardighi, 2014) investigated the potential coordinating power of the revenue sharing contract in a supply chain with one manufacturer and one supplier that collaborate to improve the design quality of a particular finished product. (Yoo, 2014) investigated a joint decision problem of the return policy and product quality in a buyer–supplier supply chain. (Taleizadeh-Ata et al., 2015) discussed the economic production and inventory model in a three-layer supply chain including one distributor, one manufacturer and one retailer for a single-product and

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general demand functions under three scenarios, and the Stackelberg approach is employed between the members, and the concavity of the profit functions is proved using several theorems. (APAHlioui et al., 2015) deal with the coordination of production, replenishment and inspection decisions for a manufacturing-oriented supply chain with a failure-prone transformation stage, random lead time and imperfect delivered lots and present an easy decision-making tool (indifference curves) to help the manager select the best quality control strategy when considering the entire supply chain. (Giri et al., 2015) considered the pricing and quality decisions of a single product in a two-echelon supply chain with multi-manufacturer and a single retailer. (Modak et al., 2015) explored channel coordination and profit division issues of a manufacturer-distributer-duopolistic retailers supply chain for a product, where the manufacturer supplies lot size of the product that contains a random portion of imperfect quality item. (He et al., 2015) investigated an assemble-to-order supply chain including a manufacturer and two complementary suppliers, one produces component associated with traditional quality while the other produces component associated with environmental quality of the manufacturer's product. (Seifbarghy et al., 2015) discussed optimal decision of a two-level supply chain consisting of a manufacturer and a retailer, where the retailer gives a final product to a competitive market with customer sensitive to price and the customer demand is assumed to be constant depending on the price and quality degree of the final product. (Giri et al., 2015) analysed a closed-loop serial supply chain consisting of a raw material supplier, a manufacturer, a retailer and a collector who collects the used product from consumers, while the remanufacturing of used items solely depends on the quality level of collected items.
As can be seen from the above literatures, scholars research on quality competition about manufacturers of supply chain, or assume that the manufacturers have the same initial market share, or assume they have the same product retail price. When the manufacturers have different initial market share, how to decision the retail price and quality level of each manufacturer and how to coordinate the supply chain, the related research in this field are very few. And this is exactly what this paper wants to carry on.

2. Model description

We consider a supply chain which contains two manufactures who occupy different market share and a retailer in our models. The manufactures sell the same function and structure products but different qualify level and wholesale price to the retailer, the retailer sell the products to the consumer with different retail price respectively. The two manufactures have different market share, we use $\alpha_1\phi$ and $\alpha_2\phi$ to express manufacture 1 and manufacture 2 market share, respectively, and $\alpha_1+\alpha_2=1$, ϕ is the base market size.
Following (Banker et al., 1998), we assume that the demand information is symmetrically known to SC members, and the demand function is linear in price and quality level. Thus, the demand function for manufacture 1 is:

$$d_i(p_i,p_j,x_i,x_j)=\alpha_i\phi-\beta p_i+\gamma p_j+\lambda x_i-\mu x_j \tag{1}$$

Where β(λ) denotes the demand responsiveness to SC's own price p_i (quality level x_i, i=1,2; j=1,2; $i\neq j$), $\gamma(\mu)$ means price (quality level) competition coefficient, which reflects the degree of price (quality level) competition among manufactures. According to (Banker et al., 1998), the cost function for manufacture i is given by

