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Impact of the downside risk of retailer on the supply chain coordination

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ABSTRACT

This paper analyzes the coordinating mechanisms for a single-period supply chain comprising of one supplier and one retailer. The later is constrained by downside risk. We model the decision problems with the newsvendor model, and then analytically derive the optimal order policies of the retailer. We have analyzed several often used coordinating mechanisms under retailer downside risk constraint. We find that none of the price-only contract, returns policies contract and revenue sharing contract can coordinate a supply chain with retailer's downside risk constraint. However, by integrating the transfer payment contract with returns policy contract and the revenue sharing contract, perfect coordination is possible. For optimal decisions of the supplier, we use the numerical method to analyze the effect of the retailer downside risk on decision variables, and profits of the supplier and the retailer. Compared with the case of no risk constraints, the study has shown that the splitting of the expected channel profits between the supplier and the retailer is dependent on the retailer's risk attitude. The more risk-reverse the retailer is, the lower are the profits earned by the retailer and, of course, the more are the profits of the supplier. We close with a discussion of contract implementation issues and future research.

1. Introduction

Most previous studies of supply chain contracts assume the decision-makers are risk neutral (Eeckhoudt, Gollier, & Schlesinger, 1995; Xiao & Xu, 2014; Rajesh & Ravi, 2015; Sawik, 2016; Wu, Kleindorfer, & Zhang, 2002). In practice, however, due to increased globalization and vertical integration, supply chains are becoming quite complex and potentially vulnerable and that lead to the decision-makers are usually risk averse. Examples of supply chain risk are reported from both the practice and the scholars. For example, Ericsson lost 400 million Euros after their semiconductor supplier located in Mexico caught on fire in 2000 (Tang, 2006). Taiwan earthquake lead to Apple company lost many customer orders in 1999 (Tang., 2006). To response supply chain risk, there are lots of policies or strategy has been studied. Tang (2006) has reviewed 6 strategies (demand management, product management, supplier selection, robust management, information management, and order allocation) to process the supply chain interrupt. Neiger, Rotaru, and Churilov (2009) proposed a value-focused process engineering to reconcile the risk occurred in supply chain. Rajesh and Ravi (2015) propose a grey-DEMATEL method for modeling supply chain risk mitigation in electronic supply chains. Sawik (2016) shows that the shipping disruption risk in the service-oriented supply portfolio is more diversified than the cost-oriented portfolio, and the later will delay the expected supply, production and distribution schedules. Among those methods, the strategies proposed for improving supply chain performance is reported most in reducing loss or mitigating risk when supply chain meets the interrupt. However, as the studies conducted in risk-free supply chain coordination, the designing effective contracts to coordinate a supply chain in risk situation have been paid little attention. In this paper, we analyze some of contracts frequently mentioned in literature and used in practice, such as wholesale price contract, returns policy contract, also called buy-back contract, and revenue sharing contract, exploring, when the retailers are risk-averse, whether and how these contracts can be modified, to achieve supply chain coordination. Specifically, we investigate whether the some of these contracts can maximize the expected channel wide profit under retailer risk constraints. Or, if not coordinated, whether it can obtain a Pareto improvement, i.e. under the retailer downside risk constraint, the supply chain system or supply chain members' profit can be improved.

There are numerous studies on risk management in economics. Here we only focus on risk management issues in supply chain. A comprehensive literature review for supply chain risk can be found in the study of Tang (2006). An earlier paper that considered supply chain members risk is by Lau and Lau (1999). In Lau and Lau

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(1999) study, the measure of supply chain risk is evaluated by the mean-variance model. Under the newsvendor supply chain structure, Lau and Lau (1999) numerically show that the manufacturer's (here supplier) returns policy can benefit the manufacturer himself but hurt the retailer, i.e. the so-called anti-intuition. Whether the contract obtained Pareto improvement depends on the manufacturer's attitude towards risk. Under the same model structure as Lau and Lau (1999), but with price-dependent demand, Agrawal and Seshadri (2000a) adopt the increasing and concave utility function in profit to measure the supply chain member risk. They show how a risk-averse retailer chooses the order quantity and the selling price in a newsvendor inventory model. They consider two ways in which price affects distribution of demand; a change in standard deviation of distribution, and a change in only the mean value of distribution. They show that, in comparison to a risk-neutral retailer, a risk-averse retailer will charge a higher price and order less in the first case, while in case of the second scenario, he will charge a lower price. Based on this research, Agrawal and Seshadri (2000b) extended the model to the multi-retailers situation. The supplier (called intermediary) designs a contract menu to induce the retailer to choose a contract from the menu that maximizes the supplier's profits and simultaneously increases the retailer's order quantity. Tsay (2002) considers how risk-aversion affects both supplier and retailer under a Stackelberg game framework. Instead of using the expected profit, this study adopts the mean-variance objective function of profit to model the supply chain risk. Tsay (2002) showed that the behavior under risk-aversion is quite different from that under risk-neutrality and the penalty for errors in estimating a channel partner's risk-aversion can be substantial. He also derives conditions in which the supplier and the buyer prefer a full-return to a without return contract. Under the mean-variance measuring risk framework, Choi, Li, and Yan (2008) analyze the risk effect on the supply chain under a returns policy. They find that channel coordination is not always achievable under the risk controlled by mean-variance. This is sufficiently different with those most literature has reported that under ignoring risk aversions of the individual decision makers, channel coordination can always be achieved by setting a returns price. Choi and Chow (2008) also use the mean-variance analyze the quick response policies such as price commitment policy, service-level commitment policy, and buy-back policy and conclude that all these policy can obtain a win-win policy under some conditions. Chen and Federgruen (2000) use mean-variance to measure the risk in a number of basic inventory models. They exhibit how a systematic mean-variance trade-off analysis can be carried out efficiently, and how the resulting strategies differ from those obtained in the standard analyses. Chen, Sim, Simchi-Levi, and Sun (2007) derive the joint optimal inventory and pricing policy with Conditional Value-at-Risk (CVaR) measure to consider risk-aversion. Wang, Webster, and Suresh (2009) use exponential utility function to measure risk for studying the inventory risk. However, Chen and Federgruen (2000), Wang et al. (2009) and Chen et al. (2007) do not deal with full supply chain problems. Cachon (2004) analyzes an advance purchase contract in a newsvendor setting and discusses the impact of the contract on allocation of inventory risk. However, the "risk" in this paper refers to the expected cost of unsold inventory. No special risk measure is considered in either decision-maker's objectives, or in constraints. Based on the CVaR measure of risk management, Xu, Meng, and Shen (2013) proposes a tri-level programming model for the three-stage supply chain management. They transfer the tri-level programming model into a bi-level programming model and results show this method can be efficient for improving the risk management of the three-stage supply chain. There are also some qualitative methods for process supply chain risk. Under the Value-at-Risk (VaR) criterion and the Conditional Value-at-Risk (CVaR) criterion, Li, Hou, Chen, and Li (2016) formulate a dual channel supply chain consisting of a risk-neutral supplier and a risk-averse retailer, where the supplier as a Stackelberg leader, and obtain the equilibrium solutions in the decentralized and centralized situations. Liu, Cao, and Salifou (2016) studies a similar supply chain risk problem, but they use expected profit less than some tolerance to measure the risk and study the information value in risk supply chain. Kleindorfer and Saad (2005) propose a conceptual framework for disruption risk in supply chain management. Here the supply chain disruption risk refers to consequences of economic disruptions caused by natural disasters, strikes, and purposeful actions of agents, such as terrorists. This paper provides a conceptual framework that addresses risk assessment and risk mitigation, both of which are fundamental to disruption risk management in supply chains. However, this paper does not consider specific risk measures for evaluating supply chain coordination. Kumar and Tiwari (2013) incorporate risk pooling policy for both safety stock and running inventory into the location, production-distribution and inventory system to minimize the supply chain cost along with determining facility location and capacity. This policy can effectively mitigate the supply chain risk, but they are not used for coordinating supply chain management. Claypool, Norman, and Needy (2014) develop a Mixed Integer Programming (MIP) model to make the design for supply chain (DFSC) decisions while simultaneously considering time-to-market risk, supplier reliability risk and strategic exposure risk, and then use discrete event simulation to test the robustness of the MIP solution for supplier capacity risk and demand risk. Testing results show that risk mitigation strategies can partially solved from the DFSC and risk model. Downside risk as a financial risk measure has been widely used in financial-economic literature (Hu & Motwani, 2014; Markowitz, 1959; Szego, 2004; Ormos & Timotity, 2016; Reboredo, Rivera-Castro, & Ugolini, 2016; Shi, Qu, & Chu, 2016). For example, Ormos and Timotity (2016) introduce an equilibrium asset pricing model with the Expected Downside Risk (EDR) and they argue that the EDR is more realistic assumptions and so their model is able to describe equilibrium expected returns with higher accuracy. However, in supply chain risk study, little attention has been paid for researchers (Lorentz, Töyli, Solakivi, & Ojala, 2016). In the following paragraph, we review the Gan, Sethi, and Yan (2004, 2005) investigation in supply chain risk measurement with downside risk, in which it is most relevant with our study.

