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Research on mixed decision contract of supply chain based on retailer handling single cycle perishable product sales surplus

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Abstract. This paper has set up supply chain mixed decision contract for seller dealing with single-cycle perishable products sales surplus. Sellers face random demand and the sales surplus at the end of the cycle is handled by sellers. At this moment, sellers bear greater risks and costs, sellers will participate in cooperation and cost sharing actively; while the conditions for sellers bearing smaller risks and costs participating in the cooperation are: the profit of supplier under cooperation increases than not cooperation or the decrease of profit is within the allowable range than not cooperation. As the supply chain model of benchmark, it can realize coordination through the contract of suppliers and sellers sharing sales surplus cost. The coordination is based on the consensus reached between parties of supply chain to maintain higher service level and try to avoid out of stock. Firstly, it describes the negotiation process of service level optimization and mixed decision contract integration; secondly, it adopts the game method of Stackelberg to solve the model; finally, it verifies the process of confirming the best decision interval with model when supply chain faces different system parameters and demand distributions through examples.

Key words. Single cycle, Perishable product, Mixed decision contract, Supply chain optimization, Seller.

1. Introduction

In recent years, with the continuously increasing of people's living standard, people have increasingly greater demand for perishable products, such as fresh food, which proposes higher demand for the supply chain management of this kind of products. Perishable products refer to the products with very short life cycle and

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have to be sold within limited time. The surplus value of this kind of products will disappear or decrease dramatically after the ending of sales cycle. However, single-cycle products refer to products with only one ordering opportunity and one sales cycle. This kind of products is with greater operation risks, because its timeliness is very strong and the demand fluctuation has greater uncertainty. Generally speaking, most of perishable products are single-cycle sales due to the short sales life cycle. This paper takes this as hypothesis and makes research on the supply chain contract coordination problem of single-cycle perishable products.

In the relationship between overall supply chain and suppliers and sellers, the design of the optimal incentive contract is established on the basis of maximization of respective utility. Individual always seeks for maximization of self effect and wants each member to participate in the contract actively. The arrangement of system must firstly meet the individual rationality and then try to realize the maximization of overall effect on this basis, or else the supply chain members may refuse to participate in cooperation or adopt an act of laziness and opportunistic behavior. The overall supply chain can't adopt compulsory contract to make suppliers and sellers select the behavior it hopes, but realize the coordination through designing acceptable contract for suppliers and sellers. The study of coordination problem of supply chain under contract is actually analyzing whether the equilibrium solution of game between members reaches or near to the optimal solution of the overall supply chain under the situation with game existed between members.

2. Description of model

2.1. *Hypothesis of model*

The supply chain contract coordination of single-cycle perishable products studied in this paper is assumed to be composed of one supplier and one seller and both of them are with risk neutrality. Sellers face random demand and the sales surplus at the end of the cycle will be handled by the seller. At this moment, the sellers bear greater risks and costs, the sellers will participate in cooperation and cost sharing actively; while the conditions for sellers bearing smaller risks and costs participating in the cooperation are: the profit of supplier under cooperation increases than not cooperation or the decrease of profit is within the allowable range than not cooperation. As the supply chain model of benchmark, it can realize coordination through the contract of suppliers and sellers sharing sales surplus cost. The coordination is based on the consensus reached between parties of supply chain to maintain higher service level and try to avoid out of stock. Related parameter hypothesis is as following:

p: unit sales price of seller's product;

c: unit purchase price of seller's product (the unit supply price of supplier);

p_x : unit production cost of supplier's product;

s_p : unit processing price of seller handling remaining products (assume the seller can't attain profit from it, that is $s_p < c$)

s_b : unit price of returning remaining products to supplier based on agreement of return contract (assume the supplier can't attain profit from it, that is $s_b < p_x$)

C_o : loss cost of unit product when supply is bigger than demand, that is the unit cost of handling surplus product;

