Research on green supply chain coordination strategy for uncertain market demand

Jian Cao*, Yangyang Chen, Bo Lu, Chenlu Tong and Gengui Zhou
Institute of Information Intelligence & Decision-making Optimization, Zhejiang University of Technology, Hangzhou, China

Abstract: Based on the status that the green market began to develop (e.g. pharmaceutical industry) in Mainland China, the paper mainly discusses how members of the green supply chain (GSC) cooperate effectively in the process of the supply chain operations. For the uncertainties existing in the market demand of the green products, the GSC coordination strategy is put forward based on the Stackelberg game that the manufacturer is the leader and distributors are the followers. The relationship between the proposed coordination strategy and several factors including the distributor's amount, the distributor's risk aversion and the uncertainties of market demand are analyzed. It indicates that, when there are uncertainties existing in the market demand of the green product, the revenue of each enterprise, the overall revenue and the customer's welfare all decrease; while the increase in the number of distributors and low risk aversion of them are beneficial to the entire GSC and the customer. The conclusions have good guidance for the operational decisions of the green supply chain when the green market is in its initial formation.

Keywords: Green supply chain; coordination strategy; stackelberg game; green market; uncertain demand; pharmaceutical industry.

INTRODUCTION

The green supply chain (GSC) is one kind of modern business pattern that mainly considers the efficiency of resource allocation and the environmental impact of the whole supply chain. If the reasonable and orderly coordination relationship among the members of the GSC has been built, it can help to reduce cost and speed up the reaction from the products to the market, increase the compatibility between the production activity and the environment and improve the system's overall competitive advantages. Whether or not the coordination strategy is efficient and operational is one of the key points to decide whether the green supply chain can operate reasonably. The market demand of the green product still has uncertainties when the green market is just emerging, especially in pharmaceutical industry in Mainland China. Combined with the actual situation, we discuss the problem that how the member companies of the green supply chain to set the price and formulate the coordination strategy when the market demand is uncertain.

At present, the research output for this problem is very sparse. The related researches can be classified into two parts. One part is about how the members of the green supply chain to formulate the coordination strategy. For example, the effectiveness of the pollution prevention in the process of the supply chain operations is closely related to the collaborations among the members of the supply chain (Vachon and Klassen, 2006). Based on the different ways of social responsibility, two kinds of coordination approaches are put forward, which make the supply chain developing in a sustainable way among the member companies (Koplin *et al*., 2007). Combined with Taiwan's electronic industry, how the environment of government system can promote the coordination and cooperation of the member companies in several different green supply chain models are analyzed (Sheu, 2011). The coordination strategies among pharmaceutical manufacturing, distribution channels and healthcare services are discussed (Narayana *et al*., 2014). Another part is talking about how to decide the supply chain system when there are uncertainties existing in the market demand of green products. For example, if manufacturers and upstream suppliers have the green-based collaboration, it could be easier to generate revenue when there are uncertainties existing in the market demand of the green products (Vachon and Klassen, 2008). A dynamic allocation/planning problem that optimized the global supply chain planning of a pharmaceutical company in view of its uncertain product demand is addressed and a feasible solution is provided (Sousa *et al*., 2011). And the market demand would be the ultimate driving factor in the green supply chain of China's enterprises building (Cao and Cao, 2013). During the research, we can learn many from the above research.

For the two-echelon GSC system consisted of one manufacturer and multiply distributors, this paper analyzes the impact from the market demand uncertain information to the member companies in decision-making, thus we get the relating coordination strategies between the manufacturer and the retailer and compare them with the coordination strategies when there are uncertainties existing in the market demand of the green

**Corresponding author:* e-mail: jcao@zjut.edu.cn

products. In addition, the paper also discusses the impact of the changes in the number of distributors, the distributors' risk aversion and the degree of uncertainty in the green market demand for the coordination strategies. The conclusions are good guidance for the operational decisions of the GSC when the green market is in initial formation, e.g. pharmaceutical industry in Mainland China.

MATERIALS AND METHODS

The decision-making process between manufacturer and their n distributors in the GSC is described as follows. Firstly, the manufacturer determines the wholesale price of the green products p_M. Then, each distributor determines its own order quantity q_{Ri}, $i=1,2,\ldots,n$. Obviously the decision-making process is in line with the typical characteristics of the Stackelberg game model.