For the supply chain downside risk coordination strategy, Gan et al. (2004) analyzed coordinated contracts (actually Pareto-optimal contracts) with three kinds of risk measures: (1) downside risk to constrained the retailer, (2) mean-variance trade-off to measure the risk of both the supplier and the retailer, and (3) exponential utility function to measure the risk of the supplier and retailer. For the first case, they show that a wholesale contract can only reach a Pareto-optimal. For the second case, revenue sharing and buy-back contracts along with a side payment to the retailer can coordinate the supply chain under some conditions that satisfied the profit allocation proportion evaluated with risk measure. For the third case, they derive a similar conclusion as in the second case. Later, Gan et al. (2005) analyzed in detail the first case in Gan et al. (2004). Specifically, they first analyzed the natural downside risk (NDR) of the buy-back and revenue-sharing contract, where the NDR is defined as the expected target profit level under risk-neutral newsvendor as the downside risk-averse newsvendor. Then they showed that the NDR with buy-back or revenue-sharing contract cannot coordinate the supply chain. Therefore, they constructed a risk-sharing contract by which it can coordination the supply chain with the wholesale price limited condition under retailer downside risk constraint. It should be pointed out that above-mentioned analysis in Gan et al. (2004, 2005) is played with Nash game.

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Our paper extends the Gan et al. (2005) study. However, we focus on the decentralized system, in which both the supplier and the retailer have self-interest objective functions and the retailer has a downside risk constraint. Specifically, we consider several kinds of contracts, such as price-only contract, returns policies contract and revenue sharing contract, to coordinate the supply chain, assuming that the retailer has a downside risk constraint. Under Stackelberg game decision sequence, we find that under the downside risk constraint, the above mentioned contracts cannot coordinate the supply chain, if the optimal order of the retailer is not the upper bound, which is a newsvendor solution in a risk-neutral case. However, if the optimal order is the upper bound, the returns policies and revenue sharing contracts will coordinate the supply chain just as in a risk-free situation. In order to coordinate the supply chain, we design a new contract, named transfer payment plus returns policies or revenue sharing contract. With transfer payment plus returns policies or revenues sharing contract, the newsvendor solution of retailer's optimal order will become the lower bound. That means, whatever the downside risk constraint is, the newsvendor solution is always an optimal order of retailer. Thus the new contract not only mitigates the risk effect on the optimal order decision, but can also effectively coordinate the supply chain with risk-free coordinating conditions. This is the main contribution of this paper. The second contribution is that under coordinated contract the splitting of the expected channel profits between the supplier and the retailer is dependent on the retailer's risk attitude. The more risk-reverse the retailer is, the lower are the profits earned by the retailer and, of course, the more are the profits of the supplier. Although we have extended the Gan et al. (2005) study in down side risk measurement for supply chain coordination, there are some differences between our study and Gan et al. (2005). On the one hand, Gan et al. (2005) study is focused on risk-sharing plus the return policy or revenue sharing to coordinate the supply chain, but our study is using the incentive contract (named transfer payment plus returns policy or revenue sharing) provided by the supplier to change retailer's order quantity to coordinate the supply chain. On the other hand, our problem settings are paid attention on risk constraint for the retailer's optimal decision, but Gan et al. (2005) considered both the supplier and the retailer optimal decision with down side risk constraint. Also, Gan et al. (2005) model assumes that the supply chain is a cooperative channel where the retailer and the supplier tell true risks to each other. Last, Gan et al. (2005) model game is played in a Nash game. Our model is played with the supplier as a Stackelberg leader and the retailer as a follower. Our problem setting can be found in Wu et al. (2002). However, Wu et al. (2002) are focused on the reservation contract.

The paper is organized as follows. After a literature review, we model and analyze the integrated channel situation, which is a benchmark for evaluating the returns policy contract in a decentralized system, in Section 2. In Section 3, we model the returns policy contract with retailer risk-aversion constraint, and show the optimal decisions of the retailer and the supplier. Section 4 gives a numerical study for analyzing the channel performance. Lastly, we conclude in Section 5 and discuss future research.

2. Integrated channel with downside risk constraint

Before presenting our model, we first list all relevant notations for readers convenient to understand our technical analysis.

Decision variables:
Q_i^*, order size, retailer's optimal solution in i type contract under risk constraint;
$\hat{Q}_i^*$, order size, retailer's newsvendor sub-optimal solution in i type contract;
$\tilde{Q}_i^*$, order size, retailer's sub-optimal solution in supply chain in i type contract under risk constraint;
b, return price of supplier;
ϕ, revenue sharing proportion of supplier;
T_i, transfer payment in i type contract;

Parameters or symbols:
p_i, retail price in i type contract;
c, production cost of supplier;
w, wholesale price of supplier;
α, the retailer's target profit, downside risk measurement index;
β, the biggest probability of the retailer's target profit below α, downside risk measurement index;
x, random demand;
$F(x)$, $F^{-1}(x)$, $f(x)$, cumulative distribution function (CDF), inverse CDF and probability density function (PDF) of x, respectively;
μ, mean value of x;
σ, standard deviation of x;
π_{ki}, expected profit of k in i type contract;
π_{ki}^*, optimal expected profit of k in i type contract;

where $i = IC$, PO, RP and RS stand for integrated channel, price-only contract, return policy contract and revenue sharing contract, respectively and $i = PO+$, $RP+$, $RS+$ stands for transfer payment plus price-only contract, transfer payment plus return policy contract and transfer payment plus revenue sharing contract; $k = r$, S, SC stand for retailer, supplier, and supply chain, respectively.

CE, Channel Efficiency.

Then we introduce our modeling process and analytical analysis. Consider a supply chain system that consists of one supplier and one retailer. As a benchmark to measure the decentralized channel performance, we first model an integrated channel situation. The supplier produces the items with cost c, the retailer orders Q units before selling season, and sells the items at retail price p to consumers during the selling season. That $p > c$ is a basic assumption in a rational economy. Here the retail price is decided by the market. The random demand x has a continuous distribution $F(x)$ and density $f(x)$ with mean μ and standard deviation σ. In addition, we assume that $F(x)$ has an inverse, which is strictly increasing, and $f(x)$ has a continuous derivative $f'(x)$. Let T represent the transfer payment from the retailer to the supplier. T may depend on Q, including delivery cost. We don't assume a specific form.

Let π_r, π_s and π_{sc} denote retailer's, supplier's and supply chain profits, respectively, then

$$\pi_r = p\min\{Q, x\} - T, \tag{1}$$
$$\pi_s = T - cQ. \tag{2}$$

Suppose the risk parameters for the retailer are (α_r, β_r). That is, the probability of the retailer's target profit level π_r being below α_r is at the most β_r. This kind of risk measurement was first proposed by Markowitz (1959), and is called downside risk in financial risk analysis. With above assumptions and following the notations in Gan et al., the decision problem of an ***I***ntegrated ***C***hannel is

$$\begin{aligned} \max_{Q \geqslant 0,} \quad & \mathrm{E}[\pi_{IC}] = pE[\min\{x, Q\}] - cQ \\ \text{s.t.} \quad & P\{p\min\{Q, x\} - cQ \leqslant \alpha\} \leqslant \beta \end{aligned} \tag{3}$$

Note that in the integrated channel, we considered the downside risk in retailer side of the supply chain. As is obvious, the objective function in (3), without the downside risk constraints, is the standard newsvendor problem, for which the optimal order quantity is $\hat{Q}^* = F^{-1}\left(\frac{p-c}{p}\right)$, where hat denotes the newsvendor solution. The problem of an integrated channel is how to work out the maximum order quantity Q^* (here equivalent to production quantity), while satisfying the risk constraint, and then take the minimum of Q_{IC}^* as the optimal solution to objective function in (3).

Proposition 1. *If $(p-c)F^{-1}(\beta) \geqslant \alpha$, then optimal production quantity of the integrated channel is*

$$Q_{IC}^* = \min\{\hat{Q}_{IC}^*, \widetilde{Q}_{IC}^*\}, \text{ where } \hat{Q}_{IC}^* = F^{-1}\left(\frac{p-c}{p}\right) \text{ and}$$
$$\widetilde{Q}_{IC}^* = \frac{pF^{-1}(\beta) - \alpha}{c}. \tag{4}$$

Proof. If we find the maximum feasible solution Q of objective function in (3), that satisfies the constraints in (3), then the optimal solution of (3) will be the minimum of Q_{IC}^*. Obviously, the risk-free solution is a newsvendor solution, $\hat{Q}^*$.

From the constraint condition of the retailer,

(1) In case of $Q \geqslant x$, substituting $(p-c)F^{-1}(\beta) \geqslant \alpha$ into the constraint of the retailer, we have

$$\begin{aligned} P\{p\min\{Q,x\} - cQ \leqslant \alpha\} \leqslant \beta &\Rightarrow P\{px - cQ \leqslant \alpha\} \leqslant \beta \\ &\Rightarrow P\left\{x \leqslant \frac{\alpha + cQ}{p}\right\} \leqslant \beta \\ &\Rightarrow F\left(\frac{\alpha + cQ}{p}\right) \leqslant \beta \\ &\Rightarrow Q \leqslant \frac{pF^{-1}(\beta) - \alpha}{c}. \end{aligned}$$

This is the maximum production quantity that satisfies risk constraint condition of the retailer.

