Making Optimal Decisions of Assembly Products in Supply Chain

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Abstract

The strategic pricing decisions of assembly products in assembly products supply chain are studied in this paper. Firstly, a two-stage assembly products supply chain model is developed. By building Nash game model, the Nash equilibrium solution of pricing strategy of supplier and assemblers is obtained. Next, a union decision model is built to analyze the optimal combination pricing strategy of assembly products, and the relationship between the optimal strategies is established. The law of the changing in combination pricing strategy, assemblers' profits and supplier's profit along with the variety of some characteristics has been investigated by using numerical simulation. The results are consistent with economics principles.

Keywords: Supply chain management; Game theory; Nash equilibrium; Assembly products.

1. Introduction

Nowadays, with the rapid changes of market, lifecycle of a product is becoming shorter and shorter. Product should be adjustable in order to meet the needs of the changing market, which has been recognized by many corporations and researchers (Dickson [3]). In this case, assembling products is an effective way to meet the changing needs, especially for PC industry (Jain [5]). Assemblers can change some components of an assembly product if market demands change. Compared with single products, the lifecycle of assembly product is longer and less costly. Each assembly product has many components, which will be supplied by some suppliers. One assembler and some components suppliers construct an assembly products supply chain (SC). Despite early recognition of the importance of the SC (Cohen[2]), only in recent years some researches were carried out for assembly products supply chain. Wang [10] took the model of an assembly-type supply chain system as a mixed-integer nonlinear programming (MINLP) problem, and found a composite formulation for the system. Cai [1] built a twice production mode of an assembly system under vendor managed inventory, and studied the operation mechanism of the assembly system, and got the suppliers' optimal inventory decisions.

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Hnaien [2] suggested a genetic algorithm for supply planning in two-level assembly system with random lead time, and found the optimal release dates for the components at level 2 in order to minimize the total expected cost. On the other hand, the assembly products supply chain is similar to Assemble-To-Order (ATO) SC, but ATO SC aims at order, not market demand (Liang [6]). Shao [8] addressed the strategic pricing decisions of a decentralized assemble-to-order system, and found that reduction of suppliers in the system does not guarantee improvement of system performance.

In some cases, there may be one supplier who monopolizes the price of an important component in the market because of shortage of capital, technology or area (Tayur [9]). For example, Intel monopolizes the mobile CPU. The supplier will supply all assemblers with the component at the same monopoly price, while each assembler has to purchase other components besides this important component. The other components are supplied by different suppliers, so their prices will be different. In this case, one monopoly supplier, some assemblers and many component suppliers construct a new assembly products SC. The assembly products SC is a common phenomenon in IT manufacture area, but there is scanty research on this issue.

This paper aims at making optimal decisions in assembly products SC, and studies the equilibrium solution for each participant in Nash game and union decision. The profit of each participant in Nash game and union decision is explored. The rest of this paper is organised as follows: In Section 2, an assembly products supply chain model is built, where there is one supplier and two assemblers. In Section 3, a Nash game model is built for three participants making decisions based on the supply chain model. A union model to maximize the total profit of the SC is built in Section 4. In Section 5, the price policy and the profits of three participants are analyzed by using a numerical simulation and the laws of changes in pricing strategy and profits with the variety of some characters are obtained. Section 6 provides the conclusions as well as suggestions for future research.

2. Assembly Products Supply Chain

The notations used in this paper are marked as follows.

c：monopoly supplier's marginal production cost for a common key component.

c_i：the cost of the other components of assembler i, not including the common key component. i=1,2.

f：monopoly supplier's wholesale price for the key component , which is the decision-making variable for supplier and the purchase cost for assembler.

r_i：assembler's price markup rate for product i, which is a product marginal profit rate and the decision-making variable for assembler. i=1,2.

$P_i=(1+r_i)(f+c_i)$：product i retail price. i=1,2.

π_i：assembler i's profit. i=1,2.

π_s：supplier's profit.

π：total profit of the SC.

q_i：the demand of product i. i=1,2.

a：the constant of market scale.

k：the parameter of market demand function q_i, which denotes price flexibility.

b：the parameter of market demand function q_i, which shows the extent that one product can substitute for the other.