$$c(d_i,x_i)=(c+vx_i)d_i+\xi x_i^2 \tag{2}$$

Thus, the quality level selected by a firm affects total costs in two ways. First, investment in a quality improvement program increases fixed production costs ξx_i^2, which is increasing and convex in the quality level x, and ξ is the fixed cost parameter. Second, the quality level also has an impact on the production cost per unit. Specifically, c denotes the variable production cost per unit not including the quality related costs. Given a quality level x_i selected by manufacture, the unit variable cost increases by vx_i, where v>0, Suppose $\lambda/\beta>v>\mu/\gamma$, this condition implies that the change in demand caused by the quality change is greater than the demand fluctuation caused by the price change. The change in demand caused by the change of one's own price or quality is greater than the demand in demand caused by the competitor's price or quality. This hypothesis is consistent with the reality.
When the retail price p_i and cost c are equal excluding the quality related costs, the demand must be greater than 0, and the reality is in line with it, namely $\alpha_1\phi-\beta p_1+\gamma p_2+\alpha_2\phi-\beta p_2+\gamma p_1=\phi-2c(\beta-\gamma)>0$.
The objective of each party is to maximize his (her) profits that can be expressed as below:

$$\pi_{M_i}(x_i,w_i)=(w_i-c-vx_i)\left(\alpha_i\phi-\beta p_i+\gamma p_j+\lambda x_i-\mu x_j\right)-\xi x_i^2 \tag{3}$$

$$\pi_R(p_1,p_2)=(p_1-w_1)(\alpha_1\phi-\beta p_1+\gamma p_2+\lambda x_1-\mu x_2)+(p_2-w_2)(\alpha_2\phi-\beta p_2+\gamma p_1+\lambda x_2-\mu x_1) \tag{4}$$

Where π_R, π_M and π_T denote the profit of the retailer, the manufacturer and the SC, respectively. We use superscripts H and J to denote manufactures cooperative and competition model, respectively. Superscript * denotes the optimal. We formulate the problem as a Stackelberg game model in which the manufacturers and the retailer form a leader–follower relationship.

3. Price and quality coordination in different market share

3.1 Competitive manufacturer model

In this model, the two manufacturers sell the same function and structure products but different qualify level and wholesale price to the retailer. The competition between the two manufactures and retailer take place in the following sequence in time:(i) The two manufacturers choose their optimal x_i and w_i at the same time to maximum their profits. (ii) The retailer sells their products to the consumer and chooses different optimal p_i to maximum his profits. The two manufacturers take the retailer's reaction into consideration when choosing their strategy. The retailer's reaction function for a given w_i and x_i can be derived from the first-order derivative of π_R in Eq. (4):

$$d\pi_R/dp_i = -2\beta p_i + 2\gamma p_j + \beta w_i - \gamma w_j + \lambda x_i - \mu x_j + \phi \alpha_i \tag{5}$$

Solving Eq. (5), we obtain the equilibrium p_1 and p_2 :

$$p_{\rm i} = ((\beta^2 - \gamma^2)w_i + (\beta\lambda - \gamma\mu)x_i + \gamma\lambda x_j - \beta\mu x_j + \beta\phi\alpha_i + \gamma\phi\alpha_j)/2(\beta^2 - \gamma^2) \tag{6}$$

Note that the Hessian of π_R is negative definite for all values of p_1 and p_2 if $\beta^2 - \gamma^2 < 0$.Substituting Eq.(6) into Eq.(3), the first-order conditions characterizing equilibrium x_i and w_i are:

$$d\pi_{M_i}/dw_i = \left(c\beta - 2\beta w_i + \gamma w_j + \lambda x_i + \beta\nu x_i - \mu x_j + \phi\alpha_i\right)/2 = 0 \tag{7}$$

$$d\pi_{M_i}/dx_i = \left(-c\lambda + (\lambda + \beta\nu)w_i - \gamma\nu w_j - 2\lambda\nu x_i - 4\xi x_i + \mu\nu x_j - \nu\phi\alpha_i\right)/2 = 0 \tag{8}$$