(2) In case of $Q < x$, going by assumption $(p-c)F^{-1}(\beta) \geqslant \alpha$, the maximum production quantity will be derived by

$$\begin{aligned} P\{p\min\{Q,x\} - cQ \leqslant \alpha\} \leqslant \beta &\Rightarrow P\{pQ - cQ \leqslant \alpha\} \leqslant \beta \\ &\Rightarrow P\left\{Q \leqslant \frac{\alpha}{p-c}\right\} \leqslant \beta \end{aligned}$$

That is $Q \leqslant \frac{\alpha}{p-c}$ is true because of the assumption. Also, it is easy to show, $Q \leqslant \frac{\alpha}{p-c} \leqslant \frac{pF^{-1}(\beta)-\alpha}{c}$.

Therefore, $\widetilde{Q}_{IC}^* = \frac{pF^{-1}(\beta)-\alpha}{c}$, where tilde denotes the solution with risk constraint.

Note that the result obtained from the above analysis satisfies the risk constraint of the retailer. Therefore, the conclusions satisfy all constraints of problem (3) and the optimal production quantity is $Q_{IC}^* = \min\{\hat{Q}_{IC}^*, \widetilde{Q}_{IC}^*\}$, where $\hat{Q}_{IC}^* = F^{-1}\left(\frac{p-c}{p}\right)$ is the optimal quantity without risk constraints (newsvendor solution), and $\widetilde{Q}_{IC}^* = \frac{pF^{-1}(\beta)-\alpha}{c}$ is a solution satisfying risk constraints of the integrated channel, or the supply chain. □

In a risk-free solution, the optimal production quantity is the solution of the newsvendor, but with downside risk constraint, the optimal production quantity is either newsvendor solution or the solution of risk constraints. However, which solution will be the optimal one for a production decision is dependent on the risk parameters. Fig. 1 shows an intuitional understanding about the final choice. We have the following remarks.

Remark 1. If $\alpha = (p-c)F^{-1}(\beta)$ and $\beta = \frac{p-c}{p}$, then $\hat{Q}_{IC}^* = \widetilde{Q}_{IC}^*$.

Remark 1 shows that the retailer's target profit level $\alpha = (p-c)F^{-1}\left(\frac{p-c}{p}\right)$ is an upper bound of the downside risk and

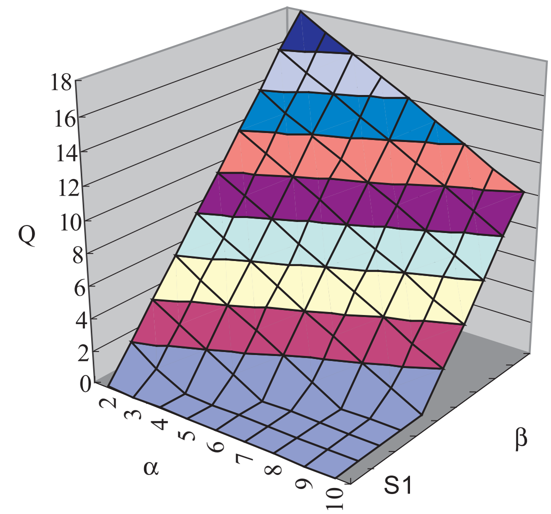

Fig. 1. Downside risk constraint order size. ($x \sim U(0,20)$, $p = 3$, $c = 1$, $\beta = 0.1$–1 with step S1 = 0.1, $\alpha = 1$–10 with step 1. Newsvendor solution is 13.333.).

the corresponding order quantity is also an upper bound of the integrated channel (or the supply chain in later sections). Note that α is dependent on the market. The optimal order quantity with downside risk will be determined as the risk-free order quantity. This provides a management insight into the integrated channel (here it is a newsvendor) or supply chain: if the retailer's attitude is risk-averse, its target profit level will be lower than a risk-free situation in the market.

To study the coordinating mechanisms, we need to define the supply chain coordination because some coordinating mechanisms under risk-neutral situations are not effective under downside risk constraints.

In this paper, we assume that the supply chain is coordinated if the expected profit in a decentralized supply chain is equal to the upper bound of expected profit in an integrated channel.

Here the upper bound of expected profit means the estimated profit of the supply chain when the optimal order is the newsvendor solution. The upper bound is used because if the retailer's attitude is more risk-averse, the optimal order quantity is less than the upper bound, and then the optimal order will be the one that satisfies the downside risk constraint.

Next we focus on the performance of some often used contracts in supply chain coordination under risk constraints, in a decentralized channel situation.

3. Coordination with down side risk

3.1. Price-only contract

Suppose a supply chain consists of one supplier and one retailer, each wanting to maximize its own profit. The supplier proposes a wholesale price policy to the retailer, with a given wholesale price w. The retailer will order Q_{PO} units before selling season, and shall then sell the products at price $p\,(> w > c)$ to the consumers. The supplier sets the wholesale price w on the basis of its estimate of the quantity that the retailer would order at this price, which would also be the level that would maximize himself profit (some literatures also call this wholesale price contract). For the retailer, if the order quantity turns out to be more than the realized demand, unsold stock will not be salvageable (retailer will bear all risk). Without loss of generalization, we assume salvage value is zero. This decision process can be treated as the Stackelberg game (detailed analysis of price-only contract under risk-free situation could be seen in Lariviere, 1999, chap. 8). Other assumptions are the same as before.

Under downside risk constraint, the retailer's decision model is

$$\begin{aligned} &\max_{Q_{PO}\geqslant 0} E[\pi_{rPO}] = pE[\min\{x, Q_{PO}\}] - wQ_{PO} \\ &\text{s.t.} \qquad P\{\pi_{r\ PO} \leqslant \alpha\} \leqslant \beta. \end{aligned} \tag{5}$$

Supplier's decision model is

$$\max_{w} E[\pi_{sPO}] = (w-c)Q_{PO}, \tag{6}$$

where Q_{PO} is the solution of retailer's decision in (5). If the downside risk parameter pair (α, β) satisfy $(p-w)F^{-1}(\beta) \geqslant \alpha$, we have the following conclusion.

Proposition 2. *If* $(p-w)F^{-1}(\beta) \geqslant \alpha$, *a risk-averse retailer under price-only contract will order* $Q^*_{PO} = \min\{\hat{Q}^*_{PO}, \widetilde{Q}^*_{PO}\}$, *in which* $\hat{Q}^*_{PO} = F^{-1}\left(\frac{p-w}{p}\right)$ *and* $\widetilde{Q}^*_{PO} = \frac{pF^{-1}(\beta)-\alpha}{w}$.

Proof. The proof is analogous to the Lemma, where substituting c for w only.

Similar to Remark 1 in the case of integrated channel, there is a relationship between the two order quantities. Note that the upper bound of retailer's optimal order is dependent on both the supplier's optimal decision and the market. Here it is omitted. In addition, because $w > c$, we have $\hat{Q}^*_{PO} < \hat{Q}^*_{IC}$ and $\widetilde{Q}^*_{PO} < \widetilde{Q}^*_{IC}$. That is to say, under the downside risk constraint, the retailer's order in price-only contract is less than in the integrated channel. Substituting Q^*_{PO} into (6), the manufacturer's problem will be

$$\max_{w} E[\pi_{sPO}] = (w-c)\min\left\{F^{-1}\left(\frac{p-w}{p}\right), \frac{pF^{-1}(\beta)-\alpha}{w}\right\}. \tag{7}$$

By $\hat{Q}^*_{PO} < \hat{Q}^*_{IC}$, we know that a price-only contract with a risk-neutral retailer cannot coordinate a supply chain (Lariviere, 1999, chap. 8). For the downside risk retailer, because $Q^*_{PO} = \min\{\hat{Q}^*_{PO}, \widetilde{Q}^*_{PO}\} < \hat{Q}^*_{IC} \Rightarrow E[\pi_{sPO}]^* + E[\pi_{rPO}]^* < E[\pi_{sc}]^* = E[\pi_{IC}]^*$, we conclude that the total expected profit under the constraint of a risk-averse retailer in a decentralized supply chain is less than that in a supply chain with a risk-neutral retailer. That is to say the price-only contract, under the downside risk constraint, cannot coordinate the supply chain. □

3.2. Return policies contract

In this case, based on the price-only contract, the supplier will accept unsold stock at price b. Due to the allowance of returned unsold inventory, the retailer will adopt an aggressive order policy and generally. Without loss of generality, we assume the retailer has no shortage (Webster and Weng, 2000). Therefore, it is possible to improve the supply chain performance. Note that there is a relationship: $p > w > b > c$.

When return policies is used in a supply chain with a risk-averse retailer, according to Stackelberg game, the supplier first announces the return policies contract to the retailer, then the retailer order will be decided. The order size of the retailer is the solution of the following decision model:

$$\begin{aligned} &\max_{Q_{RP}\geqslant 0} E[\pi_{rRP}] = pE[\min\{x, Q_{RP}\}] - wQ_{RP} + bE[\max\{Q_{RP}-x, 0\}] \\ &\text{s.t.} \qquad P\{\pi_{rRP} \leqslant \alpha\} \leqslant \beta. \end{aligned} \tag{8}$$

Anticipated the retailer's order behavior, the supplier will decide (w, b) to maximize $E[\pi_{sRP}] = (w-c)Q_{RP} - bE[\max\{Q_{RP} - x, 0\}]$. For retailer's decision, we have the following conclusion.