C_u : loss cost of unit product when supply is smaller than demand; the lost cost at this moment is the cost caused by customer loss, which is the unit profit fail to attain, $C_u = p - c$;

m : the time experienced in the whole sales cycle, m can be day, week, month, hour or any time interval. For convenient description, this paper is calculated on daily basis.

h_w : daily inventory cost of unit product. Inventory cost will not be calculated if the inventory is less than one day. Assume $p - c - \mathrm{m}h_w > 0$;

β_s : sellers bear $\beta_s mh_w$, suppliers bear $(1-\beta_s)mh_w$, $0 < \beta_s \le 1$, $\beta_s = 1$ that is sellers bear inventory cost independently;

γ_p : distribution factor of cost whose sales surplus is handled by sellers; at this moment, the sales surplus cost borne by sellers is $C_o = \gamma_p(c - s_p) + \beta_s mh_w$;

γ_b : the distribution factor of handling cost when the sales surplus is handled by suppliers. Sellers bear $\gamma_b(p_x - s_b)$, suppliers bear $(1-\gamma_b)(p_x - s_b)$, $0 \le \gamma_b < 1$, $\gamma_b = 0$ is the situation when suppliers bear handling cost independently.

Sellers face random demand x within sales cycle, demand expectation is μ, standard deviation is σ; distribution density function of demand is f(x), distribution function F(x). Distribution function meets that F is continuously differentiable and strictly increasing and F(0)=0, the inverse function of F is marked as $\mathrm{F}^{-1}(\cdot)$.

In addition, assume $\mathrm{s}_p - p_x - \mathrm{m}h_w < 0$, that is supply chain can't attain profit from handling surplus. To make it convenient for discussion, record u=$p - c - mh_w/2 > 0, v = c - s_p + mh_w > 0$.

At the same time, following four sets of hypothesis conditions have been introduced for easy discussion.

(1) The overall target of supply chain is coordinating the divergences of suppliers and sellers in profit distribution, so as to make maintaining high and stable service level as consensus and decrease the distance between optimal decision of unilateral decision and optimal decision of overall supply chain;

(2) The surplus at the end of sales cycle is handled by suppliers or sellers. Supply chain can't attain profit from surplus handling. The cooperation between sellers and suppliers is the sharing for inventory cost and handling cost of sales surplus;

(3) The distribution factor $\beta_s, \gamma_p, \gamma_b$ between suppliers and sellers for inventory cost and handling cost of sales surplus may have coordinated behavior. The overall supply chain only considers about the distribution of overall surplus cost between these two parties, but not intervene the negotiation between suppliers and sellers for distribution factor $\beta_s, \gamma_p, \gamma_b$.

(4) Both suppliers and sellers can predict the demand distribution faced by sellers accurately. The information is complete, that is both suppliers and sellers know the cost structure and income function of each other.

2.2. Operation mode of model

Sellers have to order some products based on the predicted demand before the sales cycle starts; sales surplus at the end of the cycle will be handled by sellers completely at a lower price. Under the situation of cooperation, two parties share the cost of sales surplus together (including processing cost $c - s_p$ and inventory cost mh_w of sales surplus). The distribution system is as shown in figure 1.

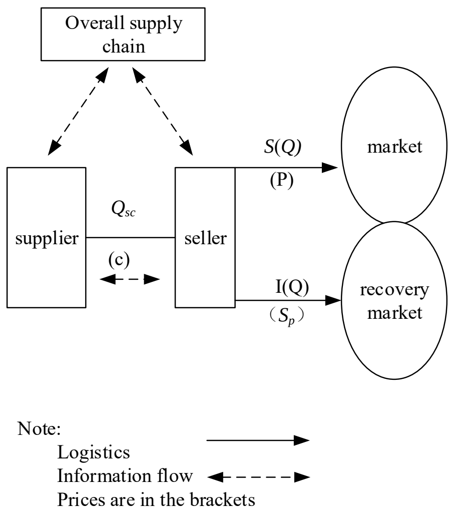

Fig. 1. Supply chain distribution system schematic diagram

The model is operated in the following way:

Firstly, sellers and suppliers predict random demand together and attain its distribution as F; and then suppliers propose one contract to sellers (that is the sharing of sales surplus cost $C_o(\beta_s, \gamma_p)$, called as C_o); assume this contract is accepted by sellers, and then the sellers will propose certain order amount on this basis. Assume members of supply chain are forced to follow the overall; under this system, suppliers have to ensure that the entire possible order amount in all contracts has to be satisfied. The suppliers do not have the right of selecting output.

