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Risk Aversion Coordination Simulation Model for Supply Chain

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Abstract

Facing the complex and changeful market environment, members of the enterprise in supply and demand network more consider seeking to build partnerships, with a specialization in a larger scope; effectively reduce all kinds of business cost of the enterprise, fully realized system scale effect. First discussed the basic characteristics of the network of supply and demand and enterprise, using the game theory analysis method and the least squares curve fitting of ideas, constructing a dynamic game model of the cooperation of supply and demand network enterprise dynamic evolution; And then analyzed the results of cooperative game, get the optimal expected revenue function and cooperation profit coefficient which is the important factor of enterprise dynamic cooperation choice to influence members of supply and demand network; Finally, considered a two layers of supply and demand system consisting of a risk averse retailer and risk aversion of the manufacturers, retailers to develop the optimal wholesale price, manufacturers to determine the optimal distribution, constructed based on revenue sharing costs shared network coordination model of supply and demand. Simulation results show that when the supply and demand system of risk aversion coefficient is higher than the risk aversion coefficient of manufacturers and retailers, the revenue sharing cost sharing contract system can be improved significantly, even perfect coordination.

Keywords: *Risk Aversion, Supply and Demand Network, Contract, Coordination, Simulation*

1. Introduction

With the progress of science and technology and economic development, the market has gradually from the traditional "relatively stable" turned into "dynamic changeable situation," any one enterprise want to remain clueless situation stable condition has been a s challenge. For this reason, many people called for enterprise management must be by "is given priority to with competition" to "give priority to with cooperation, competition is complementary" strategic shift, so academia according to this puts forward some new mode of enterprise management. Multi-functional open enterprise Supply and Demand Network (Supply and Demand Network with Multi-function and opening characteristics for enterprises, hereinafter referred to Supply and Demand Network or SDN) [1, 2]. This refers to the global resources acquisition, global manufacturing, global marketing, and improve enterprise comprehensive ability as the goal, between related enterprises, due to the interaction of "flow" formed the integration of the supply and demand of dynamic network mode of multi-functional open supply and demand. If this is right, apparently treat that level of risk, decision makers can affect the net income of each member in the supply and demand, which also affects the whole system of supply and demand coordination [2-4]. On the coordination between the traditional supply and demand, are often assumes that the leader of the manufacturers for the system. However, global industry of supply and demand is undergoing tremendous changes, retailers in consumer-centric occupies more and more important position in the market, gradually to original manufacturers dominate the supply and demand model to retailer dominated the supply and demand model. Retail industry is dominated by strong retailers [5-7], to the general product, such as consumer goods, retail giants, such as wal-mart and Carrefour, channels have become dominant, because they are the most close to consumers and provide

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one-stop shopping for its convenience, this article explores retailers dominate the two layers of contract coordination problems of the supply and demand system. At the same time, due to the uncertainty of market demand lead to the risk problems of supply and demand system, and policy makers' attitude to risk tend to have bigger difference. So, in recent years, appeared more management research literature at home and abroad based on the risk theory [8]. For risk neutral and risk aversion newsboy problem of decision-making behavior has carried on the comparative study [9]. To study the risk aversion newsboy order problems, proves that the higher the risk weighting, the less quantity of goods [10]. Using the expected utility theory to study the risk aversion newsboy decision-making behavior, it is concluded that when the retail price is higher than a certain critical value, decreases with the increasing of quantity of goods with retail prices [11]. In random demand situation, research retailer taking two parts pricing service's influence on the risk aversion customers [12]. Based on risk aversion, problem of the least random linear optimization is researched [13]. Considering stochastic demand and risk factors, by constructing the weather - linked discount contract manufacturers, studies have shown that the contract is better than other types of contracts [14]. In random demand situation considering shortage of loss, based on prospect theory to establish a risk adverse retailer's utility function, analyzed the risk adverse retailer order quantity and risk aversion coefficient, the retail price, purchase price, the salvage value per unit, unit in relationship. In the study of retailer dominated the supply and demand system, there is no document at the same time concerned about the level of risk aversion in manufacturers and retailers. In addition, the demand for business coordination problem also affected by the level of sales efforts by the attention of the scholars [15], but there's no scholar in retailers' leading system of supply and demand to consider the retailer's sales efforts.

