Research on Pareto Improvement of Two-Stage Supply Chain Based on Return and Penalty Policy

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***Abstract*—This paper does research on order quantity and profits of members in cooperative and non-cooperative supply chains. First, the supply and demand model of members of non-cooperative supply chains is established, and optimization research on order quantity and price variables in this model has been carried out. Then the cooperation model in returnable cooperative supply chain is built by introducing return and penalty variables, and optimization strategy has been provided. Finally the analog simulation of both models is conducted. It turns out that larger order quantity and better maximum total profits can be achieved in cooperative supply chains compared with that in non-cooperative ones when prices are same. Cooperative model can accomplish Pareto improvement.**

***Index Terms*—two-stage supply chain, supply chain contract, return and penalty policy, Pareto improvement**

I. INTRODUCTION

It has been the common consensus between supplier and retailer that the supply chain coordination shall be realized through mutual cooperation in the two-stage supply chain made up of suppliers and retailers. Scholars call the profit level state when total profit level of the supply chain reaches integration as coordination of supply chain. This cooperation and coordination, however, may cause decrease of profit level of some companies, as a result, to maximize the integrated profit level is not the pursuit of a company, reasonably we can not expect a company to sacrifice its interest in order to realize the coordination of supply chain and cooperation. Therefore, a suitable mechanism shall be designed so that cooperation with other companies can be reached exactly when the company is pursuing the maximum profit, in this way, the supply chain can reach coordination. In order to ease and avoid the collision in between and to increase the profits on both sides, suppliers and retailers will sign contracts to lower the risks brought about by uncertain demands of markets [1]. Among these strategies which realize cooperation in supply chains, the supply chain contract theory based on return and penalty strategy is catching increasing attention from scholars [2].

A. Supply chain contract theory

A supply chain is a functional network structure connecting the supplier, the manufacturer, the retailer and the final customer. In other words, a supply chain is a network which, with major enterprises as the center, purchases raw materials and produces intermediate products and final products through the control of information flow, material flow and capital flow, and then delivers the products to customers through sales network. It is a complicated project involving cooperation and decision making, with a goal of improving the overall profit and efficiency of the demand and supply network formed by the manufacturer, the retailer and the customer.

When the demand of market is uncertain, if the supplier and the retailer are at arm's length, and the two both make their marketing strategies according to their own maximum expected profits, which will render the supply chain in a disperse state, the overall expected profit will be lower than that in a cooperative supply chain, therefore the conflict between the two will be increasingly salient. In order to alleviate the conflict and expand sales, the supplier and the retailer will settle the problem by signing contracts and lower the risks brought about by uncertain markets. Currently, seeking strategies to lower the risks of the retailer is becoming increasingly important to supply chain management. Among these cooperation strategies of supply chains, supply chain contract theory is catching increasing attention from experts.

Supply chain contracts are the items that ensure a coordinate transaction and improve the efficiency of sales through providing proper information and incentives. Even if the best coordination is not achieved in the supply chain, there still exits the possibility of Pareto Improvement to ensure the profits on each side that are at least not lower than before.

In the two-stage supply chain made up of suppliers and retailers, the supplier makes business directly with retailer. In the supply chain of collaborative pattern, it is the sole decision makers who have all the information and full power that can make the supply chain realize maximum profit. The non-contract supply chain in actual condition, however, has the problem of "double marginal effect", that is, each individual of the supply chain aims at the maximum profit, while collaborative pattern one emphasizes win-win, the decision under two different ways is always not consistent. Therefore, it requires a

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coordination mechanism or contract which can realize the optimal profit of the supply chain as a whole, meanwhile, ensure each member of the supply chain is more willing to make efforts to realize the contract supply chain.

Currently, the supply chain contract theory research based on return and penalty strategy mainly focus on the following three aspects: 1. Research on design of buy-back contract from angle of market risk and risk preference [3, 4], 2. Research on groundless return of retailer takes malicious utilization of the return rules and corresponding countermeasures [5, 6]. 3. Research on impact of buy-back contract on the supply chain under the information asymmetry condition [7, 8].

