https://doi.org/10.1016/j.tre.2017.08.005

Capacity Investment in Supply Chain with Risk Averse Supplier Under Risk Diversification Contract

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Abstract: In a supply chain with one risk neutral manufacturer and one risk averse supplier, we propose a risk diversification contract under which the manufacturer shares the losses of excess capacity and inadequate capacity with the supplier, and a side payment is transferred from the supplier to the manufacturer. Under the Conditional Value-at-Risk (CVaR) criterion, risk diversification contract has a Pareto improvement and can allocate system performance appropriately in both symmetrical and asymmetrical demand information. In addition, this contract can coordinate supply chain and has a larger market than an option, capacity reservation, payback, revenue-sharing contract under the symmetrical demand information.

Key words: Capacity investment; Risk averse; Coordination; Nash bargaining

1 Introduction

Newsboy products, such as electronic products, automobiles, fashions, etc., characterized of upgrading rapidly and having short life cycle, have drawn wide attention. In order to ensure new products can quickly occupy the market before the replicas appear, the downstream manufacturer tends to require the upstream supplier to build a special investment for core components. Actually, the profit growth of the manufacturer is restricted by the limited capacity of his supplier, so the manufacturer expects to see a larger capacity established by his supplier. However, the supplier may reduce her investment for preventing the occurrence of excess capacity. A corresponding evident example appears between General Motors (GM) and his supplier Fisher Body.GM encourages Fisher to continue expanding her capacity after finding that the demand for automobiles greatly increased. Fisher, however, concerned that her future profit cannot recover the expense of the new investment, may then invests in less capacity than what would be jointly optimal (e.g., Klein and Benjamin, 2000).

Facing the contradiction, the manufacturer increases the supplier's capacity investment level by generally designing an appropriate incentive mechanism to achieve a “win-win” situation. In the existing research, options (e.g., Cachon and Lariviere, 2001), capacity reservation (e.g., Lv et al, 2015), relational (e.g.,Taylor and Plambeck, 2007a) and other contracts have been introduced for the capacity investment, and the supplier can ramp up her capacity investment level with those contracts under certain conditions. To the best of our knowledge, few scholars pay close attention to controlling the losses generated by both excessive and inadequate capacity. However, in practices, there exist plenty of solid evidence show the importance to consider the losses of unsold capacity and the stock-out cost. On the one hand, the excessive capacity of suppliers can induce huge losses for themselves. Such as, Solectron, a major electronics supplier had $4.7 billion in excess component inventory in 2001 (Engardio, 2001). On the other hand, the insufficient capacity building of suppliers also leads to enormous losses. For example, in 2004, Qualcomm, the world’s largest chip manufacturer, was unable to meet all of its customers' demands for its patented CDMA technology due to a shortage of foundry capacity at its suppliers (Gilbert and Xu, 2006). Thus, to deal with the supplier's loss risk generated by the deviation of capacity from demand, the key question we should investigate is: how should a suitable contract be designed by the manufacturer?

To solve this question, we consider a risk diversification contract[1] from the perspective of risk to improve the capacity investment problem. This contract includes two aspects. On one hand, loss sharing mechanism is proposed. That is, the manufacturer promises to share a part of the supplier's capacity losses and thus pushes the supplier's optimal strategy on capacity investment to approach the system's optimal condition. On the other hand, a compensation mechanism is put forward: if one agent's profit is reduced, then a compensation is transferred from the other agent to himself under the condition that the other agent's profit does not decrease.

In practices, the similar application with the risk diversification contract can be seen in the health services (e.g., Ellis and McGuire, 1990). One interesting question followed: is the risk diversification contract feasible (or worth adopting) or not? To have the answer, we need to show whether this contract can realize the supply chain coordination and Pareto improvement or not. In addition, since there exist various alternative contracts for dealing with the issue of capacity investment, why should we choose the risk diversification contract rather than others? To answer this question, we propose a contract choice criterion on the basis of ignoring the cost of signing the contract. A contract is said to be selected if satisfying three conditions below:

Firstly, this contract is feasible. That is to say, it can realize the supply chain coordination and Pareto improvement[2];

Secondly, both agents can achieve a higher performance under this contract than that under other finite contracts[3].