2. Proposed Method

A. System Analysis Under the Centralized Decision Making

Assume that the number of expected sales of the product can be expressed as $S(q,e)$, among them

$$S(q,e) = E[q-(q-D(e))^{+}] = q - \int_0^q G(q,e)dq$$

Obviously, $S(q,e)$ is about the supply quantity and dual concave function of the level effort, considering the inventory cost, uses the average inventory cost calculation, expectations for inventory cost for $hq/2$.

To risk aversion features of members of the supply and demand system, this article is based on prospect theory, using widely used in financial, economic, marketing and organizational behavior in the areas of piecewise linear function to describe the degree of risk aversion [16], the utility model is as follows

$$U(x) = \begin{cases} x - x_0 , & x \geq x_0 \\ \gamma(x-x_0), & x < x_0 \end{cases} \tag{1}$$

Among them $\gamma \geq 1$, It represents loss aversion coefficient of policymakers, the greater the γ represents the higher the degree of loss aversion. In order to simplify the calculation, assuming that policymakers initial wealth is zero, namely $x_0 = 0$

First analysis system of supply and demand under centralized decision making, manufacturers and retailers can be thought of as a whole, the profit function of the system

$$\Pi_{SC}(q,e) = \begin{cases} pD(e) - \frac{h}{2}q - cq - g(e), D(e) \leq q \\ pq - \frac{h}{2}q - cq - g(e), \quad D(e) > q \end{cases} \tag{2}$$

Expected profit function for the whole system

$$E\Pi_{SC}(q,e) = p(q - \int_0^{q-y(e)} F(\eta)d\eta) - \frac{h}{2}q - cq - g(e) \tag{3}$$

Because the system is not a risk neutral, but risk aversion, and the risk aversion coefficient is λ, so to discuss its expected utility function.

Through (2), when $D(e) > q$, the system's profit is greater than zero, there is no loss. When $D(e) \le q$, make system profit is equal to zero, get breakeven point in the system, namely $X_{sc} = \frac{(hq/2)+cq+g(e)}{p}$, order $\bar{q}_{sc} = X_{sc}$, so when $D(e) > \bar{q}_{sc}$, the system of profit is positive, when the system has a negative profit.

The available system of expected utility

$$EU_{sc} = -(\lambda-1)p\int_0^{\bar{q}_{sc}-y(e)} F(\eta)d\eta + p(q - \int_0^{q-y(e)} F(\eta)d\eta) - \frac{h}{2}q - cq - g(e) \tag{4}$$

(4) The type is about production quantity and effort levels' first derivative

$$\begin{cases} \frac{\partial EU_{SC}(q,e)}{\partial q} = -(\lambda-1)(\frac{h}{2}q + cq + g(e))F(\bar{q}_{sc} - y(e)) \\ \qquad - pF(q-y(e)) - \frac{h}{2} - c = 0 \\ \frac{\partial EU_{SC}(q,e)}{\partial e} = (\lambda-1)pF(\bar{q}_{sc} - y(e))y'(e) + \\ \qquad pF(q-y(e))y'(e) - g'(e) = 0 \end{cases} \tag{5}$$

Due to the manufacturers and retailers are risk averse, hypothesis $y(e)$ is a linear function, apparently (5) type is about production quantity and the second derivative of the effort level is less than zero, namely expected utility function of the supply and demand system is concave function about distribution and effort level, namely the optimal production quantity and level of effort $\{q^0, e^0\}$ meet (5).

B. System Analysis Under Decentralized Decision Making

In decentralized decision making system of supply and demand, manufacturers and retailers to make optimal decisions. Due to risk aversion of the manufacturers, discussed their expected utility function below. Because retailers are dominated, so suppose manufacturers recovery of the final sales of the products with the wholesale price.