Note that the Hessian of π_{M_1} and π_{M_2} are negative definite for all values of x_i and w_i if $-(\lambda + \beta\nu)^2/4 + \beta(\lambda\nu + 2\xi) < 0$. From Eq. (7) ~ Eq. (8),we find the manufactures' optimal wholesale price and quality level. Then we can get demand and profits of each member in SC as follows:

$$x_i^{J*} = C(E(F - 4A) - F\phi\alpha_j + 4A\phi\alpha_i)/(16A^2 - F^2) \tag{9}$$

$$d_i^{J*} = 2\beta\xi\left(E(F - 4A) - F\phi\alpha_j + 4A\phi\alpha_i\right)/(16A^2 - F^2) \tag{10}$$

$$\pi_{M_i}^{J*} = 4A\xi(E(F - 4A) - 4A\phi\alpha_i + F\phi\alpha_j)^2/\,(16A^2 - F^2)^2 \tag{11}$$

$$\pi_R^{J*} = (4\beta^2\xi^2(2cB(F - 4A)^2(E - \phi) + (\beta(16A^2 + F^2) - 8\gamma AF)\phi^2)/B(16A^2 - F^2)^2 \tag{12}$$

Where $A = -(\lambda + \beta\nu)^2/4 + \beta(\lambda\nu + 2\xi)$,$B = \beta^2 - \gamma^2$,C=$\lambda - \beta\nu, D = \mu - \gamma\nu, E = c(\beta - \gamma), F = CD - 4\gamma\xi$, in which $A < 0, B < 0$. From the condition $\lambda/\beta > \nu > \mu/\gamma$, we can get C>0, D<0 and F<0.

3.2 Cooperative manufacturer model

In this model, the cooperative manufacturer sell the same function and structure products but different qualify level and wholesale price to the retailer. The competition between the two manufacturer and retailer take place in the following sequence in time:(i) The two cooperative manufacturers choose their optimal x_i and w_i at the same time to maximum their overall profits. (ii) The retailer sells their products to the consumer and chooses different optimal p_i to maximum his profits. From Eq. (3) ~ Eq. (4), the profits function for the SC each member as follows:

$$\begin{aligned}\pi_M(x_1, w_1, x_2, w_2) = {} & (w_1 - c - \nu x_1)(\alpha_1\phi - \beta p_1 + \gamma p_2 + \lambda x_1 - \mu x_2) - \xi x_1^2 \\ & +(w_2 - c - \nu x_2)(\alpha_2\phi - \beta p_2 + \gamma p_1 + \lambda x_2 - \mu x_1) - \xi x_2^2\end{aligned} \tag{13}$$

$$\pi_R(p_1, p_2) = (p_1 - w_1)(\alpha_1\phi - \beta p_1 + \gamma p_2 + \lambda x_1 - \mu x_2) + (p_2 - w_2)(\alpha_2\phi - \beta p_2 + \gamma p_1 + \lambda x_2 - \mu x_1) \tag{14}$$

The two manufacturer take the retailer's reaction into consideration when choosing their strategy. The retailer's reaction function for a given w_i and x_i can be derived from the first-order derivative of π_R in Eq. (14), the results as Eq. (6) show. Substituting Eq. (6) into Eq. (13), the first-order conditions characterizing equilibrium x_i and w_i are:

$$d\pi_M/dw_i = (c\beta - c\gamma - 2\beta w_i + 2\gamma w_j + \lambda x_i + \beta\nu x_i - \mu x_j - \gamma\nu x_j + \phi\alpha_i)/2 = 0 \tag{15}$$

$$d\pi_M/dx_i = (-c\lambda + c\mu + (\lambda + \beta\nu)w_i - (\mu + \gamma\nu)w_j - 2\lambda\nu x_i - 4\xi x_i + 2\mu\nu x_j - \nu\phi\alpha_i)/2 = 0 \tag{16}$$