According to the hypothesis, suppliers own the demand information of sellers; at the same time, own related information of ordering cost and inventory cost. The game process consists of three stages:

In the first stage, suppliers determine decision variables, which is the contract of cost sharing C_o;

In the second stage, sellers determine decision variable that is order quantity Q after observed the contract declared by suppliers;

In the third stage, under the optimal decision interval (contract constraint) formed in the previous two stages, confirm marketing contract about $C_o(\beta_s, \gamma_p)$ based on their participation conditions.

First two stages of model is the advanced Stackelberg game of suppliers and is the process of joint decision forming contract constraint. The third stage is the unilateral decision making process of suppliers and sellers under this contract constraint. The final equilibrium is the marketing contract that has been reached.

When the order quantity of sellers is Q, define:

Expected sales quantity:

$$\begin{aligned} S(Q) &= E\min\{Q,x\} = Q(1-F(Q)) + \int_0^Q xf(x)dx \\ &= Q(1-F(Q)) + \int_0^Q xdF(x) = Q - \int_0^Q F(x)dx\,. \end{aligned} \tag{1}$$

Expected sales surplus amount:

$$I(Q) = E(Q-x)^+ = Q - S(Q)\,. \tag{2}$$

As $[\int_0^Q F(x)dx]'_Q = F(Q)$ increases, S(Q)and I(Q)about order quantity present monotonous increase.

In the following, we call the ordering strategy of sellers determining order quantity based on demand information when there is no cooperation and no cost sharing as strategy I and call the ordering strategy of supplier publishing contract C_o in advance and sellers determine order quantity after accepting contract as strategy II when two parties cooperate and share the sales surplus cost.

3. Profit analysis of model

3.1. *Profit analysis of strategy I*

When there is no cooperation and no cost sharing, sellers determine order quantity Q based on the optimal service level of demand information decision $CSL_r^0 = \frac{u}{u+v}$.

1) Expected profit of sellers is:

$$\begin{gathered} \pi_r^0(Q) = pS(Q) + s_pI(Q) \\ -[cS(Q) + cI(Q) + mh_w/2\cdot S(Q) + mh_wI(Q)] \end{gathered} \tag{3}$$

In which, the first part is expected sales income; the second part is expected income of sales surplus (as there is no sharing of processing cost of sales surplus, sellers own residual value s_p of surplus processing; at the same time, bear purchasing cost of sales surplus independently); the third part is cost, in which $cS(Q)$ is the purchasing cost of expected sales part, $cI(Q)$ is the purchasing cost of expected sales surplus, $mh_w/2\cdot S(Q)$ is the average inventory cost of expected sales part and the $mh_wI(Q)$ is the inventory cost of sellers bearing expected sales surplus independently. After simplification, it can get:

$$\begin{aligned} \pi_r^0(Q) &= (p-c-mh_w/2)S(Q) - (c-s_p+mh_w)I(Q) \\ &= uS(Q) - vI(Q)\,. \end{aligned} \tag{4}$$

2) Expected profit of suppliers is:

$$\pi_s^0(Q) = cQ - p_x Q = (c - p_x)Q\,. \tag{5}$$

As the sales surplus is handled by sellers, the sellers bear the cost and there is no return, the profit of suppliers is the difference between sales income and production cost. Due to following compulsory obedience system, the suppliers do not have the right of selecting output: $[\pi_s^0(Q)]'_Q = c - p_x$ is irrelevant to order amount.