(a) The manufacturer's decision analysis

The manufacturer's profit function can be expressed as

$$\Pi_M = \begin{cases} (w-c)q - w(q-D(e)), & D(e) \le q \\ (w-c)q, & D(e) > q \end{cases} \tag{6}$$

The expected profit function for manufacturers

$$E\Pi_M = wq - cq - w\int_0^{q-y(e)} F(\eta)d\eta \tag{7}$$

Analyze (7), when $\eta \le q - y(e)$, the manufacturer's profit is positive, when $\eta > q - y(e)$, to $(w-c)q - w(q-y(e)-\eta) = 0$,to get the manufacturer's profit and loss balance demand $\bar{q}^{sc} = cq/w$ .Namely when $D(e) < cq/w$,the manufacturer's profit is negative, when $D(e) \ge cq/w$, the manufacturer's profit is positive. Manufacturers expected profit function expressions are obtained by the previous analysis, according to the given utility function of expression, the expression of the expected utility of manufacturer

$$EU_M(q,e) = (\lambda_1 - 1)((w\bar{q} - cq)F(\bar{q} - e) - w\int_0^{\bar{q}-y(e)} F(\eta)d\eta) + E\Pi_M(q,e) \tag{8}$$

(8) The first order and second order derivative about the distribution q

$$\frac{\partial \mathrm{E}U_M}{\partial q} = -(\lambda_1 - 1)cF(\bar{q} - y(e)) + w - c - wF(q - y(e))$$

$$\frac{\partial^2 \mathrm{E}U_M}{\partial q^2} = -(\lambda_1 - 1)\frac{c^2}{w} f(\bar{q} - y(e)) - wf(q - y(e)) < 0$$

Obviously manufacturers expected utility function about distribution q is a strictly concave function, which is an optimal distribution q^d, makes the manufacturer's expected utility is the largest. Based on Stackelberg game process, the given wholesale price and the effort level of retailer, manufacturers determine the optimal output. Order 1 derivative is equal to zero, to obtain the meeting conditions the optimal output

$$(1-\lambda_1)cF(\bar{q}^d - y(e)) + w - c - wF(q^d - y(e)) = 0 \tag{9}$$

Through (9), you can see that the manufacturer's optimal output is less than the optimal distribution of risk neutral conditions

(b) The retailer's decision analysis

The following analysis of retailer's decision, the method is similar to the previous section; available retailer's expected utility function is

$$\begin{aligned} EU_R &= (\lambda_2 - 1)\int_0^{\bar{q}_R - y(e)} (p(y(e)+\sigma) + w(q - y(e) - \sigma) \\ &\qquad - \frac{h}{2}q - wq - g(e)) f(\sigma)d\sigma + E\Pi_R(q,e) \\ &= -(\lambda_2 - 1)(p - w)\int_0^{\bar{q}_R - y(e)} F(\sigma)d\sigma + (p - w) \\ &\qquad (q - \int_0^{q - y(e)} F(t)dt) - \frac{h}{2}q - g(e) \end{aligned} \tag{10}$$

Retailers according to manufacturer's decision, decide the optimal strategy. Ask $EU_R(q,w,e)$ about the effort level e and the wholesale price w 's derivative 1, get the meeting conditions the optimal wholesale price and effort levels $\{w^d, e^d\}$

$$\begin{cases} \dfrac{\partial EU_R}{\partial w} = (\lambda_2 - 1)\displaystyle\int_0^{\bar{q}_R - y(e)} F(\eta)d\eta - (\lambda_2 - 1)(p - w)F(\bar{q}_R - y(e)) \\ \qquad \dfrac{\frac{h}{2}\frac{\partial q}{\partial w}(p - w) + \frac{h}{2}q + g(e)}{(p - w)^2} - q + (p - w)\dfrac{\partial q}{\partial w} + \\ \qquad \displaystyle\int_0^{q - y(e)} F(\eta)d\eta - (p - w)F(q - y(e))\frac{\partial q}{\partial w} - \frac{h}{2}\frac{\partial q}{\partial w} \\ \dfrac{\partial EU_R}{\partial e} = -(\lambda_2 - 1)(p - w)F(\bar{q}_R - y(e))(\dfrac{\frac{h}{2}\frac{\partial q}{\partial e} + g'(e)}{p - w} - y'(e)) \\ -\dfrac{h}{2}\dfrac{\partial q}{\partial e} - g'(e) + (p - w)[\dfrac{\partial q}{\partial e} - F(q - y(e))(\dfrac{\partial q}{\partial e} - y'(e))] \end{cases} \tag{11}$$

To get the satisfy expression of the optimal effort level e and the wholesale price w, due to (11) is more complex, can't find out the analytical solution, the relevant analysis in the numerical simulation is presented.