Finally, this contract can allocate supply chain's performance reasonably. With the wholesale price contract as the benchmark, we first adopt the Nash bargaining model to calculate the added performance, then discuss whether there exists an arbitrary bargaining solution or not under the circumstance in which both agents' bargaining power are uncertain, and finally point out that if it exists, the arbitrary bargaining solution can completely realize the reasonable distribution of the performance.

Nowadays, decision makers pay more attention to risk due to the increasing uncertainties in the operation of supply chain. Recent empirical results are provided to support the importance of incorporating risk preferences in business practices. After a survey of 1500 executives from 90 countries, a McKinsey research report (Koller et al., 2012) points out that the decision makers demonstrate extreme levels of risk aversion regardless of the size of the investment. Hence, many scholars have called for models in which the supplier is

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[1]Risk diversification often means allocation of proportional risk to all parties to a contract (e.g., Schmitt et al., 2015). And our contract is designed to increase the system profits by sharing the risk and then allocating channel profits via a side payment. Distinguishing from risk sharing contract, and combing with the description of risk diversification, we call our contract risk diversification contract.

[2]A contract is said to coordinate the supply chain if the set of supply chain optimal actions is a Nash equilibrium, i.e., no firm has a profitable unilateral deviation from the set of supply chain optimal actions. Ideally, the optimal actions should also be a unique Nash equilibrium; otherwise, the firms may "coordinate" on a suboptimal set of actions. If a coordinating contract can allocate rents arbitrarily, then there always exists a contract that Pareto dominates a noncoordinating contract, i.e., each firm's profit is no worse off and at least one firm is strictly better off with the coordinating contract. (Cachon, 2003, p. 230).

[3] We consider a finite set of other contracts, which include revenue sharing, option, payback and capacity reservation contracts.

risk averse (e.g., Shen et al., 2013; Yoo 2014). Utility function, mean-variance, and CVaR approaches are the three main research streams of modeling risk aversion in supply chain management. Utility function and mean-variance play a good role in dealing with risk preference model, but have some defects that should be considered in the concrete processing problems. In particular, the utility function approach has a cumbersome process and it is very difficult to implement it in practice (Levy, 2015). Meanwhile, mean-variance approach basically addresses the trade-off between the expected return and the variation of the return and has no visual description of the risk (Wu et al., 2014). Thus, in order to achieve the visualization of the risk, the CVaR criterion has been widely used in practices.

Note that since being developed by Rockafellar and Uryasev 2000, the CVaR criterion, which initially focuses on financial applications, has been extended significantly to other fields such as the supply chain and inventory management field (see literature review by Heckmann et al., 2015). In particular, extensive studies are published to apply the CVaR criterion to manage the supply chain risks in many problems such as variant newsvendor models (e.g., Tomlin and Wang, 2005; Chen et al., 2009; Choi et al., 2011), supply chain disruptions (e.g., Sawik, 2011; Snyder et al, 2013), supply chain planning (e.g., Soleimani and Govindan, 2014), and supply chain coordination (e.g., He et al., 2012), etc. Also, several evident examples can be found in more fields, e.g., portfolio selection (e.g., Gülpınar and Çanakoğlu, 2017). In addition, it is required that all financial companies (such as Banks, Insurance companies, Mutual Funds) use CVaR (which is called Expected Shortfall in the financial literature)[4]. For instance, TIAA-CREFF[5], which is the largest pension fund company in the world, use CVaR for the risk management.

However, the existing capacity investment literatures only consider the supplier is risk neutral, so an interesting question naturally arise: what happens to the capacity investment decision in the presence of the supplier's risk aversion?

Based on the analysis above, we summarize the contribution of this paper as follows.

Firstly, this paper considers a supply chain model with a single supplier and a single manufacturer, and stimulates the supplier to expand her capacity investment level by managing the risk of excess and insufficient capacity. In the supply chain system, the manufacturer is risk neutral, and the supplier is risk averse, which is depicted by CVaR criterion. We also provide the rigorous proofs to illustrate the existence of the supplier's objective function for seeking to the profit maximization under CVaR criterion.