Note that the Hessian of π_M is negative definite for all values of x_i and w_i if $(4A+2F-D^2)(4A-2F-D^2)<0$.From Eq. (15) ~ Eq. (16), we find the two manufactures' optimal wholesale price and quality level. Then we can get demand and profits of each member in SC as follows:

$$x_i^{H*}=\frac{E(C-D)(D^2-4A+2F)+(4CA+DF-4\gamma D\xi)\phi\alpha_i+(D^3-2CF-4AD)\phi\alpha_j}{(4A+2F-D^2)(4A-2F-D^2)} \tag{17}$$

$$\pi_{M_i}^{H*}=\frac{\xi(-E^2(D^2-4A+2F)+4A\phi^2\alpha_i^2+2E(D^2+F)\phi\alpha_j-D^2\phi^2\alpha_j^2+2\phi\alpha_i(E(F-4A)-F\phi\alpha_j))}{(4A+2F-D^2)(4A-2F-D^2)} \tag{18}$$

$$d_i^{H*}=\frac{(2\xi(E^2(D^2-4A+2F)+(4\beta A+2\gamma F+\beta D^2)\phi\alpha_i+(\gamma D^2-4A\gamma-2\beta F)\phi\alpha_j))}{(4A+2F-D^2)(4A-2F-D^2)} \tag{19}$$

4. Results analysis

Conclusion 1: Whether the two manufacturers are competing or cooperation, the greater the market share of the manufacturers, product quality, market demand and profits of manufacturers and retailer are higher, and they increasing with the increase of the market share.

Proof: According to the results of the third section, we get $x_1^{J*}-x_2^{J*}=C\phi(\alpha_1-\alpha_2)/(4A-F)$, because $\lambda/\beta>\nu>\mu/\gamma$, we can get $4A-F>0$, $4A+F<0$, and $C>0$, so when $\alpha_1\geq\alpha_2$, $x_1^{J*}\geq x_2^{J*}$. $dx_1^{J*}/d\alpha_1=4AC\phi/(16A^2-F^2)>0$ and $dx_1^{J*}/d\alpha_2=FC\phi/(-16A^2+F^2)<0$. In the same way, we get $dx_i^{H*}/d\alpha_i>0$ and when $\alpha_1\geq\alpha_2$, $x_1^{H*}\geq x_2^{H*}$.

$d_1^{J*}-d_2^{J*}=2\beta\xi\phi(\alpha_1-\alpha_2)/(-16A^2+F^2)$, because $-16A^2+F^2>0$, so when $\alpha_1\geq\alpha_2$, $d_1^{J*}\geq d_2^{J*}$. In the same way, we can get $d_1^{H*}\geq d_2^{H*}$ when $\alpha_1\geq\alpha_2$.

In virtue of $\phi-2E>0$, $A<0$ and $16A^2-F^2<0$, so when $\alpha_1\geq\alpha_2$, $\pi_{M_1}^{J*}-\pi_{M_2}^{J*}=4A\xi\phi(\alpha_1-\alpha_2)(\phi-2E)/(16A^2-F^2)\geq0$. When $\alpha_1\geq\alpha_2$, $\pi_{M_1}^{H*}\geq\pi_{M_2}^{H*}$ can be get by the same way.

In order to further verify the impact of market share changes on product quality, wholesale price, retail price and profit, we use numerical simulation, as shown in table 1.

Table 1: Market share change numerical simulation (ϕ=10000, β=41, γ=22, c=22, v=0.26, λ=12, μ=6, ξ=4)

	Model	$\alpha_1=0.5$ $\alpha_2=0.5$	$\alpha_1=0.6$ $\alpha_2=0.4$	$\alpha_1=0.7$ $\alpha_2=0.3$	$\alpha_1=0.8$ $\alpha_2=0.2$	$\alpha_1=0.9$ $\alpha_2=0.1$
w_1	J	100	110	120	130	139
	H	145	153	161	169	178
w_2	J	100	90	80	71	61
	H	145	137	129	120	112
p_1	J	183	196	209	222	235
	H	205	217	230	242	254
p_2	J	183	170	157	144	131
	H	205	193	181	169	157
x_1	J	6.41	7.21	8.02	8.82	9.63
	H	8.00	8.81	9.61	10.42	11.22
x_2	J	6.41	5.60	4.79	3.99	3.18
	H	8.00	7.20	6.39	5.59	4.78
d_1	J	1568	1765	1963	2160	2357
	H	1148	1398	1648	1899	2149
d_2	J	1568	1370	1173	976	778
	H	1148	897	647	397	146
π_{M1}	J	119744	151790	187632	227269	270702
	H	138379	179674	224943	274184	327400
π_{M2}	J	119744	91493	67037	46377	29512
	H	138379	101057	67709	38334	12933
π_R	J	258749	259985	263695	269879	278536
	H	138635	140624	146592	156539	170464