C. Risk Aversion Both Sides Contract Model

In this section, build revenue sharing cost sharing contract $GC(w,e,\varphi,\alpha)$, also φ on behalf of revenue sharing proportion, α on behalf of the cost sharing ratio. Under this contract, the retailer share part of the sales to manufacturers, products share a part of the remaining costs at the same time, manufacturers to undertake part of cost of sales efforts.

(a) Manufacturer's decision analysis

Due to the manufacturers risk aversion, so the profit function under the GC contract is

$$\Pi_M^{sc} = \begin{cases} (1-\varphi)pD(e)-(1-\alpha)g(e)-cq+wq, & D(e) \le q \\ (1-\varphi)pq-(1-\alpha)g(e)-cq+wq, & D(e) > q \end{cases} \tag{12}$$

When demand was less than the output, in the GC contract, due to the wholesale price may be less than the manufacturing cost, so the equivalent of manufacturers and retailers have to share the rest of the loss.

So the expected profit function for manufacturers

$$E\Pi_M = (1-\varphi)pq-(1-\alpha)g(e)-(1-\varphi)p\int_0^{q-y(e)} F(\eta)d\eta - cq + wq \tag{13}$$

Analysis of (13), when $D(e) > q$, the manufacturer's profit is positive, there is no loss, and when $D(e) \le q$, the order $(1-\varphi)pD(e)-(1-\alpha)g(e)-cq+wq=0$, get a balance demand of profit and loss $X = \frac{(1-\alpha)g(e)-wq+cq}{(1-\varphi)p}$, order, $\bar{q}_M^{sc} = X$ then when $D(e) \ge \bar{q}_M^{sc}$, the manufacturer's profit is positive, when $D(e) < \bar{q}_M^{sc}$ the manufacturer's profit is negative.

So get the manufacturer's expected utility function expression

$$EU_M = (\lambda_1 - 1)\int_0^{\bar{q}-y(e)} [(1-\varphi)p(y(e)+\eta)-(1-\alpha)g(e) - cq + wq]f(\eta)d\eta + E\Pi_M \tag{14}$$

On the first derivative of distribution q, get the meeting conditions of the optimal output q^{sc}

$$\frac{\partial EU_M}{\partial q} = -(\lambda_1-1)(c-w)F(\bar{q}-y(e)) + (1-\varphi) p - (1-\varphi)pF(q-y(e)) - c + w = 0 \tag{15}$$

Obviously manufacturers expected utility function about the second derivative of the distribution q is less than zero, so the manufacturer's expected utility function is concave function of output q. Due to can't give the analytic formula of distribution q^{sc}, and q^{sc} is a function on the level of sales efforts and wholesale prices, so that

$$V = -(\lambda_1-1)(c-w)F(\bar{q}-y(e)) + (1-\varphi)p - (1-\varphi) pF(q-y(e)) - c + w$$

Using the implicit function derivative method, discuss the distribution q^{sc} and sales efforts e, the wholesale price w, the relationship between the levels λ_1 of the manufacturer risk aversion.