Secondly, under the symmetrical demand information, we first describe the risk diversification contract model, and obtain the related optimal strategies. Then a criterion to choose the risk diversification contract or other existing alternatives (including option, payback, capacity reservation and revenue-sharing contract) is introduced by considering the wholesale price contract as a benchmark model and considering the realization of supply chain coordination and Pareto improvement as the precondition of the feasibility of contract. Meanwhile, we compare the difference between the risk diversification contract and the other contracts mentioned above. Finally, we theoretically show that risk diversification contract has an arbitrary bargaining solution and a broader market acceptance than those other alternatives.

Thirdly, we discuss the risk diversification contract under the asymmetrical demand information. Under certain conditions, we find the risk diversification contract leads to a higher performance for both parties than that from the wholesale price contract, and then a rational distribution of the performance appears according the

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[4] Financial companies use CVaR, see the link: http://www.bis.org/bcbs/publ/d352.htm.

[5] Here is the website of the company: https://www.tiaa.org

agents' bargaining power. This suggests the risk diversification contract helps to enhance the probability of both parties to acquire benefit or lessen the contradiction of profit distribution. As a consequence, the risk diversification contract can impel to the long-term and orderly conduct of trade, thus inducing both parties to gain the “win-win” situation.

The remainder of this paper is organized as follows. We review the relevant literature in Section 2. Section3 formulates the basic model and states assumptions. Section 4 performs the feasibility analysis of a contract and solves a bargaining solution of risk diversification contract, and compares the difference between the risk diversification contract and the others under the symmetrical demand information. Section 5 reveals the feasible of risk diversification contract under the asymmetrical demand information. Section 6 conducts sensitivity analysis of parameters. The paper is summarized in Section 7.

2 Literature review

There is an extensive operations management literature on capacity investment decisions in various settings. These include, the impact of competition on the capacity investment (Goyal and Netessine, 2007), the timing of capacity investment decisions for established firms and start-ups facing new market (Swinney et al., 2011), the optimal capacity expansion decisions with carbon emission constraints (Song et al, 2017), and a series of studies on capacity investment contracts as follows. Cachon and Lariviere (2001) consider the capacity investment problem with the option contract, and analyze supply chain coordination under forced compliance regime and voluntary compliance regime, respectively. Tomlin (2003) improves the voluntary compliance regime of Cachon and Lariviere (2001), and points out share-the-pain contracts can increase supplier capacity in the complete information case, a result that contrasts with that of Cachon and Lariviere (2001). Murat and Wu (2005) discuss a linear capacity reservation contract, but ignore the excess capacity problem. Özer and Wei (2006) show that the channel can be coordinated under asymmetric information by combining an advance purchase contract with an appropriate payback agreement. Jin and Wu (2007) indicate that a deductible reservation contract can realize supply chain coordination. However, take-or-pay contract can bring greater profits to manufacturers. Mathur and Shah (2008) explore capacity reservation contract with penalty mechanism, and present two special cases to demonstrate the potential of achieving supply chain coordination. Davis and Leider (2014,2015) consider a capacity investment with “hold-up” problem and a capacity investment with bargaining behavior, respectively. They suggest in both issues mentioned above that an option contract is the best at increasing investment level, and thus increase the overall supply chain profits. In addition, there are also some long-term contracts to improve capacity contradiction, such as relational contract (Taylor and Plambeck, 2007b). Although those contracts mentioned before are helpful to improve the supply chain's capacity investment level, there exist some defects to alleviate the losses generated by the deviation of capacity from the demand under those contracts. In this paper, an appropriate contract is designed to solve this problem and it also increases capacity investment level.

Papers on risk sharing contracts also introduce solutions to imbalance between the supply and demand. Gan et al. (2005) design a risk-sharing contract that accomplishes channel coordination in the supply chain with one supplier and one retailer, where the retailer is downside-risk averse with the probability that the return is below a target level as her downside risk measure and the supplier is a risk-neutral agent. He and Zhang (2008) propose several risk sharing contracts that distribute the random yield risk among parties, and show that yield randomness might enhance the supply chain performance under certain conditions. He and Zhang (2010) extend He and Zhang (2008) by considering the effect of secondary market in the supply chain, and find that secondary market generally has a positive impact on supply chain performance. Although risk-sharing mechanism can effectively handle the risk of loss, there are some certain defects in reasonable profit distribution. As a way of computing the constant transfer term by using Nash arbitration scheme and Shapley value， side payment contract can realize profit reallocation (Leng and Zhu, 2009).The side payment is bidirectional and there may be franchise fee from the buyer to the seller, or slotting fee from the seller to the buyer (Kuksov and Pazgal, 2007). Since both contracts above have such advantages, this paper attempts to improve the capacity contradiction by agreeing the combined contract, namely, risk diversification contract, of risk-sharing and side payment.