It is supposed that there are two assembly products assemblers in supply chain (named as assembler 1 and 2), such as notebook PC assemblers. They need a common key component, such as a mobile CPU, which is supplied by a monopoly supplier S at a price f, and the supplier produces the component at a cost c. After obtaining the key component, the two assemblers will purchase other components. Because of different setting of assembly products made by different assemblers, the costs of other components are not the same either, c1 to assembler 1 and c2 to assembler 2, respectively. Suppose the product setting of assembler 2 is higher than assembler 1, then c1<c2. After the assemblers finished products assembling, they will distribute the products in the market at a retail price of Pi, which is made by adding a price markup rate r1 or r2 to the products whole cost. Because product 1's basic function is the same as that of product 2, they are similar products and can substitute each other. But the setting of product 2 is higher than product 1, such as shape etc., they can be seen as differentiated products. Suppose the total market scale of products 1 and 2 is 2a, and the retail price of 1 and 2 are P1 and P2, respectively. According to Wendell [11], the market demand for differentiated products 1 and 2 may be:

$$q_1=a-kP_1+bP_2\ ;\ \ q_2=a-kP_2+bP_1 \quad (1)$$

Respectively. Among them, k and b are larger than 0, and the absolute value of k denotes price flexibility, namely, the variety of demand caused by product price fluctuation. The bigger the value of k, the more the demand changes with price. The term b means the extent that one product can substitute the other, and the bigger of b, the larger the extent one can substitute the other. In this case, there are three decision-making participants, assembler 1, 2 and supplier. Each participant has its own profit and makes its decision independently. The assembly products SC including one supplier and two assemblers is shown as Fig.1, where the retail price is:

$$P_i=(1+r_i)(f+c_i);\ \ i=1,2. \quad (2)$$

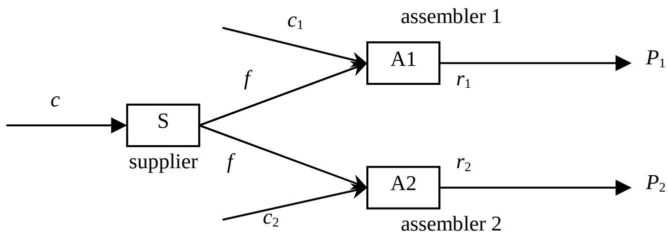

Fig.1. The structure of assembly products SC

Substituting (2) in (1), we can obtain the market demands for product 1 and 2 are:

$$q_1=a-k(1+r_1)(f+c_1)+b(1+r_2)(f+c_2)\ ;\ \ q_2=a-k(1+r_2)(f+c_2)+b(1+r_1)(f+c_1) \quad (3)$$

So the quantity of product i that assembler i will produce is q_i. From (2), we can find that one product i's profit is: $P_i-c_i = (f+c_i)\, r_i$. So the total profit of assembler i is $q_i.(P_i-c_i)$. Namely, From (1) and (2), we can obtain the profit of assembler 1 is:

$$\pi_1= (a-kP_1+bP_2)(f+c_1)\, r_1 \quad (4)$$

and the assembler 2's profit is:

$$\pi_2= (a-kP_2+bP_1)\,(f+c_2)\, r_2 \quad (5)$$

The supplier's profit is:

$$\pi_S=[2a+(P_2+P_1)(b-k)](f-c) \quad (6)$$

Theorem 1: π_1, the profit function of assembler 1 is a concave function of r_1, and π_2 is a concave function of r_2.

On the other hand, if $k>b$, the profit function of supplier, π_S, is a concave function of f.
Proof for Theorem 1: By differentiating π_1 in (4) with respect to r_1, we can obtain:

$$\partial\pi_1/\partial r_1=[a-kP_1+bP_2-k\, r_1\,(f+c_1)](f+c_1) \tag{7}$$

$$\partial^2\pi_1/\partial r_1^2= -2k(f+c_1)^2<0 \tag{8}$$

So π_1 is a concave function of r_1 , and it reaches its max. if $\partial\pi_1/\partial r_1=0$. For π_2