$$\frac{\partial q}{\partial e} = -\frac{\partial V/\partial e}{\partial V/\partial q} = -\{(\lambda_1-1)(c-w)f(\bar{q}-y(e))[(1-\alpha) g'(e)-(1-\varphi)py'(e)] + (1-\varphi)^2 p^2 f(q-y(e))y'(e)\} / -[(\lambda_1-1)(c-w)^2 f(\bar{q}-y(e)) - (1-\varphi)pf(q-y(e))] \quad \text{(Formula 16)}$$

$$\frac{\partial q}{\partial w} = -\frac{\partial V/\partial w}{\partial V/\partial q} = -[(\lambda_1-1)(1-\varphi)pF(\bar{q}-y(e)) + (1-\varphi)p +(\lambda_1-1)(c-w)f(\bar{q}-y(e))] / [-(\lambda_1-1)(c-w)^2 f(\bar{q}-y(e)) -(1-\varphi)pf(q-y(e))] \tag{17}$$

$$\frac{\partial q}{\partial \lambda} = -\frac{\partial V/\partial \lambda}{\partial V/\partial q} = --[(c-w)F(\bar{q}-y(e))(1-\varphi)p] / -[(\lambda_1-1) (c-w)^2 f(\bar{q}-y(e)) - (1-\varphi)pf(q-y(e))] \tag{18}$$

Obviously, the optimal distribution and negatively related to the level of risk aversion and positively correlated with the wholesale price, when $(1-\alpha)g'(e)-(1-\varphi)py'(e) < 0$ the output is positively correlated with effort level.

(b) Retailers' decision analysis

Similar to the previous section, the retailers' expected utility function is similarly to

$$EU_R = -(\lambda_2 - 1)\varphi p \int_0^{\bar{q}_R^s - y(e)} F(\sigma)d\sigma + (\varphi p - w - \frac{h}{2})q - \varphi p \int_0^{q-y(e)} F(\sigma)d\sigma - \alpha g(e) \quad (19)$$

Retailers watch manufacturer's decision-making, decision-making variable wholesale prices w and effort levels e, output q is a function about w and e, so can get the retailer's profit function's derivative1 about w and e, and can get the optimal wholesale price and effort levels $\{w^{sc}, e^{sc}\}$ meet the conditions

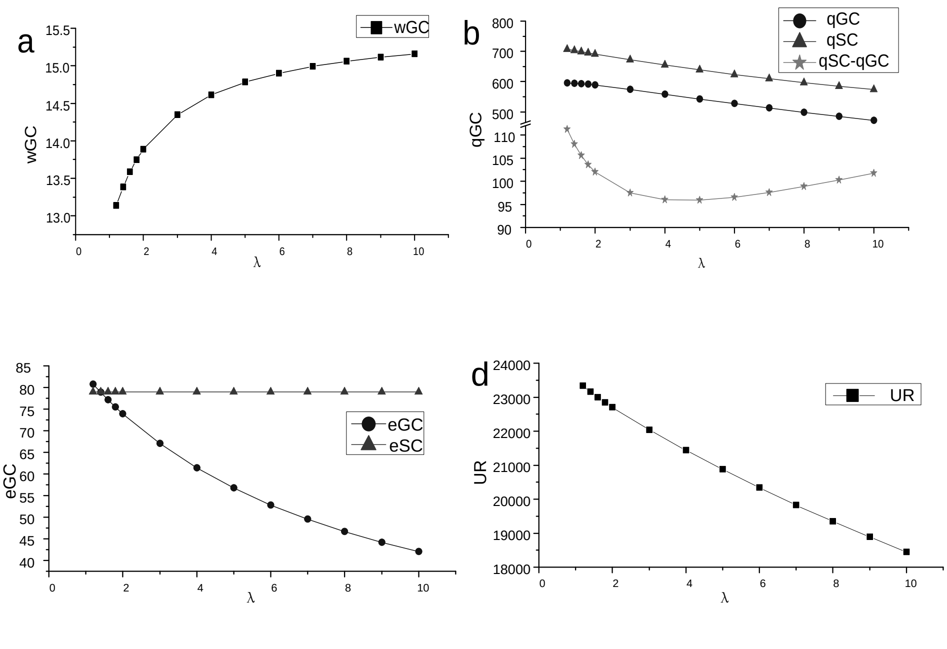
$$\begin{cases} \frac{\partial \pi_R}{\partial w} = -(\lambda_2 - 1)F(\bar{q}_R^s - y(e))(\frac{h}{2}\frac{\partial q}{\partial w} + q + w\frac{\partial q}{\partial w}) \\ -q + (\varphi p - w - \frac{h}{2})\frac{\partial q}{\partial w} - \varphi p F(q - y(e))\frac{\partial q}{\partial w} \\ \frac{\partial \pi_R}{\partial e} = -(\lambda_2 - 1)F(\bar{q}_R^s - y(e))(\frac{h}{2}\frac{\partial q}{\partial e} + w\frac{\partial q}{\partial e} + \alpha g'(e)) \\ +(\varphi p - w - \frac{h}{2})\frac{\partial q}{\partial e} - \varphi p F(q - y(e))(\frac{\partial q}{\partial e} - y'(e)) - \alpha g'(e) \end{cases} \quad (20)$$