3) Expected profit of overall supply chain

Profit of overall supply chain is the sum of profits of sellers and suppliers. Based on formula (4) and formula (5) and introducing Q=I(Q)+S(Q), it can get:

$$\begin{aligned}\pi_{SC}^0(Q) &= \pi_r^0(Q) + \pi_s^0(Q)\\ &= (p - p_x - mh_w/2)S(Q) + (s_p - p_x - mh_w)I(Q)\,.\end{aligned} \tag{6}$$

In which the first part is the profit of sold part and the second part is the profit of sales surplus.

When system parameter and demand distribution are confirmed, the optimal order quantities of seller decision $Q_r^0 = F^{-1}(CSL_r^0) = F^{-1}(\frac{u}{u+v})$ and $S(Q_r^0) = Q_r^0 - \int_0^{Q_r^0} F(x)dx$, $I(Q_r^0) = Q_r^0 - S(Q_r^0)$ are constants. Define the maximum expected profit of two parties without cooperation as:

Sellers: $\pi_r^0(Q_r^0) = uS(Q_r^0) - vI(Q_r^0) = a_0$ (constant);

Suppliers: $\pi_s^0(Q_r^0) = (c - p_x)Q_r^0 = b_0$ (constant);

Under the state without cooperation, the maximum expected profit of overall supply chain is $\pi_{SC}^0(Q_r^0) = a_0 + b_0$ (constant).

When the basic parameters of the system, especially when the selling price and cost p, c, s_p, p_x of two parties are different, a_0 and b_0 are different. For situation with $a_0 \geq b_0$, refer to examples 1, 4-2; for situation with $a_0 < b_0$, refer to example 3.

3.2. Profit analysis of strategy II

Under the situation of cooperation and sharing sales surplus cost, assume after sellers accepting the contract $C_o = C_o(\beta_s, \gamma_p)$ provided by suppliers, the optimal service level of decision is $CSL_r^* = \frac{u}{u+C_o}$ and the order quantity of decision is $Q(C_o)$.

(1) Expected profit of sellers is:

$$\begin{aligned}\pi_r(Q(C_o)) =& pS(Q(C_o)) + \gamma_p s_p I(Q(C_o))\\ &- [cS(Q(C_o)) + \gamma_p c I(Q(C_o))\\ &+ mh_w/2 \cdot S(Q(C_o))\\ &+ \beta_s mh_w I(Q(C_o))]\,.\end{aligned} \tag{7}$$

In which, the first part is expected sales income; the second part is expected income of sales surplus (s_p is the residual value of processing sales surplus, $\gamma_p s_p$ is the residual value after sharing with suppliers; in fact, when the suppliers share the processing cost of sales surplus, they share the residual value s_p of sales surplus processing and purchasing cost c of sales surplus); the third part is the cost, in which

$cS(Q(C_o))$ is purchasing cost of expected sales part, $\gamma_p cI(Q(C_o))$ is the purchasing cost of expected sales surplus after sharing (suppliers share this cost, which equals to return some purchasing cost to sellers), $mh_w/2 \cdot S(Q(C_o))$ is the average inventory cost of expected sales part, $\beta_s mh_w I(Q(C_o))$ is the inventory cost of expected sales surplus after sharing. After simplification, it can get:

$$\begin{aligned}\pi_r(Q(C_o)) =&(p-c-mh_w/2)S(Q(C_o))\\ &-[\beta_s mh_w+\gamma_p(c-s_p)]I(Q(C_o))\\ =&uS(Q(C_o))-C_oI(Q(C_o))\,.\end{aligned} \tag{8}$$

(2)Expected profit of suppliers is:

$$\begin{aligned}\pi_s(Q(C_o)) =&cQ(C_o)+(1-\gamma_p)s_pI(Q(C_o))\\ &-[p_xQ(C_o)+(1-\gamma_p)cI(Q(C_o))\\ &+(1-\beta_s)mh_wI(Q(C_o))]\,.\end{aligned} \tag{9}$$