Among oversea scholars, Yao Zhong, Stephen Leung and K K Lai [9] have conducted thorough research in the return strategy on the condition that demands are relevant to prices. T.A.Tyalor [10] has assumed that efforts and order quantity are simultaneous, and has divided feedback contracts into linear feedback and target feedback, thus proved both of the feedback models and render the supply chain into a cooperative one, and the supply chain profits can be distributed arbitrarily between supply and requisitioning parties. H.Krishnan, R. KaPuscinski and D.Butz [11] has assumed that retailers choose a certain order quantity, and then decide the efforts according to market demands observed. They believe that if demand signals and order quantity are strongly correlated, too much effort by retailers will not be necessary. In view of long-term contractual transaction between one supplier and several purchasers, H.Mendelson and T.Tunca [12] studied the information structure of supply chains and the influence that members behaviors have on the supply chain systems performance and profits. For the first time, X. Su [13] introduced customer's return of goods into supply chain system, and did research on the performance of the system respectively fewer than three circumstances including full return, no refund and partial refund.

In China, Jun Hu, Ertian Hua and Jianxin You [14] studied the realization of overall coordination integrating the model of return policy and option contract. Li Wang and Jinlin Xu [15] and other scholars analyze the combined sales of single variety and multiple varieties with maximized profits in feedback conditions, and put forward a method of determining feedback conditions and feedback degree that both buyer and seller can accept. Long Zhang, Shiji Song, Lianchen Liu and Cheng Wu [16] and other scholars prove that the amount of risk of supply and demand in return policy is invariable. In order to make up the deficiency of classic supply chain contract in flexibility difference of risk distribution, they put forward a new contract form-nonlinear buy-back contract strategy. Chenglin Shen, Xinxin Zhang and Zhiqiong Qing [17]did research on the influence that general buy-back contract, differential pricing buy-back contract and sales rebate contract have on the coordination of supply chains. Xinjun Li and Qingli Da [18] studied the reverse supply chain of single-period mono-products based on return of goods under the circumstance of random demand, and provided the basic requirements of the supply chain's coordination and the division of profits between producers and retailers. Chen et al. [19] did research on the optimum output quantity decision when producers suffer from limitation of producing resources and introduce return policy. In view of resource input, [20] studied supply chains coordination under the circumstance of progressive increase of marginal cost of both suppliers and retailers with products, using the buy-back contract. [21] did research on the improvement of performance on both sides either when information is shared by the two cooperative sides in the supply chain or not.

B. Pareto improvement

Market competition in the 21st century is not any more merely competition between enterprises, but is gradually turning into that between supply chains. A supply chain is a network which, with major enterprises as the center, purchases raw materials and produces intermediate products and final products through the control of information flow, material flow and capital flow, and then delivers the products to customers through sales network. It connects the supplier, the manufacturer, the distributor and the retailer and forms a net chain structure. Establishing strategic allies is of prior importance in supply chain management and the key factor of integrated supply chain management. It is only through building strategic allies with others that an enterprise can achieve competitive advantages. Conflicts, competition and coordination always exist in a state of cooperative game because of profit expectations of each enterprise. To realize Pareto Improvement in supply chain management is an urgent issue for all enterprises.

Pareto improvement of the supply chain means members of the supply chain cooperate with each other during the operation of supply chain on the premise that their own performance are not decreased so that performance of other members or the whole supply chain can be improved constantly. Take the simple two-stage supply chain as an example. Figure 1 shows the Pareto Improvement of supply chains.