Proposition 3. *If* $(p-w)F^{-1}(\beta) \geqslant \alpha$, *with return policies contract, the risk-averse retailer will order* $Q^*_{RP} = \min\{\hat{Q}^*_{RP}, \widetilde{Q}^*_{RP}\}$, *where* $\hat{Q}^*_{RP} = F^{-1}\left(\frac{p-w}{p-b}\right)$ *and* $\widetilde{Q}^*_{RP} = \frac{(p-b)F^{-1}(\beta)-\alpha}{w-b}$.

Proof. The optimal solution of the retailer in (8) is the minimum quantity, between the solution of the objective function and the maximum feasible domain, that satisfies the downside risk constraint.

It is known that the optimal order quantity of a retailer without risk constraint in a returns policies contract is $\hat{Q}^*_{RP} = F^{-1}\left(\frac{p-w}{p-b}\right)$, i.e. a solution of objective function in (8). For the downside risk constraint, we have

$$\begin{aligned} &P\{\pi_r \leqslant \alpha\} \leqslant \beta \\ &\quad \Rightarrow P\{p\min\{x, Q_{RP}\} - wQ_{RP} + b\max\{Q_{RP} - x, 0\} \leqslant \alpha\} \leqslant \beta \end{aligned} \tag{9}$$

(1) In case of $x \leqslant Q_{RP}$,

$$\begin{aligned} &P\{px - wQ_{RP} + b(Q_{RP} - x) \leqslant \alpha\} \leqslant \beta \\ &\quad \Rightarrow P\{(p-b)x - (w-b)Q_{RP} \leqslant \alpha\} \leqslant \beta \\ &\quad \Rightarrow P\left\{x \leqslant \frac{\alpha + (w-b)Q_{RP}}{p-b}\right\} \leqslant \beta \\ &\quad \Rightarrow F\left(\frac{\varepsilon + (w-b)Q_{RP}}{p-b}\right) \leqslant \beta \\ &\quad \Rightarrow Q_{RP} \leqslant \frac{(p-b)F^{-1}(\beta) - \alpha}{w-b}. \end{aligned}$$

(2) In case of $x > Q_{RP}$, from the retailer's target profit level, we have $Q_{RP} \leqslant \frac{\alpha}{p-w}$. According to $(p-w)F^{-1}(\beta) \geqslant \alpha$, we have $Q_{RP} \leqslant \frac{\alpha}{p-w} \leqslant \frac{(p-b)F^{-1}(\beta)-\alpha}{w-b}$.

Therefore, $\widetilde{Q}^*_{RP} = \frac{(p-b)F^{-1}(\beta)-\alpha}{w-b}$, and retailer's optimal order is

$$Q^*_{RP} = \min\left\{F^{-1}\left(\frac{p-w}{p-b}\right), \frac{(p-b)F^{-1}(\beta)-\alpha}{w-b}\right\}. \qquad \square \tag{10}$$

From above solution, we have

Remark 2. If $\alpha = (p-w)F^{-1}(\beta)$ and $\beta = \frac{p-w}{p-b}$, $\hat{Q}^*_{RP} = \widetilde{Q}^*_{RP}$.

Remark 2 shows that under returns policies contract, the optimal order of retailer with downside risk constraint has an upper bound. Note that this bound is different from that in an integrated channel, which is determined by the market. Here it is dependent on both the supplier's optimal decision, and the market.

It is known that when the retailer is risk-neutral, the returns policy contract, with the condition of $\frac{p-b}{p} = \frac{w-b}{c}$, can coordinate the supply chain. Here, in our model, it is $\hat{Q}^*_{RP} = \hat{Q}^*_{IC}$. That is to say, the upper bound in returns policy contract will coordinate the supply chain, as we described in Section 2. However, by Remark 2, under retailer's downside risk constraint, we have known that the retailer's optimal order, below the upper bound, is $\widetilde{Q}^*_{RP}$, which means $\widetilde{Q}^*_{RP} < \hat{Q}^*_{IC}$. Therefore,

$$\begin{aligned} E[\pi_{rRP}]^* + E[\pi_{sRP}]^* &= pE[\min\{x, Q^*_{RP}\}] - cQ^*_{RP} < E[\pi_{sc}]^* \\ &= pE[\min\{x, Q^*_{IC}\}] - cQ^*_{IC}. \end{aligned} \tag{11}$$

As a result, return policies could not coordinate a supply chain with a downside risk-averse retailer.

3.3. Revenue sharing contract

Under revenue sharing contract, the supplier charges a wholesale price w per unit purchased by the retailer, and the retailer keeps a percentage ϕ $(0 < \phi < 1)$ of his revenue. When revenue sharing contract is used to coordinate a supply chain with a risk-averse retailer, the supplier should decide (w, ϕ) to maximize $E[\pi_{s\ RS}] = (w-c)Q_{RS} + (1-\phi)pE[\min\{x, Q_{RS}\}]$, where Q_{RS} is the optimal order quantity of the retailer's decision:

$$\begin{aligned} &\max_{Q_{RS}\geqslant 0} E[\pi_{rRS}] = \phi pE[\min\{x, Q_{RS}\}] - wQ_{RS} \\ &\text{s.t.} \qquad P\{\pi_{rRS} \leqslant \alpha\} \leqslant \beta \end{aligned} \tag{12}$$

Proposition 4. *If* $(\phi p - w)F^{-1}(\beta) \geqslant \alpha$, *with revenue sharing contract, risk-averse retailer will order* $Q^*_{RS} = \min\{\hat{Q}^*_{RS}, \widetilde{Q}^*_{RS}\}$, *in which* $\hat{Q}^*_{RS} = F^{-1}\left(\frac{\phi p - w}{\phi p}\right)$ *and* $\widetilde{Q}^*_{RS} = \frac{\phi pF^{-1}(\beta)-\alpha}{w}$.

Proof. Analogous to Proposition 3, $\hat{Q}^*_{RS}$ is the optimal order for a retailer without risk constraints (see Cachon & Lariviere, 2005) and $\widetilde{Q}^*_{RS}$ is the maximum of the feasible domain of the risk constraint condition. The minimum of $\hat{Q}^*_{RS}$ and $\widetilde{Q}^*_{RS}$ is the optimal order Q^*_{RS} for a risk-averse retailer.

The solution of objective function in (12) is a newsvendor solution, i.e. $\hat{Q}^*_{RS} = F^{-1}\left(\frac{\phi p - w}{\phi p}\right)$. For the risk constraint condition in (12), we have

$$P\{\pi_{rRS} \leqslant \alpha\} \leqslant \beta \Rightarrow P\{\phi p \min\{x, Q_{RS}\} - wQ_{RS}\} \leqslant \beta$$

(1) In case of $x \leqslant Q_{RS}$, we have

$$P\{\phi px - wQ_{RS} \leqslant \alpha\} \leqslant \beta \Rightarrow P\left\{x \leqslant \frac{\alpha + wQ_{RS}}{\phi p}\right\} \leqslant \beta$$
$$\Rightarrow F\left(\frac{\alpha + wQ_{RS}}{\phi p}\right) \leqslant \beta \Rightarrow Q_{RS} \leqslant \frac{\phi pF^{-1}(\beta) - \alpha}{w}$$

(2) In case of $x > Q_{RS}$, we have $Q_{RS} \leqslant \frac{\alpha}{\phi p - w} \leqslant \frac{\phi pF^{-1}(\beta)-\alpha}{w}$ by $\alpha \leqslant (\phi p - w)F^{-1}(\beta)$.

In summary, $\widetilde{Q}^*_{RS} = \frac{\phi pF^{-1}(\beta)-\alpha}{w}$.

Therefore, retailer's optimal order is

$$\begin{aligned} Q^*_{RS} &= \min\left\{\hat{Q}^*_{RS}, \widetilde{Q}^*_{RS}\right\} \\ &= \min\left\{F^{-1}\left(\frac{\phi p - w}{\phi p}\right), \frac{\phi pF^{-1}(\beta) - \alpha}{w}\right\} \qquad \square \end{aligned} \tag{13}$$

Similar to Remark 2, we still obtain the upper bound of optimal order of the downside risk-averse retailer in Remark 3.

Remark 3. If $\alpha = (\phi p - w)F^{-1}(\beta)$ and $\beta = \frac{\phi p - w}{\phi p}$, $\hat{Q}^*_{RP} = \widetilde{Q}^*_{RP}$.