As can be seen from table 1, with the increase in the market share of manufacturer 1, whether in the manufacturer's competition or cooperation mode, the product wholesale price, retail price, product quality,

profits of manufacturer and retailer increased. And the larger market share of manufacturer, his products wholesale price, retail price, product quality level, profits of manufacturer and retailer are also higher.
From table 2 we can see that the cooperation between the manufacturers is beneficial to improve the quality level of products and the profits of the manufacturers, but not beneficial to the retailer. Manufacturers' competition is beneficial to improve the profits of retailer, but not beneficial to the manufacturers. Then we can get conclusion 2 and 3.
Conclusion 2: Under the condition of cooperation, the wholesale price, retail price, product quality level and the profits of manufacture are higher than those of the competition, but the market demand and the profits of the retailer are lower.

Table 2: Products quality level, market demand and profits gap of two manufacturers change with the market share of the gap (ϕ=10000, β=41, γ=22, c=22, v=0.26, λ=12, μ=6, ξ=4)

$\Delta\alpha$		0	0.2	0.4	0.6	0.8
Δx	J	0	1.61	3.23	4.83	6.44
	H	0	1.61	3.22	4.83	6.44
$\Delta\Delta x$		0	0	0	0	0
Δd	J	0	395	790	1184	1579
	H	0	501	1001	1502	2003
$\Delta\Delta d$		0	106	211	318	424
$\Delta\pi_M$	J	0	60297	120595	180892	241190
	H	0	78617	157234	235850	314467
$\Delta\Delta\pi_M$		0	18320	36639	54958	73277

Conclusion 3: For the same market share gap, the gap between the two manufacturers' demand and the profits in cooperation model are greater than that of the competition model, while the gap of quality level in the cooperation model is the same as that of the competition model, and they all increase with the increase of the market share gap.
Conclusion 3 denotes that with the increase of the market share gap of the two manufacturers, both in the competition and cooperation models, the gap of product quality level, the demand and the profits of the two manufacturers increase, the increase of the quality level gap in competition model is in agreement with the cooperation model. Compared with competition model, the increase range of the gap of the product demand and the profits of the two manufacturers in the cooperation model are larger.
The above three conclusions show that, for the competition manufacturers, the market share has important influence on the quality level of the products, the greater the market share, the higher the quality of the products, and the higher of the profits. Manufacturers' cooperation is conducive to the improvement of product quality level and the increase of profits, but not conducive to the retailer.

5. Conclusion

This paper focuses on a supply chain contained two competing manufacturers with different market share and a retailer, examined the impact of different market share on product quality level and supply chain profits while the two manufacturers' competition and cooperation. By means of game theory and simulations, we find that: from the market share point of view, whether the two manufacturers are competing or cooperation, the greater the market share of the manufacturers, product quality level, market demand and profits of manufacturers and retailer are higher, and they increasing with the increase of the market share. Under the condition of cooperation, the wholesale price, retail price, product quality level and the profits of manufacture are higher than those of the competition, but the market demand and the profits of the retailer are lower. For the same market share gap, the gap between the two manufacturers' demand and the profits in cooperation model are greater than that of the competition model, while the gap of quality level in the cooperation model is the same as that of the competition model, and they all increase with the increase of the market share gap.
This paper only analyses the situation of two manufacturers and one retailer, and the coordination of supply chain including multi manufacturers and retailers with different market share is our further research.

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