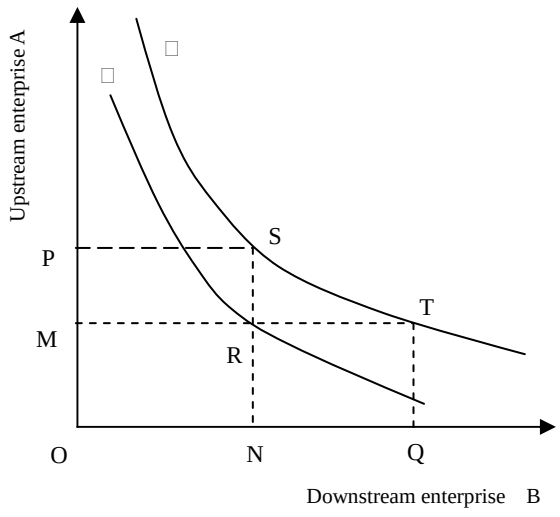

Figure 1. Pareto Improvement of the Supply Chain Management

Indifference curve I stands for the overall profit level of the upstream enterprise A and the downstream enterprise B before the implementation of supply chain cooperative management. Each point on curve I stand for a different profit distribution plan of the upstream enterprise or the downstream enterprise. Point R stands for the actual distribution plan. At this point, enterprise A gets a profit of OM while enterprise B gets a profit of ON. After the implementation of supply chain cooperative management, the overall profit level of both sides is improved, as is shown by indifference curve II. In order to make sure that the profit of enterprise A does not decrease, the distribution plan must go above the point T (or equal to T) on the curve II. As for enterprise B, the distribution plan must go under the point S (or equal to S) on the curve II. The closed interval between S and T on the curve II is the Pareto Improvement interval, in which each point on the curve II can achieve Pareto Improvement. The profit of enterprise A can be increased to OP, and that of enterprise B can be increased to OQ.

[22] discussed the forming process of enterprise cooperative game of the supply chain based on the game theory, analyzed strategy selection and profit distribution when non-cooperative game and cooperative game realize the Pareto optimality and found out a solution to optimal strategy selection of the enterprise on the supply chain to realize Pareto optimality by applying dynamic planning while discussing the shortage of Nash cooperative game. [23] analyzed a two-echelon supply chain inventory model that products are perishable and sold over a single selling season, and introduced a special buy-back contract that supply chain members optimal decision makings are discussed under different contract parameters after analyzing a traditional buy-back contract. Research shows that the supply chain can be coordinated and the supplier and the retailer can gain a Pareto improvement under the buy-back contract. Yang et al. [24] proposed and simulated the profit optimization models on the supplier and wholesaler by Taking the changeable demand and whether conducting common replenishment epoch strategy or not into consideration, The results revealed that multi-party benefit's Pareto improvement could be realized through common replenishment epoch strategy.

This paper first built a non-cooperative supply model of suppliers and retailers in a two-stage supply chain and optimized it. Then it introduced return and penalty policies into traditional supply chains, and reinstated the chain into a cooperative state. In this state, the method to determine the parameters is provided, and the existence and uniqueness of optimum retail price and optimum order quantity is proved. Pareto improvement is realized and the problem of failure in coordination in traditional supply chain contracts is solved.

II. Study on Supply and Demand Model of Suply Chain

To make the research easy, a one-producer-one-retailer two-stage supply chain is assumed. The supply chain is producer centered, i.e. the producer decides the parameters of return, bonus or penalty. The members of the supply chain are totally rational, i.e. the two sides will follow the principle of maximum profits. And it only considers one kind of products, i.e. the supplier and retailer distribute one commodity.

A. Supply and demand model in non-cooperative supply chain

On a supply chain that is not in the state of cooperative game, each enterprise is an independent market economy subject which is only in competition with others instead of cooperation. Therefore, in order to maximize their own profit, the enterprises on the supply chain, like participants in a game, choose the strategy from which they can benefit the most, bargain frequently, default their payments and try everything they can to transit the cost to the supplier or the customer. If the supplier fails to meet the requirements of the demand side, the latter will choose a more suitable supplier to take the place of the former. The upstream and the downstream are in fierce competition, which is reigned by individual rationality.