$$\partial\pi_2/\partial r_2=[a-kP_2+bP_1-k\, r_2\,(f+c_2)](f+c_2) \tag{9}$$

$$\partial^2\pi_2/\partial r_2^2= -2k(f+c_2)^2<0 \tag{10}$$

So π_2 is a concave function of r_2, and it reaches its max. if $\partial\pi_2/\partial r_2=0$. For π_S

$$\partial\pi_S/\partial f=2a+(b-k)[P_2+P_1+(2+r_1+r_2)(f-c)] \tag{11}$$

$$\partial^2\pi_S/\partial f^2=2(b-k)(f+c_2)^2 \tag{12}$$

If $k>b$, the profit function of supplier, π_S, is a concave function of f, and it reaches its maximum if $\partial\pi_S/\partial f=0$.

3. Nash Game

In Nash game model, the strategy of one participant must be the optimal response to the strategies adopted by the others (Nash [7]). In assembly products supply chain, the decision-making variable of assembler i is price markup rate r_i, and that of supplier is component sale price f, which belongs to a continuous real number field. The maximal profit of assembler i can be described by a mathematical model: $\max_{r_i} \pi_i(r_i)$. It is known from theorem 1 that the optimal price markup rate r_i meets the equation: $\partial\pi_i/\partial r_i=0$. From (7) and (9), we can obtain:

$$a-k(f+c_1)(1+2r_1)+b(f+c_2)(1+r_2)=0\ ;\ \ a-k(f+c_2)(1+2r_2)+b(f+c_1)(1+r_1)=0 \tag{13}$$

For the same reason, the optimal supplier sale price meets equation: $\partial\pi_s/\partial f=0$. From (11), we have:

$$2a+(b-k)[(2+r_1+r_2)(2f-c)+c_1(1+r_1)+c_2(1+r_2)]=0 \tag{14}$$

$$f=\frac{(2a/(k-b)-c_1(1+r_1)-c_2(1+r_2))}{2(2+r_1+r_2)}+c/2 \tag{15}$$

In Nash equilibrium of assembly products supply chain, given the supplier's pricing strategy f, the optimal price markup rate r_i of assembler i can be obtained from (13). Similarly, we can obtain the optimal supplier sale price f from (15) if the assemblers' price markup rate strategies are given. So the pricing strategy of Nash equilibrium can be obtained from the combination of (13) and (15).

From (13), the optimal r_i can be obtained:

$$r_1=\frac{2ka_1+ba_2}{(f+c_1)(4k^2-b^2)};$$

$$r_2=\frac{2ka_2+ba_1}{(f+c_2)(4k^2-b^2)} \tag{16}$$

In (16), $a_1= a-k(f+c_1)+b(f+c_2)$; $a_2= a-k(f+c_2)+b(f+c_1)$. Substituting (16) in (14), we obtained:

$$2k^2(c_1+c_2+4f-2c)+(2f-c+c_1)[kb(f+c_2)+a(2k+b)]/(f+c_1)+(2f-c+c_2)[kb(f+c_1)+a(2k+b)]/(f+c_2)=2a(4k^2-b^2)/(k-b) \tag{17}$$

Equation (17) is a cubic equation with one variable, and the optimal f^* can be obtained by solving the equation. Substituting this f^* in (16), we can obtain the optimal r_i^*. Because of the complexity of the optimal solutions, we will not show these solutions in details.

4. Union Decision

If assembler and supplier make a union decision, they will form a new system, and the three participant's game will be turned into an optimal decision-making question of one SC. In union decision model, the profit of SC is maximized according to the principle that the total profit is much more important than that of one participant. When maximizing total profit, the assignment of total profit to each participant can be adjusted in order to make each participant gain as many profits as possible, which is a union profit distribution problem. The profit each participant gains must be more than what it gains under no-union decision.

In union decision model, the supplier sale price f is regarded as inner transfer price, which influences each participant's profit, but not on the total profit. The total profit is determined by product cost and retail price, and decision-making of supplier sale price f will be an effective way to coordinate the relationship between participants in the SC.