In the process of the GSC operations, the marginal sales cost of each distributor's green products c_R may differ. However, because the green products are homogeneous and we ignore the differences in time and space in the consumer's purchase process, as well as various marketing strategies which are adopted by different distributors on a competitive sale. It can be regarded that the green product selling price p_R is consistent, and let $p_{Ri}= p_R$. When the market demand is certain, we assume that the total sales of green products q and p_R satisfy the following linear inverse relationship,

$$q=a-bp_R\ , \tag{1}$$

Where a, b are constants, $a,b>0$. When there are uncertainties existing in the market demand, we assume that q and p_R satisfy the following equation,

$$q=a-bp_R+t\ , \tag{2}$$

Where t represents the uncertainties of market demand, $t\in N\left(0,\sigma^2\right)$. Herein, we assume the green products, which are ordered by the rational distributors are eventually sold out, thus the distributors' order quantities are the sales. Meanwhile, for the same green products in the same region, we assume that multiple distributors compete with each other for sale. The assumption is consistent with the most realistic product sale situation.

Let the marginal production cost of green products be c_M. In order to ensure the rational operations of the GSC, we get the constraint $p_R>c_M+c_{Ri}$. To calculate the expectation on both sides of Eq. (2) and meet the rational requirement of the members of the supply chain, i.e., E [q]≥0, it is satisfied that $a-b(c_M+c_{Ri})>0$.

Then we analyze the following two cases. First, we analyze how the members of the GSC to make decisions when the market demand is certain. Then we analyze how the manufacturer and the distributor to make decisions when there are uncertainties existing in the market demand.

THEORETICAL ANALYSIS

The coordination model based on the situation of certain market demand

When the market demands are determined, we get that the relationship between p_R and q satisfies the following equation according to Eq. (1),

$$p_R=a/b-q/b\ . \tag{3}$$

Combined with $q=\sum_{i=1}^{n}q_{R_i}$, we get the revenue functions of the manufacturer and various distrusts as follows,

$$\pi_M=\left(p_M-c_M\right)q=\left(p_M-c_M\right)\left(a-bq_R\right)\ , \tag{4}$$

$$\pi_{R_i}=\left(p_R-p_M-c_{R_i}\right)q_{R_i}=\left(a/b-p_M-c_{R_i}-b^{-1}\sum_{j=1}^{n}q_{R_j}\right)q_{R_i}\ . \tag{5}$$

Usually p_M is decided by the manufacturer firstly, then various distributors decide q_{Ri}. That satisfies a typical Stackelberg game. The game decisions on the production amount among each distributor are in line with the characteristics of the Cournot model (Fudenberg, 2002). The game process is solved by using the backward induction, the measure is described as follows.

Firstly, by considering the decision-making process of each distributor, we get that the optimally first-order condition which is made by the manufacturer i satisfies the following equation,

$$\partial\pi_{R_i}/\partial q_{R_i}=a/b-p_M-c_{R_i}-b^{-1}\left(q_{R_i}+\sum_{j=1}^{n}q_{R_j}\right)=0\ . \tag{6}$$

If c_{Ri} differs, q_{Ri} is also not the same. According to Eq. (6), we can calculate q_{Ri} by integrating n first-order conditions. In order to simplify the description of this problem, we just consider the situation that c_{Ri} is the same in this paper and let $c_{Ri}=c_R$. Because of the same cost, the same selling price and the same sales of each distributor, we can let $q_{Ri}=q_R$. Thus we can know that all distributor's revenues are also the same, let $л_{Ri}= л_R$. Based on these conclusions, the optimally first-order Eq. (6) satisfies the following equation,

$$a/b-p_M-c_R-b^{-1}\left(n+1\right)q_R=0\ . \tag{7}$$

Then we get the solutions

$$q_R=\left(n+1\right)^{-1}\left(a-bp_M-bc_R\right)\ , \tag{8}$$

$$q=n\left(n+1\right)^{-1}\left(a-bp_M-bc_R\right)\ , \tag{9}$$

We consider the manufacturer's decision-making process in the following. By putting Eq. (9) into Eq. (4), we get

$$\pi_M=\left(p_M-c_M\right)q=n\left(n+1\right)^{-1}\left(p_M-c_M\right)\left(a-bp_M-bc_R\right)\ . \tag{10}$$