Suppose that the market demand meets $X(P,\xi)=y(p)+\xi=a-bp+\xi$ and ξ meets the uniform distribution of $[A,B]$, $f(\xi)=\frac{1}{B-A}$, $F(\xi)=\frac{\xi-A}{B-A}$, $F^{-1}(\xi)=A+(B-A)\xi$; the distribution of probability density function and distribution function of $X(P,\xi)$ are respectively $f(x\mid p)=f(x-y(p))$ and $F(x\mid p)=F(x-y(p))$.

Regardless of over orders cost and shortage cost, we set up a profit model in non-cooperative supply and demand mode:

$$\Pi_R(Q,p,w)=(p-w)Q-(p-v)\int_{y(p)}^{Q}F(x-y(p))dx \tag{1}$$

In which, Q is the orders of retailer, w is wholesale price of supplier, p is retail price, and v is salvage value of unsold goods.

Followings can be got from the assumption:

$$Q^*=Q(p)=F^{-1}(\frac{p-w}{p-v})+y(p)=a-bp+A+(B-A)\frac{p-w}{p-v} \tag{2}$$

$$\Pi_R(Q(p),p,w)=(p-w)\left[a-bp+A+\frac{(B-A)(p-w)}{2(p-v)}\right] \tag{3}$$

As well, the optimal price p shall meet:

$$\frac{\partial\Pi_R(Q(p^*),p^*,w)}{\partial p}=a-2bp^*+bw+A+\frac{(B-A)(p^*-w)(p^*+w-2v)}{2(p^*-v)^2}=0 \tag{4}$$

B. Model in cooperative supply chain

The optimal goal of supply chain management in cooperative mode is to integrate the supply chain and thus realize the maximum profit of the whole supply

chain. When the supplier and the retailer belong to one economic entity, the integration of the supply chain is the integration of supply and distribution. After products of a certain amount are produced, they are directly sold to customers at retail prices. An optimal order quantity (or production quantity) is what should be found in order to maximize the total profit of the supply chain. When the supplier and the retailer belong to different economic entities, the retailer in the integrated supply chain orders products according to the principle of profit maximization based on the contract parameters provided by the supplier. Therefore, in order to expand sales under the circumstance of supply chain integration, the supplier must provide proper incentive to enhance the cooperation among the supply chain members, so as to make sure the retailer consciously makes decisions in accordance with the optimal target of the whole supply chain. This paper mainly discusses the two-stage supply chains that belong to different economic entities respectively.

1. Supply and demand model in general cooperative supply chain

The basic knowledge of supply chain indicates that if the orders of retailer is Q and actual demand $x < Q$, the sales $s(Q) = x$; if actual demand $x \geq Q$, the sales $s(Q) = Q$ [25].

Suppose that the expected sales under given orders and retail price $S(Q, p)$, we can get based on mathematical statistics:

$$S(Q,p) = \int_0^{\infty} (Q \wedge x) f(x \mid p)dx = \int_0^{\infty} \int_y^{Q \wedge x} dy f(x \mid p)dx = \int_0^{Q} \int_y^{\infty} f(x \mid p)dxdy = Q - \int_0^{Q} f(x \mid p)dx \tag{5}$$

The overall expected profit of the entire supply chain $\Pi_T(Q, p)$:

$$\Pi_T(Q,p) = pS(Q,p) + v(Q - S(Q,p)) - cQ = (p-v)S(Q,p) - (c-v)Q \tag{6}$$

where c is production cost of unit product.

Based on the above formula, the optimal price p under given orders shall meet following condition:

$$\frac{\partial \Pi_T(Q, p^*)}{\partial p} = S(Q, p^*) + (p^* - v)\frac{\partial S(Q, p^*)}{\partial p} = 0 \tag{7}$$

The optimal orders Q^* under given price shall meet following condition:

$$\frac{\partial \Pi_T(Q^*, p)}{\partial Q} = (p - v)\frac{\partial S(Q^*, p)}{\partial Q} - (c - v) = 0 \tag{8}$$

Equation (7) and (8) are the necessary conditions for any cooperative modes of supply chain. In the event that either of the formulas cannot be met, the node enterprise in the supply chain cannot accomplish supply chain cooperation.