It is known that in case of a risk-neutral retailer, the revenue sharing contract, with the condition of $w = \phi c$, can coordinate the supply chain. Here, in our model, satisfying this condition will lead to $\hat{Q}^*_{RS} = \hat{Q}^*_{IC}$. That is to say, the upper bound in revenue sharing contract will coordinate the supply chain, as described in Section 2. However, by Remark 3, under retailer's downside risk constraint, optimal order will be below the upper bound, i.e. $\widetilde{Q}^*_{RS} < \hat{Q}^*_{IC}$. Therefore,

$$\begin{aligned} E[\pi_{rRS}]^* + E[\pi_{sRS}]^* &= \phi pE[\min\{x, Q^*_{RS}\}] - cQ^*_{RS} < E[\pi_{SC}]^* \\ &= \phi pE[\min\{x, Q^*_{IC}\}] - cQ^*_{IC}. \end{aligned} \tag{14}$$

As a result, revenue sharing contract could not coordinate a supply chain with a downside risk-averse retailer.

4. Design of coordination policies

Because price-only, returns policies and revenue sharing contracts cannot coordinate a supply chain with a risk-averse retailer, it is necessary to explore new policies. Aforementioned analysis has shown that with the downside risk constraint, the retailer's optimal order is either the upper bound (newsvendor solution), or the solution of the risk constraint. As we have shown, the returns policy contract and the revenue sharing contract could coordinate the supply chain only at the upper bound. This provides an opportunity, if we design a new contract that can mitigate the downside risk constraint such that the newsvendor solution becomes the lower bound of a retailer's optimal order. In other words, the retailer's optimal order is always the newsvendor solution, which means that the whole supply chain will be coordinated. Going by this idea, in this paper, we use the transfer payment, plus a specific contract, to coordinate the supply chain. Specifically, when the supply chain implements a specific contract, like a returns policy contract, the supplier also commits to pay a certain amount of compensation in cash to the retailer, in order to decrease the risks faced by the retailer. However, if the retailer is risk-free, the supplier will not make any transfer payment. With a reasonable transfer payment, the risk faced by the retailer may be mitigated (see next section for risk mitigation definition), or the risk will not affect the supply chain performance, as in a risk-neutral situation. This mechanism is similar to a two-part tariff. The difference is that our transfer payment is a decision variable that denotes a cash payment by the supplier, and it is dependent on the contract terms and risk attitude.

4.1. Transfer payment plus price-only contract

Transfer payment plus price-only policy contract is a contract in which the supplier announces a wholesale price w per unit and tells the retailer that he will pay a part of profits T to the retailer, at the end of the sales period. Under price-only contract, the supplier will decide (w, T_{PO}) to maximize $E[\pi_{s_{PO+}}] = (w-c)Q_{PO+} - T_{PO}$, where Q_{PO+} is the solution to the retailer's decision model in (15).

$$\begin{aligned} &\max_{Q_{PO+}\geqslant 0} E[\pi_{rPO+}] = pE[\min\{x, Q_{PO+}\}] - wQ_{PO+} + T_{PO} \\ &\text{s.t.} \qquad P\{[\pi_{rPO+} \leqslant \alpha\} \leqslant \beta. \end{aligned} \tag{15}$$

Because in addition to the normal profit from sales, the retailer could also get transfer payment T_{PO} at the end of the sales period, the downside risk pair (α, β) could satisfy $(p-w)F^{-1}(\beta) \geqslant \alpha - T_{PO}$, if the retailer is rational.

Proposition 5. *If* $(p-w)F^{-1}(\beta) \geqslant \alpha - T_{PO}$, *with transfer payment plus the price-only contract, a downside risk-averse retailer could order* $Q^*_{PO+} = \min\{\hat{Q}^*_{PO+}, \widetilde{Q}^*_{PO+}\}$, *where* $\hat{Q}^*_{PO+} = F^{-1}\left(\frac{p-w}{p}\right)$ *and* $\widetilde{Q}^*_{PO+} = \frac{pF^{-1}(\beta)-\alpha+T_{PO}}{w}$.

Proof. $\hat{Q}^*_{PO+} = F^{-1}\left(\frac{p-w}{p}\right)$ is the optimal order for the retailer without risk constraints. $\widetilde{Q}^*_{PO+}$ is the maximum in the feasible domain of risk constraint condition. The minimum of $\hat{Q}^*_{PO+}$ and $\widetilde{Q}^*_{PO+}$ is the optimal order Q^*_{PO+} for the downside risk-averse retailer.

For the risk constraint condition in (15), we have

$$P\{\pi_{rPO+} \leqslant \alpha\} \leqslant \beta = P\{pE[\min\{x, Q_{PO+}\}] - wQ_{PO+} + T_{PO} \leqslant \alpha\} \leqslant \beta$$

(1) When $x \leqslant Q_{PO+}$,

$$P\{px - wQ_{PO+} + T_{PO} \leqslant \alpha\} \leqslant \beta \Rightarrow P\left\{x \leqslant \frac{\alpha - T_{PO} + wQ_{PO+}}{p}\right\} \leqslant \beta$$
$$\Rightarrow F\left(\frac{\alpha - T_{PO} + wQ_{PO+}}{p}\right) \leqslant \beta$$
$$\Rightarrow Q_{PO+} \leqslant \frac{pF^{-1}(\beta) - \alpha + T_{PO}}{w}.$$

(2) When $x > Q_{PO+}$, from the retailer's target profit level, we have $Q_{PO+} \leqslant \frac{\alpha - T_{PO}}{p-w}$, by $(p-w)F^{-1}(\beta) \geqslant \alpha - T_{PO}$, $Q_{PO+} \leqslant \frac{\alpha - T_{PO}}{p-w} \leqslant \frac{pF^{-1}(\beta)-\alpha+T_{PO}}{w}$.

In summary, $\widetilde{Q}^*_{PO+} = \frac{pF^{-1}(\beta)-\alpha+T_{PO}}{w}$.

Therefore, the optimal order for the retailer under the transfer payment plus price-only contract provided by the supplier is

$$Q^*_{PO+} = \min\left\{F^{-1}\left(\frac{p-w}{p}\right), \frac{pF^{-1}(\beta) - \alpha + T_{PO}}{w}\right\}. \quad \square \tag{16}$$

Note that the supplier would never make transfer payment to the retailer if there is no risk constraint for the retailer. Proposition 5 shows that under price-only contract, if the retailer's target profit level in downside risk constraint situation increases by T_{PO}, compared to the profit in case of a contract without transfer payment, it can effectively mitigate the risk effect. And also, we have the following remark for the relationship between risk constraint solution and the newsvendor solution, in the transfer payment plus price-only contract.

Remark 4. If $\alpha = (p-w)F^{-1}(\beta) + T_{PO}$ and $\beta = \frac{p-w}{p}$, $\hat{Q}^*_{PO+} = \widetilde{Q}^*_{PO+}$.

As analyzed in Section 3.1, the transfer payment plus price-only contract still could not coordinate the supply chain, because the upper bound of the optimal order $\hat{Q}^*_{PO+}$ is smaller than $\hat{Q}^*_{IC}$. However, the transfer payment can effectively mitigate the risk taken by the retailer. Before we summarize this feature, we first introduce our definition of risk mitigation.

In this paper, we assume that the downside risk is mitigated if the optimal order, limited by downside risk constraint, is always more than the optimal order of the objective function of the retailer. In this case, the retailer's optimal order will be decided by the newsvendor solution, not the one decided by the retailer's downside risk.

Corollary 1. *If downside risk $\beta \geqslant \frac{p-w}{p}$, the transfer payment plus price-only contract could mitigate the effect of risk constraint when retailer is downside risk-averse. The optimal transfer payment is*

$$T^*_{PO} = \max\left\{0, wF^{-1}\left(\frac{p-w}{p}\right) + \alpha - pF^{-1}(\beta)\right\} \tag{17}$$

Proof. First, the transfer payment will be zero if there are no risk constraints. That is to say $T^*_{PO} = 0$, if retailer is risk-neutral. Second, to mitigate the effect of downside risk constraint, it is necessary that $\hat{Q}^*_{PO+} \leqslant \widetilde{Q}^*_{PO+} \Rightarrow F^{-1}\left(\frac{p-w}{p}\right) \leqslant \frac{pF^{-1}(\beta)-\alpha+T_{PO}}{w}$, then we have

$$T_{PO} \geqslant wF^{-1}\left(\frac{p-w}{p}\right) + \alpha - pF^{-1}(\beta). \tag{18}$$

Therefore, $T^*_{PO} = \max\left\{0, wF^{-1}\left(\frac{p-w}{p}\right) + \alpha - pF^{-1}(\beta)\right\}$. The supplier can decide the T_{PO} and the condition of $(p-w)F^{-1}(\beta) \geqslant \alpha - T_{PO}$ under $\beta \geqslant \frac{p-w}{p}$ is satisfied simultaneously. Therefore, by transfer payment T_{PO}, retailer's optimal order will be the newsvendor solution. The effect of retailer's risk attitude on the optimal order will definitely be eliminated. □

The above corollary also shows that the newsvendor solution will become the lower bound of retailer's optimal order, under the transfer payment plus the price-only contract. Apparently, even if transfer payment plus the price-only contract could eliminate the effect of the retailer's risk constraint on the optimal order, it cannot coordinate the supply chain, because the optimal order of the retailer (here newsvendor solution) is smaller than the optimal order in case of an integrated channel. However, this inspires us to think that coordination may be achieved when transfer payment is combined with other coordination policies.