Literature on policymaker's risk aversion behavior can also show the advantages of our proposed methods. Utility functions (e.g., Choi and Ruszczyński, 2011; Sayın et al., 2014), mean-variance (e.g., Cui et al., 2016; Xue et al., 2016; Liu et al., 2016), and CVaR are the three main research streams of modeling risk aversion in supply chain management. We refer interested readers to Jammernegg and Kischka (2012) for dealing with the ordering policies of newsvendors with CVaR risk measure, and we review the main contributions on this approach, which is widely used in the financial and supply chain fields. For instance, in newsvendor models, Chen et al. (2009) consider the optimal ordering and pricing in a risk-averse newsvendor model under stochastic price-dependent demand by applying the CVaR criterion, and point out that the risk averse optimal order quantity may not be less than the risk-neutral optimal order quantity for the additive demand model. In supply chain planning, Soleimani and Govindan (2014) develop a mean-CVaR two-stage stochastic programming model, and show that the model behaves more conservative (lower costs) by increasing the weight of CVaR part and decreasing the value of confidence level in CVaR. In supply chain disruptions, by introducing the CVaR risk measure, Sawik et al (2013) indicates that the risk-averse suppliers with high disruption probability are allotted the lowest fractions of the total demand for parts or are not selected at all.

According to the above comprehensive analysis, this paper applies CVaR to describe the risk averse supplier's performance, then probes the optimal capacity investment strategy under risk diversification contract, and discusses the feasibility and advantage of this contract. This paper differs from the previous literature on capacity investment in three ways.

First, we introduce the supplier's risk aversion behaver into capacity investment issues, and we consider the shortage cost and the losses of unsold capacity simultaneously. However, in the existing capacity investment literatures, the supplier is risk neutral, and the scholars only consider excessive capacity or insufficient capacity, even consider none of them.

Next, a new style contract, namely risk diversification contract, is proposed to deal with the capacity investment contradiction.

Last, a choice criterion of contracts is proposed, and we apply the mathematical method to prove the feasibility of this criterion.

3 Model formulation

3.1 Assumptions and notations

Considering a supply chain consists of one supplier and one manufacturer in a single-period, we assume the demand information is symmetrical. The manufacturer is responsible for product research and development, sells the finished product at a unit retail price p during a selling season with his forecast of customer demand x and has one opportunity to place an exact order with the corresponding spare parts of the quantum of demand from his supplier by paying the unit wholesale price w before the selling season. The supplier sets the capacity investment level K at the unit production cost c_s and the unit capacity investment cost c_k. If the capacity is greater than the realized demand, the supplier must dispose of the remaining capacity at a loss, which means the losses of any unsold capacity is v_s per unit. If the capacity is less than the realized demand, the managers would lose some profits, while the unit shortage cost are g and v_m for supplier and manufacturer, respectively. To avoid triviality, we assume that the cost of product research and development is zero, $p > w > c_s + c_k > 0$, $v_s \geq 0$, $g \geq 0$, $p - w > v_m \geq 0$.

The customer demand x with an increasing generalized failure rate (IGFR)[6], is a stochastic variable with probability density function (PDF) $f(\cdot)$ and cumulative density function (CDF) $F(\cdot)$. Without loss of generality, we assume that $F(0) = 0$, and for simplicity, $F(x)$ is assumed to be continuous and strictly increasing in x. The manufacturer provides an "accept or reject" type of contract, and the supplier decides the optimal capacity investment level after accepting the contract. Now demand is realized and the manufacturer places an exact order to his supplier. The supplier fulfills the order and if demand does not equal capacity, lost sales or excess capacity is observed (Fig.1).