The total profit of assembly products supply chain is the sum of three participants' profits in SC:

$$\pi=\pi_1+\pi_2+\pi_s=(a-kP_1+bP_2)(P_1-f-c_1)+(a-kP_2+bP_1)(P_2-f-c_2)+[2a+(P_2+P_1)(b-k)](f-c) \tag{18}$$

From the system theory point of view, the assembly products supply chain can be regarded as a system. The input of the system is supplier's cost c, assembler's costs c_1 and c_2. The output of the system is the product retail prices P_1 and P_2. Thus, the SC total profit is the sum of the profits of products 1 and 2:

$$\pi=(a-kP_1+bP_2)(P_1-c-c_1)+(a-kP_2+bP_1)(P_2-c-c_2) \tag{19}$$

In union decision model, decision variables are price markup rate r_i and component sale price f. It is easy to prove that π, the total profit function of SC, is a concave function of r_1 , r_2 and f. The optimal price markup rate r_i can be obtain from equation $\partial\pi/\partial r_i=0$:

$$-k(P_1-c_1-c)+a-kP_1+bP_2+b(P_2-c_2-c)=0 \quad (20)$$

$$-k(P_2-c_2-c)+a-kP_2+bP_1+b(P_1-c_1-c)=0 \quad (21)$$

Differentiating (19) with respect to f:

$$\partial\pi/\partial f=(1+r_1)(-k(P_1-c_1-c)+a-kP_1+bP_2)+b(1+r_2)(P_1-c_1-c)+(1+r_2)(-k(P_2-c_2-c)+a-kP_2+bP_1)+b(1+r_1)(P_2-c_2-c) \quad (22)$$

Substituting (20) and (21) in (22), we obtain: $\partial\pi/\partial f=0$. Namely, under the condition of (20) and (21), $\partial\pi/\partial f=0$ is an identical equation, which proves that f is only a inner status variable (shift payment), not a decision variable.
Adding (20) to (21), we have:

$$P_1+P_2= c +(c_1+ c_2)/2+a/(k-b) \quad (23)$$

It is the retail price obtained from equation (23) that makes the total profit of the SC maximal. From (23), it is known that the retail price only relies on supplier and assembler's cost, namely system input. Equation (23) describes the relationship between decision variables (f, r_1, r_2) when SC total profit reaches its maximum, but the real values of decision variables (f, r_1, r_2) are determined by treaty or by Nash bargaining model (Wendell [11]). In fact, the status of each participant in SC determines its profit in union model.

5. Numerical Simulation for Nash Game

Supposing there is a CPU clip supplier S, which sells the same CPU chip to two PC assembly products assemblers simultaneously. Given CPU chip's cost, c is 100; and the cost of the other components of assembler 1, c_1 is 800, and that of assembler 2, c_2 is 760. The relationship between retail price and market demand of product 1 or 2 can be shown in demand function: $q_1=2000-2P_1+P_2$; $q_2=2000-2P_2+P_1$. The corresponding parameters are: $c=100$, $c_1=800$; $c_2=760$; $a=2000$;$k=2$;$b=1$. These parameters meet the conditions of Theorem 1, and the solution of Nash equilibrium can be obtained from combination of (16) and (17). The solution is: $(r_1,r_2, f)=(0.174, 0.199, 502.912)$, and it can be obtained by using Newton iterative method. The profits of assemblers 1 and 2 and the supplier can be worked out as: $(\pi_1, \pi_2, \pi_S)=(103080, 126030, 385230)$. Obviously, the supplier will earn much more than each assembler in the SC.

The Nash equilibrium solution will change with the variety of market scale a, supplier's cost c, assembler i's other components cost c_i, and market demand function's parameter k or b etc..

If market scale a increases from 1000 to 2800, the corresponding parameters such as supplier sale price f, assembler's price markup rate r_i, three participants' profits, market demand will change with the variety of a, which is shown in Fig. 2, where the data are taken from Tab. 1. From Fig. 2 and Tab. 1, we can draw some conclusions: 1) With the increasing of market scale a, the values of all of the above parameters will increase too. Namely, market scale enlarging results in larger output of the whole SC. 2) The supplier sale price f is much higher than its cost, so supplier will earn much more profit, which comes from its monopoly status in market. We can also observe that the profit increment of supplier is higher than that of each assembler. In short, with the increasing of market scale, the performance of every participant in SC will increase.