In which, the first part $cQ(C_o)$ is sales income; the second part $(1-\gamma_p)s_pI(Q(C_o))$ is the expected income of sales surplus, $(1-\gamma_p)s_p$ is the residual value of sharing sellers processing surplus; the third part is cost, in which $p_xQ(C_o)$ is production cost, $(1-\gamma_p)cI(Q(C_o))$ is the purchasing cost of sharing the expected sales surplus of sellers (in fact, when the suppliers share the processing cost of sales surplus, it shares the purchasing cost c of sellers for sales surplus, which equals to offer some profits to sellers), suppliers do not share the overage inventory cost of the sold part and only share the inventory cost $\beta_s mh_w I(Q(C_o))$ of expected sales surplus. After simplification, it can get:

$$\begin{aligned}\pi_s(Q(C_o)) =&(c-p_x)Q(C_o)-[(1-\gamma_p)(c-s_p)\\ &+(1-\beta_s)mh_w]I(Q(C_o))\\ =&(c-p_x)Q(C_o)-(v-C_o)I(Q(C_o))\end{aligned} \tag{10}$$

(2) Expected profit of overall supply chain

Profit of overall supply chain is the sum of profits of suppliers and sellers. It can get from (8) and (10) that:

$$\begin{aligned}\pi_{SC}(Q(C_o)) =&\pi_r(Q(C_o))+\pi_s(Q(C_o))\\ =&(p-c-mh_w/2)S(Q(C_o))\\ &+(c-p_x)Q(C_o)-(c-s_p+mh_w)I(Q(C_o))\end{aligned}$$

Substitute $I(Q(C_o))=Q(C_o)-S(Q(C_o))$, it can get:

$$\begin{aligned}\pi_{SC}(Q(C_o)) =&(p-p_x-mh_w/2)S(Q(C_o))\\ &+(s_p-p_x-mh_w)I(Q(C_o))\,.\end{aligned} \tag{11}$$

The same as strategy I, this is because cost sharing is actually the transfer payment between members of supply chain, which happens only between members and does not affect the overall profit. It can be learnt from (6) that the profit of overall supply chain is irrelevant to contract C_0 and only relevant to order quantity Q.

4. Example analysis

Table 1. System parameter table

Example	p (RMB)	c (RMB)	sp (RMB)	px (RMB)	m (day)	hw (RMB)	μ (pc)	σ	v (RMB)
Example 1	39	18	12	10	100	0.1	100	10	16
Example 2	39	18	12	5	100	0.1	1000	50	16
Example 3	20	16	13	11	30	0.1	1000	200	6

(1) Example 1

When the system parameter is the example 1 in table 4-1, the participation interval of sellers is [0, 16]. Suppliers promise that expected profit at the end of contract is smaller than the profit without cooperation$b_0 = 800$, but numerical calculation indicates that from $C_o^{r0} = 10.8$, $1 - [\pi_s(Q_r^*(C_o^{r0})]/b_0 \leq 0.01$, suppliers promise that the expected profit of contract C_o^{r0} decreases less than 1% than that without cooperation. Therefore, the participation internal of suppliers is $C_o^{\in}[C_o^{r0}, v] = [10.8, 16]$; at this moment, $\pi_s(Q_r^*(C_o^{r0}) = 791.9616$.

$\pi_r(Q_r^*(C_o^{r0}) = 1496.122$, $\pi_s(Q_r^*(C_o^{r0}) + \pi_r(Q_r^*(C_o^{r0}) = 2288.0835 > a_0 + b_0$, the total profit of supply chain under contract $C_o^{r0} = 10.8$ is increased than noncooperation.

In addition, $Q_r^0 = 100$, $Q_r^*(C_o^{r0}) = 102.44, Q_{SC}^* = 106.7449$, $Q_r^0 < Q_r^*(C_o^{r0}) < Q_{SC}^*$, therefore, the equilibrium solution of game is $C_o^{\in}[C_o^{r0}, v]$, that is $[10.8, 16]$. As$Q_r^*(C_o^*) \leq Q_{SC}^*$, $\pi_{SC}(Q_r^*(C_o^{r0}) = 2288.0835$, it is smaller than optimal of overall supply chain$\pi_{SC}(Q_{SC}^*) = 2298.3114$, this example belongs to the situation shown in figure 2.