2. The demand and supply mode of the supply chain under the return and penalty policy

The return policy is one under which the supplier buys back from the retailer the products that haven't been sold within the sales period at a reasonable price, so as to stimulate the order quantity from the retailer and expand sales. The penalty policy is one under which the supplier sets up a sales target for the retailer, and if the latter fulfills that target, the supplier will implement the return policy on the retailer, otherwise the supplier will penalize the retailer for the part that fails to fulfill the target. Compared with the return policy which lowers the retailer's overstock cost, the penalty policy heightens the retailer's OOS (out of stock) cost. Therefore the two modes both propel the retailer to increase order quantity.

If supplier and retailer, members of supply chain, introduce return and penalty policy and seek for supply chain cooperation, the profit function of retailer can be expressed as:

$$\Pi_R(Q,p,r,\tau) = pS(Q,p) + r(Q - S(Q,p)) - wQ + \tau[S(Q,p) - T]$$

$$= (p - r + \tau)S(Q,p) - (w - r)Q - \tau T \tag{9}$$

In which, w is wholesale price the supplier provides retailer; T is target sales the supplier provides retailer based on cooperation; r is the returnable price of each product the supplier provides retailer as to the part over T after retail ends, and $r < w$; τ is penalty provided by the supplier as to each product within the parts unsold.

Based on the general supply and demand model under supply chain cooperation, the optimal price p^* that meets (7) shall also meet the following:

$$\frac{\partial \Pi_R(Q, p^*, r, \tau)}{\partial p} = S(Q, p^*) + (p^* - r + \tau)\frac{\partial S(Q, p^*)}{\partial p} = 0 \tag{10}$$

With comparison between (10) and (7), if $\tau = r - v$, (10) is workable.

Substitute $\tau = r - v$ into (9), we can get:

$$\Pi_R(Q,p,r,\tau) = (p-v)S(Q,p) - (w-r)Q - (r-v)T \tag{11}$$

Based on the general supply and demand model under supply chain cooperation, the optimal orders Q^* that meets (11) shall also meet the following:

$$\frac{\partial \Pi_R(Q^*, p, r, \tau)}{\partial Q} = (p - v)\frac{\partial S(Q^*, p)}{\partial Q} - (w - r) = 0 \tag{12}$$

With comparison between (12) and (8), if

$w-r=c-v$, that is, $r=w+v-c$, (12) is workable.

Thus, on the condition that the supply and demand depend on price, the introduction of return and penalty policy can ensure the cooperation between members of supply chain, and the cooperative parameters can meet following conditions:

$$\begin{cases} \tau = r - v \\ r = w + v - c \end{cases} \tag{13}$$

Meanwhile, we can get based on the assumption in □. A:

$$S(Q,p) = Q - \int_{A+y(p)}^{Q} F(x - y(p))dx \tag{14}$$

Substitute (14) into (6), we can get:

$$\Pi_T(Q,p) = (p-c)Q - (p-v)\int_{A+y(p)}^{Q} F(x-y(p))dx \tag{15}$$

Based on (15), the optimal orders Q^* as to the given p meets the following:

$$\frac{\partial \Pi_T(Q^*,p)}{\partial Q} = (p-c) - (p-v)F(Q^* - y(p)) = 0$$

That is :

$$Q^* = Q(p) = F^{-1}(\frac{p-c}{p-v}) + y(p) \tag{16}$$

Substitute (16) and the average value $\mu = x - y(p)$ of demand X into (15), and we can get:

$$\Pi_T(Q(p),p) = (p-c)y(p) + (p-v)\int_{A}^{F^{-1}(\frac{p-c}{p-v})} \mu f(\mu)d\mu \tag{17}$$

Based on the above assumption, we can get further from (17):

$$\Pi_T(Q(p),p) = (p-c)\left[a - bp + A + \frac{(B-A)(p-c)}{2(p-v)}\right] \tag{18}$$