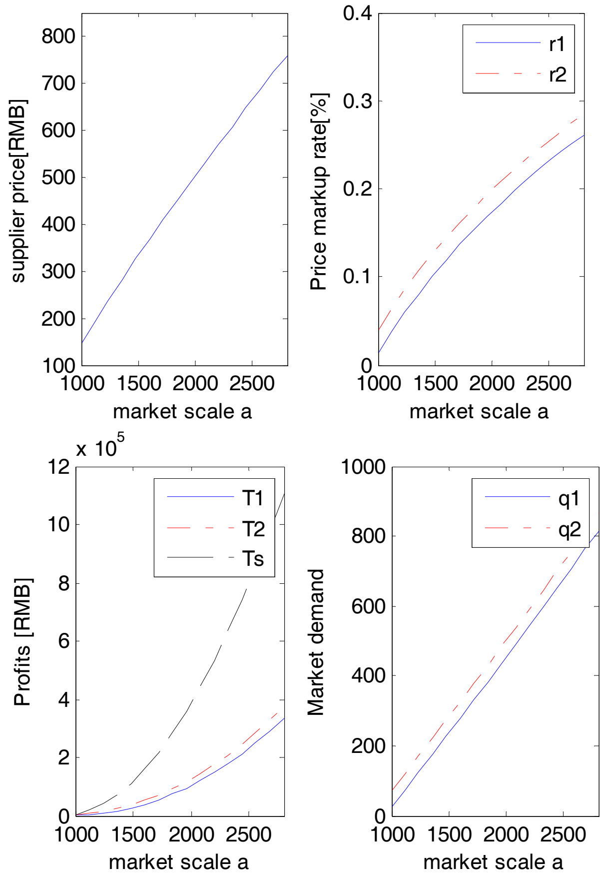

Fig. 2. the variety charts with market scale changing

Table 1
The generated data when market scale changing in Nash game

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
a	1000	1120	1240	1360	1480	1600	1720	1840	1960	2080	2200	2320	2440	2560	2680	2800
f	147.25	193.17	237.96	281.76	324.70	366.88	408.37	449.25	489.58	529.41	568.78	607.73	646.29	684.50	722.37	759.94
r_1	0.013	0.037	0.060	0.081	0.101	0.119	0.137	0.153	0.169	0.184	0.199	0.212	0.225	0.238	0.250	0.262
r_2	0.040	0.064	0.086	0.107	0.126	0.145	0.162	0.178	0.194	0.209	0.223	0.236	0.249	0.261	0.273	0.284
π_1	300	2729	7691	15282	25583	38665	54589	73408	95169	119916	147685	178511	212425	249454	289624	332959
π_2	2628	7428	14797	24826	37593	53165	71601	92952	117263	144575	174924	208344	244863	284510	327308	373281
π_s	4583	18240	40844	72278	112440	161237	218585	284407	358633	441199	532047	631122	738375	853759	977232	1108753
π	7511	28398	63331	112385	175616	253067	344774	450766	571065	705690	854656	1017977	1195663	1387723	1594165	1814994
q_1	24.5	73.9	124.0	174.8	226.2	278.1	330.4	383.2	436.3	489.7	543.5	597.5	651.8	706.3	761.1	816.0
q_2	72.5	121.9	172.0	222.8	274.2	326.1	378.4	431.2	484.3	537.7	591.5	645.5	699.8	754.3	809.1	864.0

Fig. 3 reveals the changing of Nash equilibrium solution curves when the supplier's cost varies from 50 to 200. The data are shown in Tab. 2. Several conclusions can be drawn: 1). With the increasing of supplier's cost, all the parameters will decrease except supplier sale price *f*. The raising of supplier cost leads its profit decrease, so supplier will increase its monopoly component sale price. As a result, assembler has to cut down product price markup rate in order to avoid high retail price affecting market demand. Namely supplier transfers some profit loss caused by cost increasing to assembler, which makes assembler profit cut down. 2). The extent of supplier profit decreasing is higher than that of assembler, due to the reason that the source of profit loss comes directly from supplier's cost increasing, and assembler only adjusts its price markup rate to this loss to a finite extent. 3). On the other hand, because an entity in SC only gives finite reactions to external circumstances' changing, the increasing of the supplier's cost will ultimately make assembly products' retail price increase, which makes market demand diminish. So we can say that high supplier's cost will make every participant's profit loss in the SC.