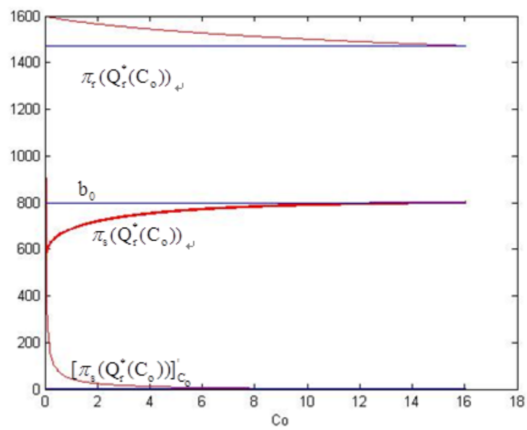

Fig. 2. Output result of example 1

Table 2. Example 1 equilibrium analysis table

Supplier participation interval	a_0 (RMB)	b_0 RMB	Overall optimal $\pi_{SC}(Q^*_{SC})$	Optimal order quantity of supply chain Q^*_{SC}	Optimal order quantity without cooperation	Decision point C_o^{r0}
[10.8, 16]	1472.3384	800	2298.3114	106.7448	100	10.8
Contract C_o	Seller's profit under contract $\pi_r(Q^*_r(C^*_o))$	Supplier's profit under contract $\pi_s(Q^*_r(C^*_o))$	Sum of profits of two parties under contract $\pi_{SC}(Q^*_r(C^*_o))$	Sum of profits of two parties without cooperation a_0+b_0	Differentiation for C_o	Order quantity under contract $Q^*_r(C^*_o)$
...	...	...	...	...	...	...
1.23	1576.574	695.9524	2272.526 starts to be bigger than a_0+b_0	2272.3384	37.51	114.6712
...	Decrease progressively...	Increase progressively...	Increase progressively...	2272.3384	Decrease progressively...	Decrease progressively...
5.32	1532.301	766.0104	2298.3114 (achieve the biggest)	2272.3384	8.25	106.7574
...	Decrease progressively...	Increase progressively...	Decrease progressively...	2272.3384	Decrease progressively...	Decrease progressively...
5.87	1527.934	770.2137	2298.1475	2272.3384	7.226448	106.1805
$C_o^{r0}=10.8$	1496.122	791.9616	2288.0835	2272.3384	2.51	102.4413
...	Decrease progressively...	Increase progressively...	Decrease progressively...	2272.3384	Start to be smaller than 0...	Decrease progressively...
16	1472.426 Near a_0	799.981 Near b_0	2272.4074	2272.3384	0.86	100.0086

The reason for bigger difference between game result and overall optimal is that the conditions for suppliers to participate in the cooperation are too strict; therefore, two parties can negotiation for this and loosen supplier participation conditions to improve the overall income after cooperation: when the suppliers take the decrease of expected profit of commitment contract does not exceed 2.5% than noncooperation as participation condition, the participation interval of suppliers is [5.87, 16]. The overall income after cooperation is $\pi_{SC}(Q_r^*(C_o^{r0}) = 2298.1475$, and then it is very close to overall optimal. Figure 6 and table 2 are output results of example 1.