The expression formula of $\frac{\partial q}{\partial w}$ and $\frac{\partial q}{\partial e}$ substitute to the above equations, it can be concluded that the optimal wholesale price and effort level expression. Due to the satisfy expression formula is complicated to get the optimal effort level e and wholesale prices w, cannot find out the analytical solution, the relevant analysis in the numerical simulation is presented.

3. Experiments and Analysis

In front of the analysis of the different situation, optimal distribution, wholesale price and effort level to satisfy expression of supply and demand system, but the expression of part variables is more complex, did not give the corresponding analytical solution, nor to the risk aversion coefficient of manufacturers and retailers to relative analysis on the influence of supply and demand system, in this section, the simulation analysis.

Assuming that, $p = 100$ $c = 20$ $h = 2$ $y(e) = e$ $g(e) = \frac{1}{2}e^2$ $\varepsilon \sim U[0,800]$ $F(\eta) = \varepsilon / 800$ $F^{-1}(\eta) = 800\varepsilon$ the data in the Table below is calculated by Mathematica9.0



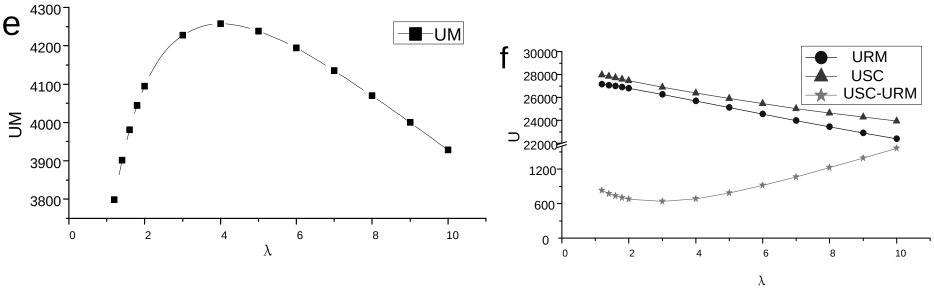


Figure 1. When $\lambda_1 = \lambda_2 = \lambda$, The Influence of λ's Change on Supply and Demand System