Based on (18), we can get that the optimal solution p^* meets:

$$\frac{\partial \Pi_T(Q(p^*),p^*)}{\partial p} = a - 2bp^* + A + \frac{(B-A)(p^*-c)(p^*+c-2v)}{2(p^*-v)^2} = 0 \tag{19}$$

Meanwhile based on (16), we can get that the optimal orders:

$$Q^* = Q(p) = F^{-1}(\frac{p-c}{p-v}) + y(p) = a - bp + A + \frac{(B-A)(p-c)}{(p-v)} \tag{20}$$

III. SIMULATION RESULTS

This case takes the supply chain made up of one supplier and one retailer as the object of study. Parameters in the hypothetical model are c=4, w=10, v=1, A=40, B=100, A=500, b=10, we can get followings based on the forgoing analysis:

A. Supply and demand model in non-cooperative supply chain

Based on (4), we can get p^*=30.5; from (2), we can get Q^*=276.6; from (3), we can get the retailer profit $\Pi_R(Q^*,p^*,w)$ =5244.9, the supplier profit $\Pi_S(Q^*,p^*,w) = (w-c)Q^* = 1660$, and the gross profit of supply chain $\Pi_T(Q^*,p^*,w) = \Pi_S(Q^*,p^*,w) + \Pi_R(Q^*,p^*,w) = 6904.9$.

B. Supply and demand model in returnable supply chain

Based on (19), we can get p^*=30.4; from (20) ,we can get Q^*=290; from (18), we can get that the profit of the entire supply chain in cooperative mode $\Pi_T^*(Q^*,p^*) = 6941.5$.

Based on (2) and (20), we can draw the relation graph of retail price and orders in non-cooperative mode and cooperative mode, see in Figure 2. The figure 2 clearly indicates that the orders are a decreasing function of retail price. In combination with the sample, in non-cooperative mode, if retail price increases to *p*=59.1, the orders decrease to 0; in returnable mode, if retail price increases to *p* =59.7, the orders decrease to 0.

The difference of the retailers order quantities in cooperative model and that in non-cooperative model decrease along with the increase of prices. See in Figure 3. From Figure 3, we can see that the lower the price goes under 30, the less the difference between retailers order quantities in the two models.