4.2. Transfer payment plus return policies

With transfer payment committed by the supplier, the returns policies game will be played as follows. The supplier maximizes $E[\pi_{sRP+}] = (w-c)Q_{RP+} - T_{RP} - bE[\max\{Q_{RP+} - x, 0\}]$ with respect to w, b and T_{RP}, where Q_{RP+} is the retailer's optimal decision, that is,

$$\max_{Q_{RP+} \geqslant 0} E[\pi_{rRP+}] = pE[\min\{x, Q_{RP+}\}] - wQ_{RP+} + bE[\max\{Q_{RP+} - x, 0\}] + T_{RP}$$
$$\text{s.t.} \quad P\{\pi_{rRP+} \leqslant \alpha\} \leqslant \beta. \tag{19}$$

Note that $p > w > b > c$. The retailer's optimal order has the following solution.

Proposition 6. *If $(p-w)F^{-1}(\beta) \geqslant \alpha - T_{RP}$, with transfer payment plus return policies, the risk-averse retailer will order $Q^*_{RP+} = \min\{\hat{Q}^*_{RP+}, \widetilde{Q}^*_{RP+}\}$, in which $\hat{Q}^*_{RP+} = F^{-1}\left(\frac{p-w}{p-b}\right)$ and $\widetilde{Q}^*_{RP+} = \frac{(p-b)F^{-1}(\beta)-\alpha+T_{RP}}{w-b}$.*

Proof. For the risk free retailer, $\hat{Q}^*_{RP+}$ is the optimal order of the newsvendor, i.e. $\hat{Q}^*_{RP+} = F^{-1}\left(\frac{p-w}{p-b}\right)$. For the downside risk constraint in (19), $\widetilde{Q}^*_{RP+}$ is the maximum in the feasible domain of the risk constraint condition. Optimal order Q^*_{RP+} for risk-averse retailer will be the minimum between $\hat{Q}^*_{RP+}$ and $\widetilde{Q}^*_{RP+}$.

For downside risk constraint $P\{\pi_r \leqslant \alpha\} \leqslant \beta$, we have

$$P\{\pi_{rRP+} \leqslant \alpha\} \leqslant \beta$$
$$\Rightarrow P\{pE[\min\{x, Q_{RP+}\}] - wQ_{RP+} + bE[\max\{Q_{RP+} - x, 0\}] + T_{RP}\} \leqslant \beta$$

(1) When $x \leqslant Q_{RP+}$:

$$P\{px - wQ_{RP+} + b(Q_{RP+} - x) + T_{RP} \leqslant \alpha\} \leqslant \beta$$
$$\Rightarrow P\{(p-b)x - (w-b)Q_{RP+} + T_{RP} \leqslant \alpha\} \leqslant \beta$$
$$\Rightarrow P\{x \leqslant \frac{\alpha - T_{RP} + (w-b)Q_{RP+}}{p-b}\} \leqslant \beta$$
$$\Rightarrow F\left(\frac{\alpha - T_{RP} + (w-b)Q_{RP+}}{p-b}\right) \leqslant \beta$$
$$\Rightarrow Q_{RP+} \leqslant \frac{(p-b)F^{-1}(\beta) - \alpha + T_{RP}}{w-b}.$$

(2) When $x > Q_{RP+}$,

$$Q_{RP+} \leqslant \frac{\alpha - T_{RP}}{p-w} \leqslant \frac{(p-b)F^{-1}(\beta) - \alpha + T_{RP}}{w-b} \text{ by } \alpha - T_{RP} \leqslant (p-w)F^{-1}(\beta).$$

In summary, $\widetilde{Q}^*_{Rp+} = \frac{(p-b)F^{-1}(\beta)-\alpha+T_{RP}}{w-b}$.

Therefore, retailer's optimal order is

$$Q^*_{RP+} = \min\left\{F^{-1}\left(\frac{p-w}{p-b}\right), \frac{(p-b)F^{-1}(\beta) - \alpha + T_{RP}}{w-b}\right\} \quad \square \tag{20}$$

Note that the supplier would never make the transfer payment to the retailer if the retailer has no risk constraint.

Remark 5. If $\alpha = (p-w)F^{-1}(\beta) + T_{RP}$ and $\beta = \frac{p-w}{p-b}$, $\hat{Q}^*_{RP+} = \widetilde{Q}^*_{RP+}$.

By the transfer payment plus returns policies contract, it is possible to coordinate the supply chain, because the upper bound of the optimal order $\hat{Q}^*_{RP+}$ could be equal to $\hat{Q}^*_{IC}$, when $\frac{p-w}{p-b} = \frac{p-c}{p}$, or equivalently $\frac{p-b}{p} = \frac{w-b}{c}$. On the other hand, by the transfer payment plus returns policies contract, if the supplier provides for an appropriate transfer payment, it can achieve supply chain coordination. We summarize this feature with the following theorem.

Theorem 1. *If downside risk is $\beta \geqslant \frac{p-w}{p-b}$, the transfer payment plus returns policies contract could mitigate the effect of risk constraint and completely coordinate the supply chain, when retailer is downside risk-averse. Optimal transfer payment is as follows*:

$$T^*_{RP} = \max\left\{0, \alpha + (w-b)F^{-1}\left(\frac{p-w}{p-b}\right) - (p-b)F^{-1}(\beta)\right\}. \tag{21}$$

Proof. By the transfer payment contract, transfer payment amount would be zero, if there is no risk constraint for the retailer. In order to mitigate the effect of the downside risk constraint, it is necessary that

$$\widetilde{Q}^*_{RP+} \geqslant \hat{Q}^*_{RP+} \Rightarrow \frac{(p-b)F^{-1}(\beta) - \alpha + T_{RP}}{w-b} \geqslant F^{-1}\left(\frac{p-w}{p-b}\right)$$

Therefore,

$$T_{RP} \geqslant \alpha + (w-b)F^{-1}\left(\frac{p-w}{p-b}\right) - (p-b)F^{-1}(\beta). \tag{22}$$

The inequality (22) satisfies the condition of $(p-w)F^{-1}(\beta) \geqslant \alpha - T_{RP}$ under $\beta \geqslant \frac{p-w}{p-b}$. That means the order, limited by the downside risk constraint, can still be the optimal order. Taking the minimum of (22), we can get (21). T_{RP} can be decided by the supplier. Therefore, the impact of retailer's risk attitude on the supply chain will definitely be mitigated with the transfer payment plus returns policies contract.

From (22), the retailer will always order the lower bound, that is,

$$Q^*_{RP+} = \hat{Q}^*_{RP+} = F^{-1}\left(\frac{p-w}{p-b}\right).$$

With $\frac{p-b}{p} = \frac{w-b}{c}$, we have

$$Q^*_{RP+} = F^{-1}\left(\frac{p-w}{p-b}\right) = F^{-1}\left(\frac{p-c}{p}\right) = Q^*_{IC}.$$

Going by our assumption of supply chain coordination, the supply chain is coordinated. On the other hand, if $T^*_{RP} = 0$, supply chain decisions will be similar to those in the situation where all the agents are risk-neutral. In short, the transfer payment plus returns policies contract could completely coordinate the supply chain. □

For the supplier's expected profit, substituting (21) into

$$E[\pi_{sRP+}] = (w-c)Q_{RP+} - T_{RP} - bE[\max\{Q_{RP+} - x, 0\}],$$

we have

$$E[\pi_{sRP+}] = (w-c)Q^*_{RP+} - \left[\frac{c(p-w)}{p-c}Q^*_{RP+} - \frac{p(p-w)}{p-c}F^{-1}(\beta)\right] - b\int_0^{Q^*_{RP+}} F(x)dx \tag{23}$$

One can see that the supplier's decision model (23) is a function of w and b. It is known that if the inverse cumulative distribution function (CDF) did not exist, the closed-form solution of supplier's decision cannot be obtained. However, we borrow a numerical method to analyze features of the supplier's decision.

4.3. Transfer payment plus revenue sharing contract

Under transfer payment plus revenue sharing contract, the supplier will maximize $E[\pi_{sRS+}] = (w-c)Q_{RS+} - T_{RS} + (1-\phi)pE[\min\{x, Q_{RS+}\}]$ with respect to w, ϕ and T_{RS}, where Q_{RS+} is the optimal decision for the retailer, under the problem

$$\max_{Q_{RS+} \geqslant 0} E[\pi_{r_{RS+}}] = \phi pE[\min\{x, Q_{RS+}\}] - wQ_{RS+} + T_{RS} \quad \text{s.t.} \quad P\{\pi_{rRS+} \leqslant \alpha\} \leqslant \beta \tag{24}$$

Note that $p \geqslant w \geqslant c$, $1 > \phi > 0$, and the supplier would never make transfer payment to the retailer if there is no risk constraint. The retailer's optimal order has the following solution.