(2) Example 2

When the system parameter is the example 2 in table 1, the participation interval of sellers is [0, 16]; $b_0 = 13000$, $a_0 = 15361.6923$; numerical calculation indicates that from $C_o^r = 5.42$, suppliers promise that the expected profit at the end of contract is bigger than the profit without cooperation, which is $\pi_s(Q_r^*(C_o) \geq b_0$. Therefore, the participation interval of suppliers is $C_o \in [C_o^r, v] = [5.42, 16]$. When $C_o = 9.8020$, $[\pi_s(Q_r^*(C_o)]'_{C_o} = -0.0096 < 0$, the expected profit of supplier is the biggest; in addition, at this moment, $Q_r^0 = 1000, Q_r^*(C_o^*) = 1015, Q_{SC}^* = 1065.9$, $Q_r^0 < Q_r^*(C_o^r) < Q_{SC}^*$, $\pi_s^*(Q_r^*(C_o^*) = 13022$, $\pi_r(Q_r^*(C_o^*) = 15509$; $\pi_{SC}(Q_r^*(C_o^*)) = 28531 > a_0 + b_0$, which is that under contract C_o^*, the total profit of supply chain increases than noncooperation, so the equilibrium solution is $C_o \in [C_o^r, C_o^*] = [5.42, 9.802]$. In addition, when $C_o = 15.978$, $[\pi_s(Q_r^*(C_o)]'_{C_o} = -5.1874 < 0$, $\pi_s^*(Q_r^*(C_o) = 13000 \geq b_0$, $\pi_r(Q_r^*(C_o) = 15362 > a_0$. Figure 7 and table 3 are the output results of numerical calculation of example 2.

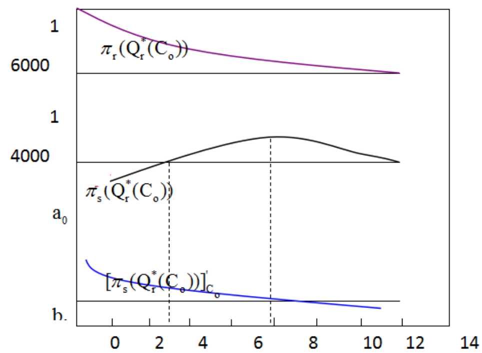

Fig. 3. Output result diagram of example 2

5. Conclusions

This paper discusses the process and steps of service level optimization and supply chain mixed decision contract integration. On this basis, it proposes supply chain model of sellers processing surplus, adopts Stackelberg game method to solve the model, verifies through three examples and describes the process of making equilibrium analysis and confirming optimal decision interval with model when the supply chain faces different system parameters and demand distributions.

Table 3. Example 2 equilibrium analysis table

Supplier participation interval	a_0 (RMB)	b_0 (RMB)	$\pi_{SC}(Q^*_{SC})$ Overall optimal	Optimal order quantity of supply chain	Optimal order quantity without cooperation	$[C^r_0, C^*_0]$ Decision interval
[5.42, 16]	15361.69	13000	28732.1990	1065.9005	1000.	[5.42, 9.802]
Contract C_0	Seller's profit under contract $\pi_r(Q^*_r)(C^*_0)$	Supplier's profit under contract $\pi_r(Q^*_r)(C^*_0)$	Sum of profits of two parties under contract $\pi_{SC}(Q^*_r(C_0*))$	Sum of profits of two parties without cooperation $a_0 + b_0$	$\pi_{SC}(Q^*_r(C_0*))$ Differentiation for C_0	Oder quantity under contract $Q^*_r(C^*_0)$
1.64	15853.15	12879.05	28732.197 Maximum	28361.6923	68.59	1066.103
...	Decrease progressively...	Increase progressively...	Decrease progressively...	28361.6923	Decrease progressively...	Decrease progressively...
$C^r_0 = 5.42$	15657.57	13000.2 start to be bigger than b_0	28657.83 is bigger than $a_0 + b_0$	28361.6923	13.47	1033.259
...	Decrease progressively...	Increase progressively...	Decrease progressively...	28361.6923	Decrease progressively...	Decrease progressively...
$C^*_0 = 9.802$	15509.74	13022.01 Reach the maximum	28531.755	28361.6923	-0.0096 Start to be smaller than 0	1015.389
...	Decrease progressively...	Increase progressively	Decrease progressively...	28361.6923	Decrease progressively...	Decrease progressively...
16	15362.13 Near a_0	13000.12 b_0 Near b_0	28362.253	28361.6923	-5.18	1000.043

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