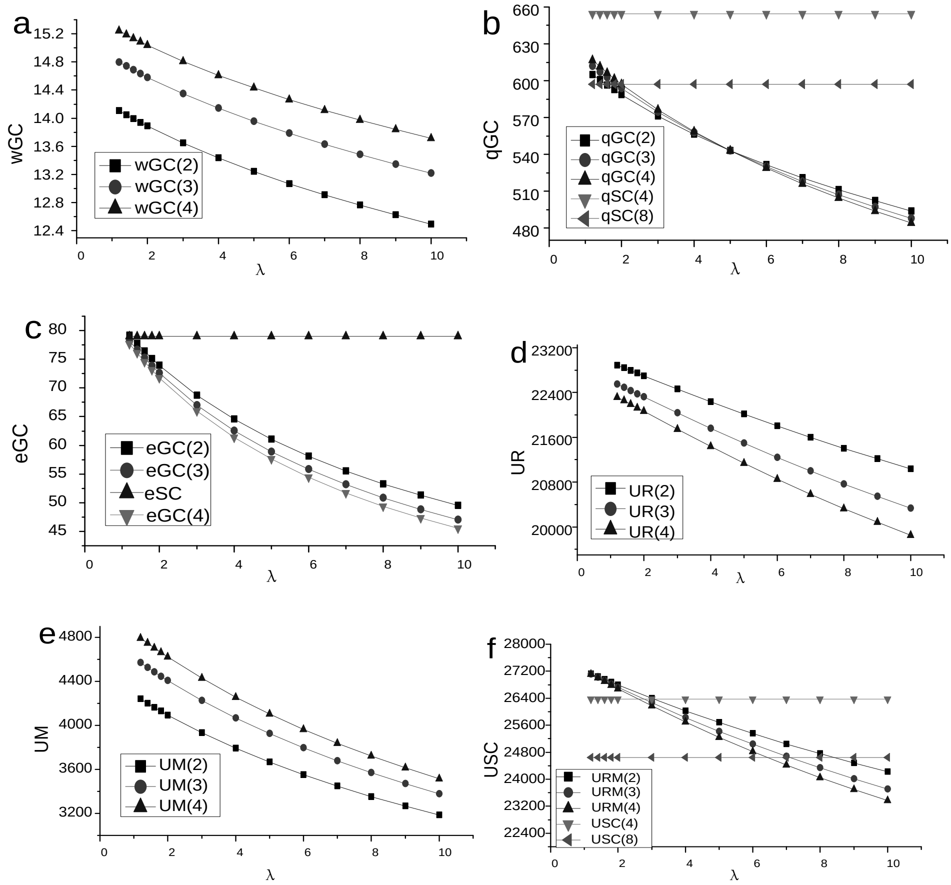
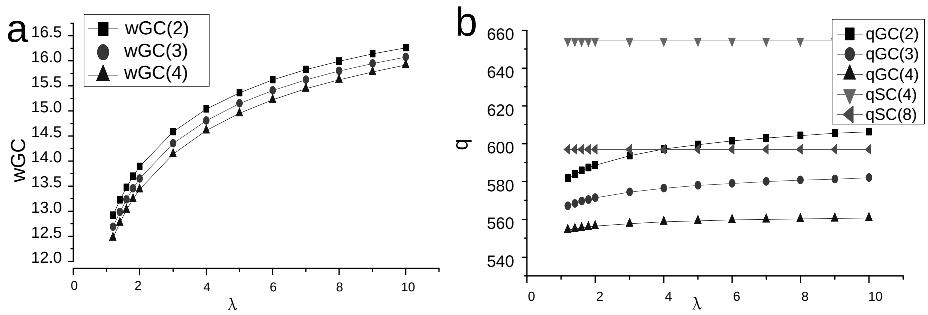


Figure 2. When $\lambda = 4,8, \lambda_1 = 2,3,4$, The Influence of λ_2's Change on Supply and Demand System