Combined with the optimally first-order condition $\partial\pi_M/\partial p_M=0$ which is about how the manufacturer to decide p_M, we obtain

$$p_M^N=0.5\left(a/b+c_M-c_R\right)\ , \tag{11}$$

Where the superscript N represents the result when the market demand is certain, then the expanded equations are put forward as follows,

$$q_R^N = 0.5(n+1)^{-1}\left[a - b(c_M + c_R)\right], \quad (12)$$

$$q^N = 0.5n(n+1)^{-1}\left[a - b(c_M + c_R)\right], \quad (13)$$

$$p_R^N = 0.5(n+1)^{-1} b^{-1}\left[(n+2)a + nb(c_M + c_R)\right]. \quad (14)$$

By further calculation, we get the manufacturer's revenue π_M^N , the distributor's revenue π_R^N and the total revenue of the green supply chain π_T^N as follows,

$$\pi_M^N = 0.25n(n+1)^{-1} b^{-1}\left[a - b(c_M + c_R)\right]^2, \quad (15)$$

$$\pi_R^N = 0.25(n+1)^{-2} b^{-1}\left[a - b(c_M + c_R)\right]^2, \quad (16)$$

$$\pi_T^N = 0.25(n^2 + 2n)(n+1)^{-2} b^{-1}\left[a - b(c_M + c_R)\right]^2. \quad (17)$$

The coordination model based on the situation of uncertain market demand

When there are uncertainties existing in the market demand for the green products, combined with the Eq. (2), we know the relationship between the selling price and the aggregate demand satisfies the following equation,

$$p_R = a/b + t/b - b^{-1}q. \quad (18)$$

Ignoring the cost coming from searching the uncertainties of the market demand, we get the revenue functions of the manufacturer and the distributor,

$$\pi_M = (p_M - c_M)q = (p_M - c_M)(a - bq_R + t), \quad (19)$$

$$\pi_{R_i} = \left(a/b + t/b - p_M - c_{R_i} - b^{-1}\sum_{j=1}^{n} q_{R_j}\right) q_{R_i}. \quad (20)$$

By using the negative exponential utility function $U_R(\pi_{R_i}) = -e^{-r_i \pi_{R_i}}$ to represent the utility function of the distributor i (Xu and Chen, 2013) (Herein r_i is the risk predilection coefficient of i, $r_i>0$, $r_i=0$ and $r_i<0$ respectively represent the risk averse, risk neutral and risk preferences of the distributor i), we establish the certainty equivalent of distributor i to be W. Based on $EU_{Ri}=U_{Ri}(W)$, we get the equation $EU_{R_i} = -e^{-r_i(m - \frac{r_i v}{2})} = -e^{-r_i(W)}$. Then we get $W = m - \frac{r_i v}{2}$ where m represents the mean value of π_{R_i} and v represents the variance of π_{Ri}. Then we get the following equations $m = \left(a/b - p_M - c_{R_i} - b^{-1}\sum_{j=1}^{n} q_{R_j}\right) q_{R_i}$ and $v = b^{-2}\sigma^2 q_{R_i}^2$. Therefore, we obtain the expectation revenue of the distributor i,

$$E\pi_{R_i} = \left(a/b - p_M - c_{R_i} - b^{-1}\sum_{j=1}^{n} q_{R_j}\right) q_{R_i} - 0.5b^{-2} r_i \sigma^2 q_{R_i}^2. \quad (21)$$

For the emerging green product market, the prospects are uncertain. So the rational distributor tends to adopt the risk aversion attitude when there are uncertainties existing in market demand. Therefore, we just consider the situation that all distributors adopt the risk aversion attitude in the following research, i.e., $r_i>0$.

We take the partial derivative of Eq.(21) respect to q_{Ri} and get the optimally first-order condition of the expectation revenue of the distributor i, it is given

$$\partial E\pi_{R_i} / \partial q_{R_i} = a/b - p_M - c_{R_i} - b^{-1}\left(q_{R_i} + \sum_{j=1}^{n} q_{R_j}\right) - b^{-2} r_i \sigma^2 q_{R_i} = 0 \cdot \quad (22)$$

In order to simplify the analysis, we assume the selling cost and the risk preference coefficient of each distributor are the same, $r_i=r$. We think the sales of each distributor are the same, $q_{Ri}=q_R$. Thus revenues of all distributors are the same, $\pi_{Ri}=\pi_R$. From Eq. (22) we obtain

$$q_R = b\left[(n+1)b + r\sigma^2\right]^{-1}(a - bp_M - bc_R), \quad (23)$$

$$q = nb\left[(n+1)b + r\sigma^2\right]^{-1}(a - bp_M - bc_R). \quad (24)$$

We also consider the manufacturer's attitude is risk neutral. Putting Eq. (24) into Eq. (19) and the equation of the manufacturer's expectation revenue is as the following,

$$E\pi_M = nb\left[(n+1)b + r\sigma^2\right]^{-1}(p_M - c_M)(a - bp_M - bc_R). \quad (25)$$