Fig. 4 shows the changing of Nash equilibrium solution curves when assembler 1's cost varies from 700 to 800. The data are shown in Tab. 3. We can draw some conclusions from Fig. 4 and Tab. 3:1) With the increasing of assembler 1's cost, the parameters of supplier and assembler 1 will decrease, while those of assembler 2 will increase. Because the increasing of assembler 1's cost will make its retail price increase, it will make its product market demand cut down. If product market demand cuts down, the demand of key component supplied by supplier will also cut down. As a result, the supplier's key component sale price will cut down, and its profit will decrease. On the other hand, assemblers 1 and 2 are competitors in market, and the increasing of product 1's retail price will make product 2's market demand increase. Thus, the profit and markup rate of assembler 2 will increase. 2) There is a point of intersection in Fig. 4, which shows that the price markup rate, demand and profit will be the same for the two assemblers if the other components cost of assembler 1 is equal to that of assembler 2. So we can conclude that enterprise's cost determines its profit and status in SC. The increasing of one assembler's cost will make its profit and supplier's profit reduce, but benefit its competitor. The variety charts with the changing of assembler 2's cost is the same as Fig. 4.

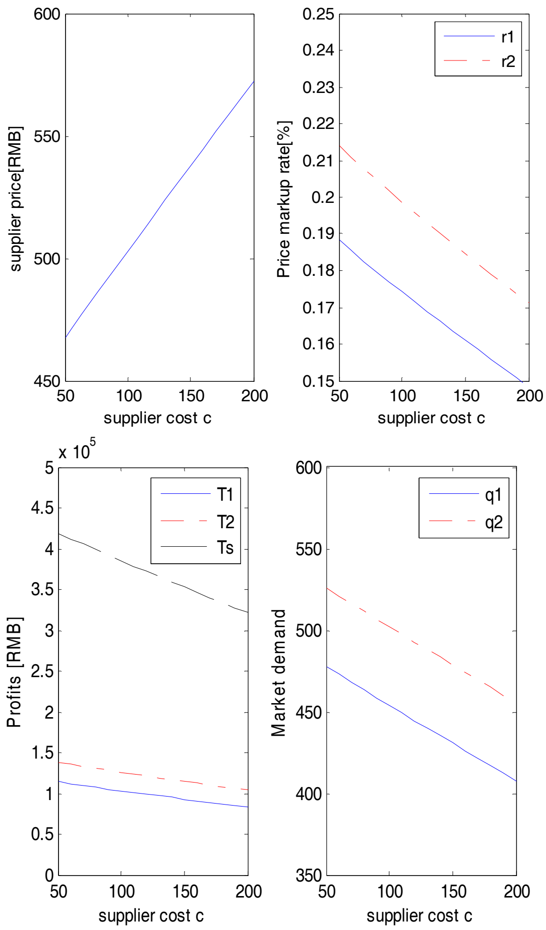

Fig. 3. The variety charts with supplier's cost changing

Table 2
The generated data when supplier's cost changing in Nash game

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
c	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
f	467.58	474.68	481.77	488.83	495.88	502.91	509.92	516.92	523.9	530.86	537.81	544.74	551.65	558.55	565.43	572.3
r_1	0.188	0.186	0.183	0.180	0.177	0.174	0.172	0.169	0.166	0.164	0.161	0.159	0.156	0.154	0.151	0.149
r_2	0.214	0.211	0.208	0.205	0.202	0.199	0.196	0.193	0.190	0.187	0.185	0.182	0.179	0.176	0.174	0.171
π_1	114057	111807	109585	107390	105224	103085	100973	98888	96830	94798	92792	90813	88859	86931	85028	83151
π_2	138135	135657	133208	130788	128396	126031	123695	121386	119105	116850	114622	112421	110246	108097	105974	103877
π_s	418927	412094	405307	398567	391875	385231	378636	372089	365591	359144	352746	346398	340101	333855	327661	321518
π	671119	659558	648099	636745	625494	614347	603303	592363	581526	570792	560160	549632	539207	528884	518663	508546
q_1	477.6	472.9	468.2	463.4	458.8	454.1	449.4	444.7	440.1	435.4	430.8	426.2	421.6	417.0	412.4	407.8
q_2	525.6	520.9	516.2	511.4	506.8	502.1	497.4	492.7	488.1	483.4	478.8	474.2	469.6	465.0	460.4	455.8