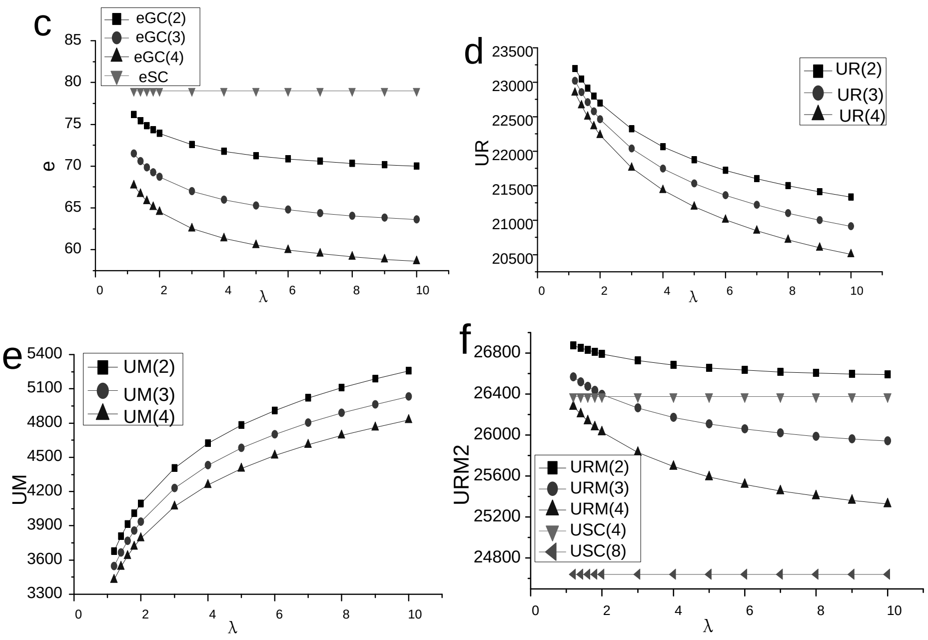


Figure 3. When $\lambda = 4,8, \lambda_2 = 2,3,4$, The Influence of λ_1's Change on Supply and Demand System

From the Figure 2 can also be found that it contains six figure are convex function and decreases with the increase of retailer's risk aversion coefficient. Below, it will analyze the impact of the level of risk aversion manufacturer's change on the system.

Figure 3 describes when risk aversion levels of system $\lambda = 4$ and $\lambda = 8$, the retailer's level of risk aversion $\lambda_2 = 2$, $\lambda_2 = 3$ and $\lambda_2 = 4$ the change in the level of risk aversion of the manufacturers on the system. Figure 3 (a) shows that as an increased level of risk aversion of the manufacturer, wholesale prices continue to increase, increased speed decreases gradually. Figure 3 (b) show that as an increased level of risk aversion of the manufacturer, the optimal output increasing, the same as manufacturers and retailers of risk aversion levels below the level of risk aversion of the whole system, the system output under the GC contract can achieve even more than the optimal distribution under centralized decision making. Figure 3 (c) and 3 (d) show that the optimal effort level and the retailer's expected utility under the GC contract is reduced ceaselessly, and retailers, the higher the level of risk aversion, the optimal effort level and the retailer's expected utility decreases faster. Figure 3 (e) shows that manufacturer's expected utility increase with the increase of the level of manufacturers risk aversion, and the increased speed decreases with the increase of the level of retailers risk aversion. Figure 3 (f) show that the expected utility of the supply and demand system with the manufacturer's risk aversion decreases with the increase of the level, the higher the level of risk aversion, and retailers reduce the faster, and when the level of risk aversion of the manufacturers and retailers is smaller than the system of the level of risk aversion, the expected utility of supply and demand system under the GC contract can achieved the expected utility of the system under centralized decision making.

As can be seen from the figure 3, with the increase of the manufacturer's risk aversion coefficient, the change trend of different variables are different, the wholesale price, output, and manufacturer's expected utility increase with the increase of the coefficient of risk aversion of the manufacturers, effort level, the retailer's expected utility and the expected utility of the whole system decreases with the increase of the manufacturer's risk aversion coefficient.

Combined with figure 2 and 3, when risk aversion coefficient of the supply and demand system is less than the coefficient of risk aversion of manufacturers and retailers, contract can significantly improve even perfect coordination of the supply and demand system.

4. Conclusion

This paper analyzes the manufacturers and retailers are risk averse, product demand, affected by the retailers' sales efforts level, retailers have wholesale pricing power system coordination problem of supply and demand. When the manufacturer's risk aversion coefficient and the retailer's risk aversion coefficient is not at the same time, the manufacturer's risk aversion and the retailers' risk aversion levels affect supply and demand system is different, as the manufacturer's risk aversion levels unchanged, with the increase of retailer's level of risk aversion, the optimal distribution, effort level, wholesale price and expected utility system is reduced, and when the retailer at constant levels of risk aversion, with the increase of manufacturer level of risk aversion, the wholesale price and the manufacturer's expected utility is increased, the rest of the decision variables is reduced. When risk aversion levels higher than the manufacturers and retailers in the supply and demand system of the level of risk aversion, the system of supply and demand under the GC contract can reach even exceed the expected utility of supply and demand system under centralized decision making, and when the system risk aversion at constant level, the higher the risk aversion coefficient of manufacturers and retailers, the smaller the GC contract to coordinate the function of the system of supply and demand, and found that the retailer's level of risk aversion of the impact on the system than manufacturers risk aversion levels are more significant impact on system.

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