Based on the optimally first-order condition of the manufacturer, $\partial E\pi_M / \partial p_M = 0$, it is gotten that

$$p_M^Y = 0.5(a/b + c_M - c_R), \quad (26)$$

where the superscript Y represents the result when there are uncertainties existing in the market demand. Then the further equations are put forward as follows,

$$q_R^Y = 0.5b\left[(n+1)b + r\sigma^2\right]^{-1}\left[a - b(c_M + c_R)\right], \quad (27)$$

$$q^Y = 0.5b\left[(n+1)b + r\sigma^2\right]^{-1}\left[a - b(c_M + c_R)\right], \quad (28)$$

$$Ep_R^Y = 0.5\left[(n+1)b + r\sigma^2\right]^{-1}\left[(n+2)a + nb(c_M + c_R) + \frac{2ar\sigma^2}{b}\right], \quad (29)$$

$$E\pi_M^Y = 0.25n\left[(n+1)b + r\sigma^2\right]^{-1}\left[a - b(c_M + c_R)\right]^2, \quad (30)$$

$$E\pi_R^Y = 0.125(2b + r\sigma^2)\left[(n+1)b + r\sigma^2\right]^{-2}\left[a - b(c_M + c_R)\right]^2, \quad (31)$$

$$E\pi_T^Y = 0.125n(2nb + 4b + 3r\sigma^2)\left[(n+1)b + r\sigma^2\right]^{-2}\left[a - b(c_M + c_R)\right]^2 \cdot \quad (32)$$

Then we discuss the relationship among the relevant parameters, decision variables and the target functions when there are uncertainties existing in the market demand. Combined with the model, the main parameters involved in the GSC operations including the number of distributors n, the seller's risk aversion coefficient r and the variance of the uncertainties σ^2 (Obviously, σ^2 is the greater, the greater the uncertainty is). The main decision variables involved in the GSC operations including the wholesale price of the manufacturer p_M^Y , the distributor's market expectation price Ep_R^Y , order quantities for each distributor q_R^Y and the total sales in the market q^Y . The target functions involved in the GSC operation including the manufacturer's expectation revenue $E\pi_M^Y$, the distributor's expectation revenue $E\pi_R^Y$ and the total revenue of the green supply chain $E\pi_T^Y$. By further analysis, we get more conclusions.

The numerical simulation

In this section, we adopt the numerical analysis to show the effect from the related parameters to the decision variables and objective functions in the GSC operations. Firstly, let the basic date be $a = 10$, $b = 5$, $c_M = 0.5$, $c_R = 0.25$, $n = 3$, $r = 0.5$ and $\sigma^2 = 2$.

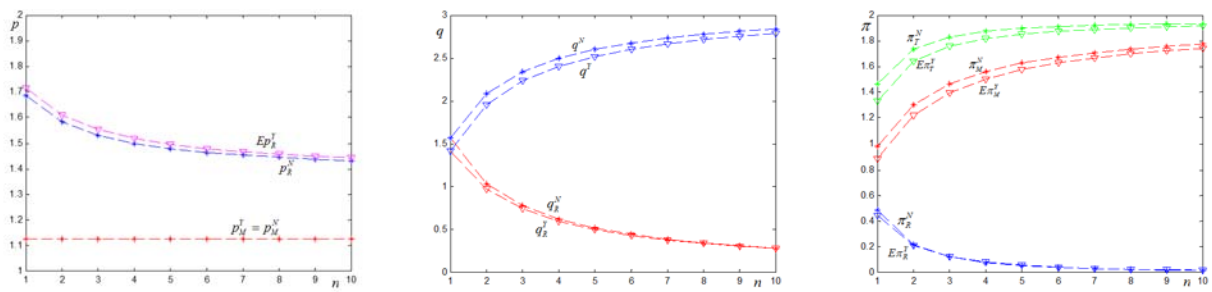
Case 1: n is a random number between 1 and 10. We compare the relationship between n and the decision variables and the relationship between n and the target revenue when the market demand is certain or uncertain. The differences are showed in fig. 1.

Case 2: r is a random number between 0 and 5. We compare r and the decision variables, and the relationship between n and the target revenue when the market demand is certain or uncertain. The differences are showed in fig. 2.

Case 3: σ^2 is a random number between 0 and 10. We compare the relationship between σ^2 and the decision variables and the relationship between σ^2 and the target revenue when the market demand is certain or uncertain. The differences are showed in fig. 3.