Proposition 7. *If $(p-w)F^{-1}(\beta) \geqslant \alpha - T_{RS}$, with transfer payment plus revenue sharing contract, a risk-averse retailer would order $Q^*_{RS+} = \min\{\hat{Q}^*_{RS+}, \widetilde{Q}^*_{RS+}\}$, where $\hat{Q}^*_{RS+} = F^{-1}\left(\frac{\phi p-w}{\phi p}\right)$ and $\widetilde{Q}^*_{RS+} = \frac{\phi pF^{-1}(\beta)-\alpha+T_{RS}}{w}$.*

Proof. $\hat{Q}^*_{RS+}$ is the optimal order for a retailer without risk constraints, so optimal order is a newsvendor solution, that is $\hat{Q}^*_{RS+} = F^{-1}\left(\frac{\phi p-w}{\phi p}\right)$. $\widetilde{Q}^*_{RS+}$ is the maximum in feasible domain of downside risk constraint. The minimum of $\hat{Q}^*_{RS+}$ and $\widetilde{Q}^*_{RS+}$ is the optimal order Q^*_{RS+} for a risk-averse retailer. For the downside risk constraint in (24), we have

$$P\{\pi_{rRS+} \leqslant \alpha\} \leqslant \beta \Rightarrow P\{\phi pE[\min\{x, Q_{RS+}\}] - wQ_{RS+} + T_{RS} \leqslant \alpha\} \leqslant \beta$$

(1) When $x \leqslant Q_{RS+}$,

$$\begin{aligned} P\{\phi px - wQ_{RS+} + T_{RS} \leqslant \alpha\} \leqslant \beta &\Rightarrow P\{\phi px \leqslant \alpha + wQ_{RS+} - T_{RS}\} \leqslant \beta \\ &\Rightarrow P\left\{x \leqslant \frac{\alpha + wQ_{RS+} - T_{RS}}{\phi p}\right\} \leqslant \beta \\ &\Rightarrow F\left(\frac{\alpha - T_{RS} + wQ_{RS+}}{\phi p}\right) \leqslant \beta \\ &\Rightarrow Q_{RS+} \leqslant \frac{\phi pF^{-1}(\beta) - \alpha + T_{RS}}{w}. \end{aligned}$$

(2) When $x > Q_{RS+}$, from retailer's target profit level, we have

$$Q_{RS+} \leqslant \frac{\alpha - T_{RS}}{\phi p - w} \leqslant \frac{\phi pF^{-1}(\beta) - \alpha + T_{RS}}{w} \text{ by } (p-w)F^{-1}(\beta) \geqslant \alpha - T_{RS}.$$

In summary, $\widetilde{Q}^*_{RS+} \leqslant \frac{\phi pF^{-1}(\beta)-\alpha+T_{RS}}{w}$.

Retailer's optimal order is

$$Q^*_{RS+} = \min\left\{F^{-1}\left(\frac{\phi p - w}{\phi p}\right), \frac{\phi pF^{-1}(\beta) - \alpha + T_{RS}}{w}\right\} \quad \square \tag{25}$$

Theorem 2. *If downside risk is $\beta \geqslant \frac{\phi p-w}{\phi p}$, the transfer payment plus revenue sharing contract could mitigate the effect of risk constraint and completely coordinate supply chain, when retailer is downside risk-averse. Optimal transfer payment is as follows,*

$$T^*_{RS} = \max\left\{0, \alpha + wF^{-1}\left(\frac{\phi p - w}{\phi p}\right) - \phi pF^{-1}(\beta)\right\} \tag{26}$$

Proof. By the transfer payment plus revenue sharing contract, the supplier will not provide any transfer payment to the retailer, if there is no risk constraint. In order to mitigate the impact of risk constraint on the optimal order decision, it is necessary that

$$\hat{Q}^*_{RS+} \geqslant \widetilde{Q}^*_{RS+} \Rightarrow \frac{\phi p F^{-1}(\beta) - \alpha + T_{RS}}{w} \geqslant F^{-1}\left(\frac{\phi p - w}{\phi p}\right)$$

That is

$$T_{RS} \geqslant \alpha + wF^{-1}\left(\frac{\phi p - w}{\phi p}\right) - \phi p F^{-1}(\beta) \tag{27}$$

The minimum of T_{RS} in (27) is supplier's optimal decision, so (26) follows.

The (27) satisfies the condition of $(p-w)F^{-1}(\beta) \geqslant \alpha - T_{RP}$ under $\beta \geqslant \frac{\phi p - w}{\phi p}$. That means the order limited by the downside risk constraint can still be the optimal order. Therefore, the effect of retailer's risk attitude on the supply chain will definitely be mitigated with transfer payment plus revenue sharing contract.

The retailer will always order $F^{-1}\left(\frac{\phi p - w}{\phi p}\right)$, if he can get transfer payment T^*_{RS}. From (27), the retailer will always order the lower bound, that is,

$$Q^*_{RS+} = \hat{Q}^*_{RS+} = F^{-1}\left(\frac{\phi p - w}{\phi p}\right).$$

With $w = \phi c$, we have

$$Q^*_{RS+} = F^{-1}\left(\frac{\phi p - w}{\phi p}\right) = F^{-1}\left(\frac{p - c}{p}\right) = Q^*_{IC}.$$

Going by our assumption about supply chain coordination, the supply chain is coordinated. On the other hand, if $T^*_{RP} = 0$, supply chain decisions are the same as in the situation where all the agents are risk-neutral. In short, the transfer payment plus return policies contract could completely coordinate the supply chain. □

Now we consider the supplier's optimal decision model. Substituting $T_{RS} = \alpha + \phi c F^{-1}\left(\frac{p-c}{p}\right) - \phi p F^{-1}(\beta)$ into

$$E[\pi_{sRS+}] = (w - c)Q_{RS+} - T_{RS} + (1-\phi)pE[\min\{x, Q_{RS+}\}],$$

we have

$$E[\pi_{sRS+}] = (\phi c - c)Q^*_{RS+} - (\alpha + \phi c Q^*_{RS+} - \phi p F^{-1}(\beta)) + (1-\phi)p\left(Q^*_{RS+} - \int_0^{Q^*_{RS+}} F(x)dx\right) \tag{28}$$

Similar to the case of transfer payment plus returns policies contract, one can see that supplier's decision model (30) is a function of w and ϕ. It is known that if the inverse CDF did not exist, the closed-form solution of supplier's decision cannot be obtained. Next, we use a numerical method to analyze features of the supplier' decision.

5. Numerical analysis

Analytical solutions for the supplier's optimal decision are quite difficult to obtain in case of both the transfer payment plus returns policies and revenue sharing contract. Numerical experiments are used to analyze features of the coordinating mechanisms. Assume that $c = 1$, $p = 3$, the density function of random demand x follows a uniform distribution with mean value $\mu = 25$ and the coefficient of variation $\tau = \frac{\sigma}{\mu}$ indicating the degree of variation of demand, whose values are 0.35, 0.45, and 0.55. Assume retailer's target profit level is $\alpha = 8$, and downside risk is $\beta = 0.25$, 0.20 and 0.15 respectively. Notice two risk decision pairs (α_1, β_1) and (α_2, β_2) ; if $\alpha_1 \leqslant \alpha_2$ and $\beta_1 \geqslant \beta_2$, then the risk-averse pair (α_1, β_1) has a lower aversion to risk than that of (α_2, β_2). So if $\beta = 0.15$, in this case, the retailer has a higher risk-aversion than $\beta = 0.25$. Tables 1 and 2 show the optimal decisions of supply chain and optimal profits of supplier and retailer under transfer payment plus returns policies and revenue sharing contracts, respectively. Some select results in Table 1 have reported some particular values, based on wholesale price w. In each panel of β, we have selected three solutions. (1) The solution in the first line is optimal wholesale price w^* under the transfer payment plus returns policies contract, that is, the optimal wholesale price under coordinated supply chain; it equals to the one without a coordinating mechanism (no transfer payment) under downside risk constraint; (2) the solutions in the second line is the situation that a lower bound of the optimal wholesale price, the value that the supplier's optimal profits are equal to the profits when no coordinating contract limits the supply chain with a risk-averse retailer, and it is the minimum wholesale price that the supplier chooses under transfer payment plus returns policies contract; and (3) the last line solution is the situation that a wholesale price upper bound, that is, $w = 0.29999$, is the value that the wholesale price is appropriate to the retail price, and corresponding to this wholesale price, the profits of the supplier reach the upper bound and the retailer's profits reach the lower bound. Therefore, the splitting of the channel profit (π^*_r/π^*_s) will get to the lowest proportion.

Select results in Table 2 have reported some particular values, based on revenue sharing proportion ϕ. In each panel of β, we have selected three solutions. (1) The first line solution is the upper bound of optimal revenue sharing proportion obtained by the supplier, i.e. $1 - \phi \to 1$, or $w = \phi c = 0.00001$, the corresponding optimal profits of supplier and retailer are the upper and lower bounds, respectively, while the retailer still holds its target profit level; (2) the second line solution is the lower bound of optimal revenue sharing proportion obtained by the supplier, the value obtained when supplier's optimal profit, obtained by the transfer payment plus revenue sharing contract, equals to the one obtained when there is no coordinating contract to control the supply chain. This sharing proportion is the minimum that the supplier selects under the transfer payment plus revenue sharing contract, and this condition also decides the upper bound of the wholesale price; and (3) the last line solution is the situation that the revenue sharing proportion equal 0.5, that is, when retailer's optimal profit equals to the supplier's optimal profit $(\pi^*_r/\pi^*_s = 0.5)$.