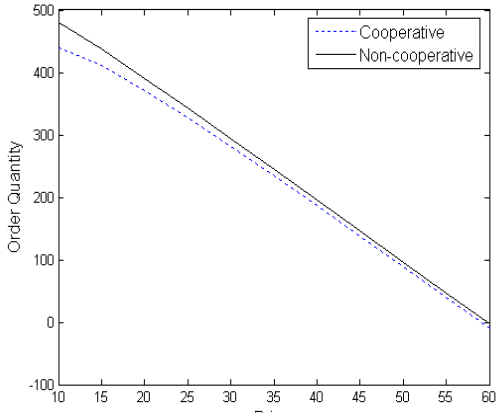

Figure 2. Relation graph between price and order quantity

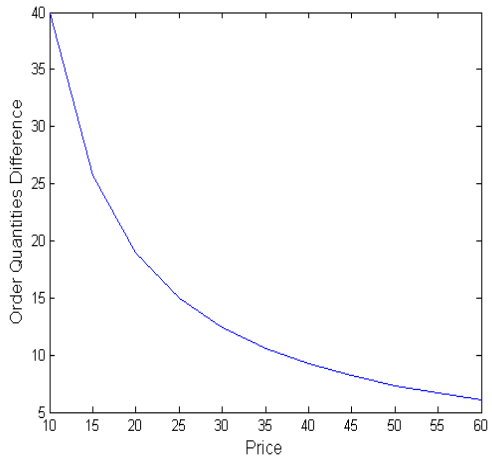

Figure 3. Relation graph between price and order quantities difference

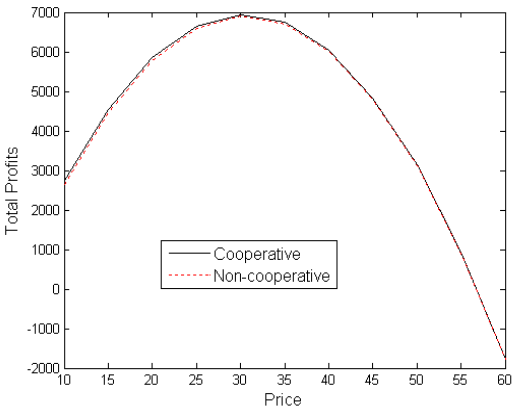

Figure4. Relation graph between price and total profit

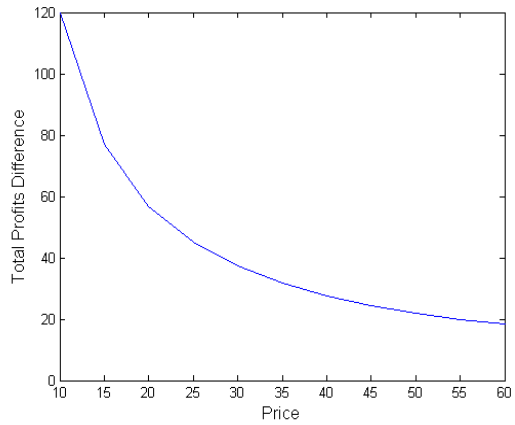

Figure 5. Relation graph between price and total profits difference

According to (3) and (18), the relevance between price and total profits in the two models can be seen. See in Figure 4. From Figure 4, we can see clearly that the total profit of supply chains is a quasi concave function of price. There is an optimum price that makes the maximum profit. In cooperative model, the price that makes maximum total profit is lower than that in non-cooperative model. The total profit in cooperative model is higher than that in non-cooperative model. In this case, the difference is 6941.5-6904.9=36.6.

The difference between total profits in cooperative model and non-cooperative model will decrease with the increase of prices. See in Figure 5. Figure 5 shows that when p=10, the difference is 119, the highest. In regard to the rate of decrease of the difference, p=30 is a boundary point. In feasible price interval, the lower the price goes under 30, the less the difference.

IV. CONCLUSIONS

By introducing the policy on return and penalty, this paper solves the difficult problem that the traditional supply chain contract is unable to result in supply chain coordination. A simulation research is made on the problem of two-stage supply chain under the return and penalty strategy in combination with the actual example using software MATLAB7.0. The result shows the order quantity is decreasing function of retail price within the reasonable price range, the sales volume under cooperative mode is larger than that under non-cooperative mode, difference between which is quasi-convex function of retail price, the lower the retail price, the larger the difference of the sales volume between the two, when the retail price is 30, the difference of the sales volume between the two diminishes rapidly, when it reach 60, the number turns to 0. The total profit of supply chain in cooperative mode is quasi-concave function of retail prices. There exists an optimal retail price that makes the biggest profit of supply chain. The price responding to maximum total profit is less than that of non-cooperative mode, and the total profit of supply chain is more than that of non-cooperative mode.

Further study orientation:

1. Take into consideration the consumers' purchasing power and the expected profits of the supplier and the retailer, and further study the Pareto Improvement interval of the cooperation between the supplier and the retailer based on the former study on the Pareto Improvement of supply chain management. Every distribution plan within this interval can ensure a rise of one enterprise and make sure the profit of another does not fall. Therefore, both sides will be more willing to cooperate and true Pareto Improvement is realized. The next step focuses on the Pareto optimal point of two-stage supply chains. At this point, the total profit of the supply chain reaches the top.

2. Research in this paper is limited to mono-product return and penalty policy of the supply chain, while the products can be more complex in future research, therefore, the supply chain cooperative mode based on multiple products will be the direction of following research. 3. This paper focuses on Pareto improvement of two-stage supply chain, the next research shall expand to multi-stage supply chain and multiple supplier and retailers with a view to unveil the inherent law of Pareto

optimality in the management of general supply chain.

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