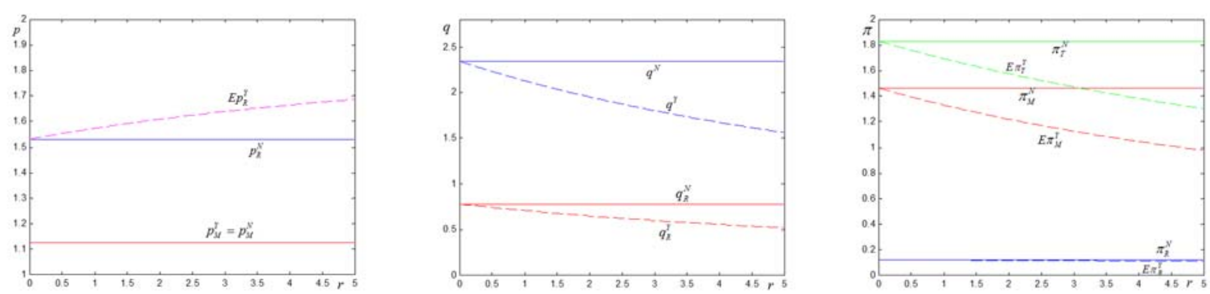
RESULTS

Conclusion 1: The statements of the relationship among the number of the distributors n, each decision variables



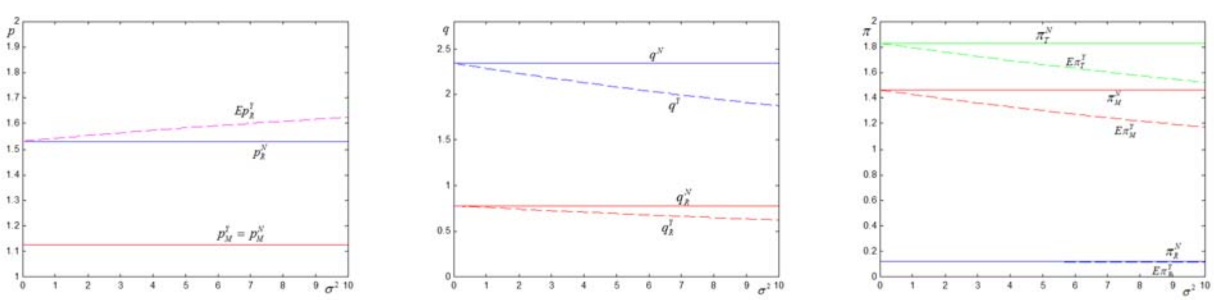
(a) The relationship between n and p (b) The relationship between n and q (c) The relationship between n and π

Fig.1: The relationship between n and various decision variables and functions



(a) The relationship between r and p (b) The relationship between r and q (c) The relationship between r and π

Fig.2: The relationship between r and various decision variables and functions



(a) The relationship between σ^2 and p (b) The relationship between σ^2 and q (c) The relationship between σ^2 and π

Fig. 3: The relationship between σ^2 and various decision variables and functions

in the GSC and their revenues are described as follows:
(1) With n increase, each distributor's actual sale q_R^N reduces, while the total sale q^N increases.
(2) With n increases, the market price of the green product p_R^N falls which is consistent with the fact and it is beneficial to consumers. The wholesale price of the green product p_M^N is staying the same.
(3) With n increases, π_M^N and π_T^N increase while π_R^N falls. That means the increase in the number of distributors is beneficial to the manufacturers and the whole green supply chain, but not to the single distributor.

Conclusion 2: When there are uncertainties existing in the market demand, the statements of the relationship between the relevant parameters *n*, *r*, σ^2 and the main decision variables p_M^Y, Ep_R^Y, q_R^Y, q^Y are described as follows.
(1) The wholesale price of the green product is independent from the above parameters and $p_M^Y = p_M^N$. That means that the manufacturer's decision is not subject to market demand uncertainties, which are based on the Stackelberg game.
(2) With the increase of *n*, Ep_R^Y falls as well as q_R^Y, but q^y increase. These conclusions are consistent with the *conclusion 1*. That means the increase in the number of distributors is beneficial to the customer.
(3) With the increase of *r*, Ep_R^Y also increases. But q_R^Y decrease as well as q^Y. There is another explanation. Since the green product market is an emerging market, the distributor in high-risk aversion tends to order less green products that is consistent with the fact.
(4) With the increase of σ^2, Ep_R^Y increase, q_R^Y decrease as well as q^Y.