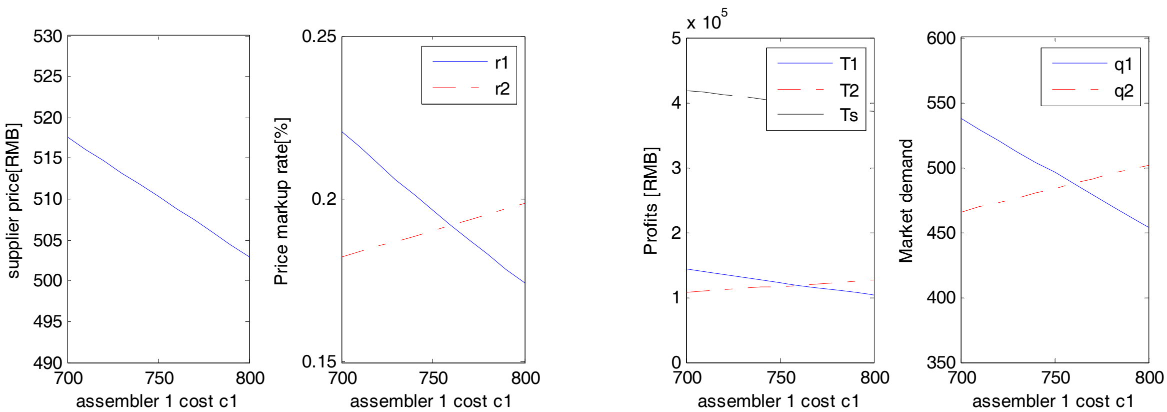

Fig. 4. the variety charts with assembler 1's cost changing

Table 3
The generated data when assembler 1's cost changing in Nash game

	1	2	3	4	5	6	7	8	9	10	11
c_1	700	710	720	730	740	750	760	770	780	790	800
f	517.52	516.11	514.68	513.25	511.8	510.35	508.88	507.4	505.92	504.42	502.91
r_1	0.221	0.216	0.211	0.206	0.201	0.197	0.192	0.188	0.183	0.179	0.174
r_2	0.182	0.184	0.186	0.187	0.189	0.190	0.192	0.194	0.195	0.197	0.199
π_1	144537	140060	135657	131328	127074	122893	118785	114751	110790	106901	103085
π_2	108418	110104	111807	113526	115263	117016	118785	120572	122375	124195	126031
π_s	418899	415492	412094	408704	405323	401951	398588	395234	391890	388556	385231
π	671854	665656	659558	653559	647659	641859	636159	630557	625055	619651	614347
q_1	537.7	529.3	520.9	512.5	504.1	495.8	487.4	479.1	470.7	462.4	454.1
q_2	465.7	469.3	472.9	476.5	480.1	483.8	487.4	491.1	494.7	498.4	502.1

6. Conclusions

In this paper, a two-stage assembly products supply chain model was developed. We studied the product pricing strategy in the SC by building Nash game model and union decision model. In Nash game model, an optimal combination price strategy of assembly products was developed, and the relationship between supplier's strategy and assembler's strategy was investigated in the union decision model. Using numeric simulation, we studied how Nash equilibrium solutions change along with variations in some parameters, such as market scale a, supplier cost *c*, assembler *i* cost, and drew the following conclusions: 1) All the entities' performances in SC will increase with the increasing of market scale. 2) High supplier's cost will make every participant's profit decrease in the SC. 3) the cost increasing of one assembler will make its profit and the supplier's profit Decrease, but it will benefit its competitors. All of these conclusions are consistent with economic principles.

The future work may concentrate on applying the proposed model to the instances where more suppliers and assemblers are involved. This is interesting and significant for supply chain theory, though not directly and in a straightforward way.

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