Tables 1 and 2 illustrate that: (1) CE (channel efficiency) = 100% shows that the transfer payment plus returns policies contract, or revenue sharing contract, can completely coordinate a supply chain with a downside risk-averse retailer. The optimal order size of the retailer can maximize total expected profit of supply chain, without destroying the downside risk constraints, which means that the retailer could always get its retained profit α under a given downside risk; (2) the transfer payment plus returns policies contract, or revenue sharing contract, could allocate supply chain's profits freely when the retailer is risk-averse, meaning our new contracts are flexible for coordinating the supply chain; (3) if both deviation of demand and retailer's risk-averse attitude (β) are too low, the downside risk condition may not affect supply chain decisions. Therefore, the supplier does not make any transfer payment to the retailer (We have not shown when $\tau = 0.3$ and $\beta = 0.2$ and 0.25, $T^* = 0$); (4) in transfer payment plus return polices contract, the supplier should pay more as transfer payment to the retailer if whole price is higher. On the other hand, under the transfer payment plus revenue sharing contract, the supplier should pay more as transfer payment to the retailer if the percent share of the supplier $(1 - \varphi)$ is higher; and (5) With the same demand variation, retailer's optimal profits decrease with increase of risk-aversion.

Table 1
The numerical analysis for the transfer payment plus returns policy contract under the retailer downside risk constraint.

τ	β	w^*	T^*	b^*	π_r^*	π_s^*	π_r^*/π_s^*	Q_r^*	$\pi_r^* + \pi_s^*$	CE [a]
0.35	0.25	2.48718	2.30385	2.23077	12.53367	27.36268	0.45806	30.0518	39.8963	1
		2.12021	0.00000	1.68032	17.55014	22.34621	0.78537	30.0518		
		2.99999	7.99989	2.99999	8.00009	31.89626	0.25082	30.0518		
	0.2	2.48718	3.46965	2.23077	13.69947	26.19688	0.52294	30.0518		
		2.14071	0.40885	1.71106	17.55014	22.34621	0.78537	30.0518		
		2.99999	7.99991	2.99999	8.00011	31.89624	0.25082	30.0518		
	0.15	2.67099	5.84142	2.50649	12.40451	27.49184	0.45121	30.0518		
		2.28663	3.31964	1.92994	17.55014	22.34621	0.78537	30.0518		
		2.99999	7.99993	2.99999	8.00013	31.89621	0.25082	30.0518		
0.45	0.25	2.21225	2.37686	1.81838	16.95403	20.05561	0.84535	31.4952	37.0096	1
		2.12730	1.77048	1.69095	17.91960	19.09004	0.93869	31.4952		
		2.99999	7.99993	2.99999	8.00011	29.00953	0.27578	31.4952		
	0.2	2.40083	5.47426	2.10124	16.56183	20.44781	0.80996	31.4952		
		2.30581	5.07371	1.95871	17.91960	19.09004	0.93869	31.4952		
		2.99999	7.99996	2.99999	8.00014	29.00950	0.27578	31.4952		
	0.15	2.67357	7.57807	2.51036	13.61857	23.39107	0.58221	31.4952		
		2.42369	7.25509	2.13554	17.91960	19.09004	0.93869	31.4952		
		2.99999	7.99999	2.99999	8.00017	29.00947	0.27578	31.4952		
0.55	0.25	2.16449	5.35232	1.74674	19.60732	14.51555	1.35078	32.9386	34.1229	1
		2.33085	5.87949	1.99627	17.29622	16.82665	1.02791	32.9386		
		2.99999	7.99997	2.99999	8.00014	26.12273	0.30625	32.9386		
	0.2	2.45565	8.21960	2.18347	17.50701	16.61586	1.05363	32.9386		
		2.46772	8.21473	2.20158	17.29622	16.82665	1.02791	32.9386		
		2.99999	8.00000	2.99999	8.00017	26.12269	0.30625	32.9386		
	0.15	2.67456	9.29387	2.51184	14.84633	19.27654	0.77018	32.9386		
		2.55811	9.75687	2.33716	17.29622	16.82665	1.02791	32.9386		
		2.99999	8.00004	2.99999	8.00021	26.12266	0.30626	32.9386		

[a] CE is the ratio of the optimal expected profits of the supply chain with the retailer risk constraints under the downside risk constraint to the optimal expected profits of the integrated channel under the retailer no risk constraint.

Table 2
The numerical analysis for the transfer payment plus revenue sharing contract under the retailer downside risk constraint.

τ	β	w^*	T^*	ϕ^*	π_r^*	π_s^*	π_r^*/π_s^*	Q_r^*	$\pi_r^* + \pi_s^*$	CE
0.35	0.25	0.00001	7.99978	0.00001	8.00018	31.89617	0.25082	30.0518	39.8963	1
		0.43989	0.00000	0.43989	17.55014	22.34621	0.78537	30.0518		
		0.29968	1.34255	0.29968	13.29878	26.59757	0.50000	30.0518		
	0.2	0.00001	7.99982	0.00001	8.00022	31.89612	0.25082	30.0518		
		0.42965	0.40885	0.42965	17.55014	22.34621	0.78537	30.0518		
		0.23838	3.78814	0.23838	13.29878	26.59756	0.50000	30.0518		
	0.15	0.00001	7.99987	0.00001	8.00027	31.89608	0.25082	30.0518		
		0.36944	3.15234	0.36944	17.89151	22.00484	0.81307	30.0518		
		0.19790	5.40315	0.19790	13.29880	26.59755	0.50000	30.0518		
0.45	0.25	0.00001	7.99990	0.00001	8.00025	27.56596	0.29022	31.4952	37.0096	1
		0.43635	1.77048	0.43635	17.91960	19.09004	0.93869	31.4952		
		0.19076	5.27665	0.19076	12.33654	24.67310	0.50000	31.4952		
	0.2	0.00001	7.99992	0.00001	8.00029	29.00935	0.27578	31.4952		
		0.36326	4.93743	0.36326	18.38156	18.62808	0.98677	31.4952		
		0.15174	6.72071	0.15174	12.33656	24.67308	0.50000	31.4952		
	0.15	0.00001	7.99997	0.00001	8.00034	29.00930	0.27579	31.4952		
		0.36846	7.04748	0.36846	20.68418	16.32546	1.26699	31.4952		
		0.12597	7.67435	0.12597	12.33656	24.67308	0.50000	31.4952		
0.55	0.25	0.00001	7.99994	0.00001	8.00028	26.12259	0.30626	32.9386	34.1229	1
		0.33458	5.87949	0.33458	17.29622	16.82665	1.02791	32.9386		
		0.12144	7.23031	0.12144	11.37429	22.74858	0.50000	32.9386		
	0.2	0.00001	8.00001	0.00001	8.00035	26.12252	0.30626	32.9386		
		0.33834	8.27298	0.33834	19.81816	14.30471	1.38543	32.9386		
		0.09660	8.07794	0.09660	11.37428	22.74859	0.50000	32.9386		
	0.15	0.00001	8.00008	0.00001	8.00042	26.12245	0.30627	32.9386		
		0.36809	10.92688	0.36809	23.48717	10.63570	2.20833	32.9386		
		0.08020	8.63770	0.08020	11.37428	22.74858	0.50000	32.9386		

It is reasonable that the more risk one is willing to bear, the higher the returns will be.

6. Conclusions and further research direction

This paper investigates supply chain coordination with several contracts, under retailer's risk constraint. The risk measure used in this paper is downside risk, which is widely used in financial risk literature. We show that the price-only contract cannot coordinate a decentralized channel under retailer's downside risk constraints and the returns policies and revenue sharing contract also cannot coordinate the supply chain if the lower bound of retailer's optimal order is not the newsvendor solution. This is significant different with previous research findings that the return policy and revenues sharing contract both can coordinate the supply chain under risk-neutral supply chain (see Cachon & Lariviere, 2005). Going by the transfer payment plus returns policies or revenue sharing contract, the newsvendor solution will become the lower bound of retailer's optimal order decision, such that it can effectively mitigate the effects of downside risk on the optimal order decision of the retailer, and the supply chain will be coordinated perfectly. By numerical study, we also see that the supplier's optimal decisions, obtained through our coordinating contract, have some flexibility. Gan et al. (2005) analyze the natural downside risk (NDR) effects on coordination of an integrated channel. The natural downside risk, in fact, is the lowest bound of risk constraint, when the retailer is risk-free. Therefore, the NDR is equal to the lower bound of optimal profit of the retailer in our model.

In this paper, we assume that retailer's risk attitude is public information. It is reasonable in some cases. However, that the risk attitude is private information is much more common in real world. As in Voigt (2011) pointed out, the supply chain information is not effectively communicated among the members of supply chain will lead to the information asymmetry. In fact, Lei, Li, and Liu (2012), Yao and Feng (2013) and Yao, Xu, and Chen (2014), they are trying to investigate the risk information asymmetric supply chain coordination problems. Further research should pay attention to coordinating mechanisms wherein retailer's risk attitude is private.

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