Conclusion 3: When there are uncertainties existing in the market demand, with the increase of *n*, $E\pi_R^Y$ decrease, but $E\pi_M^Y$ increases as well as $E\pi_T^Y$. That means the increase in the number of distributors is beneficial to the manufacturer but not to the single distributor.

Conclusion 4: When there are uncertainties existing in market demand, the relationship between *r* and $E\pi_M^Y$, $E\pi_R^Y$, $E\pi_T^Y$ are described as follows.
(1) With the increase of *r*, $E\pi_M^Y$ and $E\pi_T^Y$ decrease. If the distributor is more conservative, it is more unfavorable to the manufacturer as well as to the entire GSC.
(2) The relationship between *r* and $E\pi_R^Y$ is described as follows. If $n < 3 + r\sigma^2/b$, with the increase of *r*, $E\pi_R^Y$ decreases. If $n > 3 + r\sigma^2/b$, with the increase of *r*, $E\pi_R^Y$ increases. If $n = 3 + r\sigma^2/b$, $E\pi_R^Y$ is a constant which has no relation to *r*.

Conclusion 5: When there are uncertainties existing in the market demand, the relationship between σ^2 and $E\pi_M^Y$, $E\pi_R^Y$, $E\pi_T^Y$ are described as follows.
(1) With the increase of σ^2, $E\pi_M^Y$ and $E\pi_T^Y$ decrease, Which means the green product market demand is more uncertain, the revenue of the manufacturer and the GSC are lower.
(2) The relationship between σ^2 and $E\pi_R^Y$ is described as follows. If $n < 3 + r\sigma^2/b$, with the increase of σ^2, $E\pi_R^Y$ decreases. If $n > 3 + r\sigma^2/b$, with the increase of σ^2, $E\pi_R^Y$ increases. If $n = 3 + r\sigma^2/b$, $E\pi_R^Y$ is the constant.

Conclusion 6: In the process of the GSC operations and there are uncertainties existing in the market demand. Comparing with the situation that the market demand is certain, we get the following conclusions. With the rise of the market price of the GSC, the total output decrease as well as the revenue of each member company and the total GSC (Combined with the numerical simulation, there is an exception. When $n>3+r\sigma^2/b$, we get $E\pi_R^Y > \pi_R^N$, the manufacturer's revenue and the overall revenue decrease). Under normal circumstances the existence of the uncertainties in the green product market demand is not beneficial to the member companies of the GSC and the customer.

DISCUSSION

We can see from the *conclusion 1* that it is beneficial to the improvement of the manufacturer's revenuer if more distributors can join the supply chain in the case of market demand is certain. But one point should be especially introduced. In the process of the GSC operations, the increase of distributors also leads to the increase of the management cost from the manufacturer to the distributor as well as the management risk and difficulty. They are not conducive to maintaining the stability in the GSC operations. Therefore, the number of the distributor should be adequate.

From fig. 1, we know that when there are uncertainties existing in market demand, with the increase of the number of distributors, the whole-price of the manufacturer is staying the same, the expectation market price of the distributor increase. But its sale has a slight decrease as well as the total sales, which differ from the situation that the market demand is certain. In addition, the overall revenue of the manufacturer, the distributor and the green supply chain are all in slight decrease.

From fig. 2, we know that when there are uncertainties existing in the market demand, with the increase of *r*, the whole-price of the manufacturer is staying the same, the expectation market price of each distributor increase. But its sales has a slight decrease as well as the total sales .In addition, the overall revenue of the manufacturer, the distributor and the GSC all decrease constantly.

Comparing fig. 3 with fig. 2, we can see that the variation tendencies of the decision variables and the target revenues are consistent with the variation tendency that the distributor's risk aversion is consistently increase when uncertainties in the market demand get more.

This paper is mainly discuss the effect from the uncertainties existing in market demand of the green product to the GSC operations and puts forward the coordination strategy of the GSC which is based on the Stacklberg game that the manufacture is the leader, each distributor is the follower. We discuss the relationship among the proposed coordination strategy and the number of distributors, distributor's risk aversion and the degree of uncertainty in the green market demand. We also analyze the coordination strategies of the GSC when the market demand is certain. Then, we get the following conclusions. When there are uncertainties existing in the market demand of the green product, the revenue of each member company, the overall revenue and the customer's welfare all decrease, that is not conducive to the efficient operation of the GSC. The conclusions are helpful to the operational decisions of the GSC when the green market is at its initial stages.

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