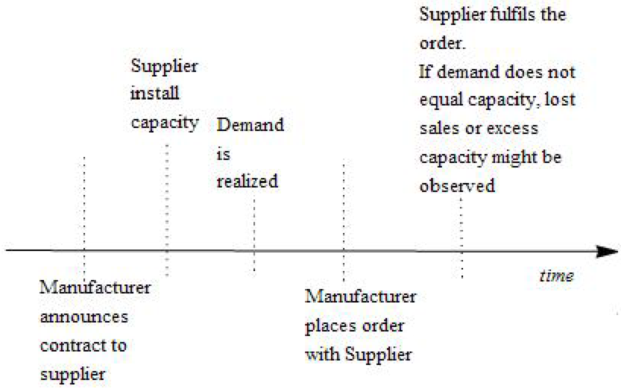

Fig. 1: Sequence of events

In addition, π denotes the expected profit; Superscript $*$, s and m denote optimality, supplier and manufacturer, respectively; Subscripts I, D, a, O, B, R and Φ denote supply chain, wholesale price contract, risk diversification contract, option contract, payback contract, capacity reservation contract and revenue sharing contract, respectively.

3.2 Risk Measure: CVaR

We assume that the supplier is at risk-averse preference. Considering the CVaR criterion that exhibits risk aversion, and according to the description of Rockafellar and Uryasev (2000, 2002) description, CVaR can be defined as

$$CVaR_\eta = \max_{\sigma \in R}\{\sigma - \frac{1}{\eta}E(\sigma - Y)^+\},$$

where Y is a random variable; E is the expectation operator; σ reflects the target profit of the newsvendor; $\eta \in (0,1]$ reflects the degree of risk aversion (the smaller η is, the more risk averse the newsvendor is), and $\eta = 1$ corresponds to the risk neutrality scenario. Throughout this paper, we use the following notation:

$x^+ = \max\{x, 0\}$.

3.3 Benchmark models

[6]A random variable x has an IGFR, if $(\frac{xf(x)}{1-F(x)})' \geq 0$ for all x in its domain. Most widely used distributions (e.g., the uniform, normal, negative exponential, Weibull and gamma distributions) in the operations management literatures have an IGFR (Lariviere and Martin, 2006).

Assume q is the order quantity placed by supplier to manufacturer, now demand is realized that $q = x$. If $S(K)$ represent the sales for a given capacity K, it would be $S(K) = E\min\{K, q\} = E\min\{K, x\} = K - \int_0^K F(x)dx$. If excess capacity is observed, then $(K-x)^+ = K - S(K)$; On the other hand, $(x-K)^+ = \mu - S(K)$ for the lost sales, where $\mu = E(x)$ [7].

3.3.1 Centralized model

In the centralized case, all members behave as part of a unified system, and then the supply chain system's expected profit is

$$\pi_I = (p - c_s)S(K) - v_s(K-x)^+ - g(x-K)^+ - v_m(x-K)^+ - c_k K. \tag{1}$$

π_I is concave regarding K with the second derivative $\partial^2\pi_I / \partial K^2 = -(p - c_s + v_s + g + v_m) f(K) < 0$,based on maximized profits of the whole supply chain system, we can obtain the optimal capacity investment level satisfies the first order derivative $\partial\pi_I / \partial K = 0$, i.e.,

$$F(K_I^*) = \frac{p - c_s - c_k + g + v_m}{p - c_s + v_s + g + v_m}. \tag{2}$$

3.3.2 Decentralized model

In the decentralized case, we consider the wholesale price contract, and then the expected profit of the manufacturer and the supplier in the wholesale price contract are given by the following equations, respectively.

$$\pi_D^m = (p - w)S(K) - v_m(x-K)^+, \tag{3}$$

$$\begin{aligned}\pi_D^s &= (w - c_s)S(K) - v_s(K-x)^+ - g(x-K)^+ - c_k K \\ &= (w - c_s - c_k)K - L(w, K),\end{aligned}$$

where $L(w, K) = (w - c_s + v_s)(K-x)^+ + g(x-K)^+$ is the loss generated by the deviation of capacity from the manufacturer's order quantity.

From the definition of CVaR, the supplier's CVaR performance function with wholesale price contract satisfies that

$$CVaR_\eta \pi_D^s = \max_{\sigma \in R}\{\sigma - \frac{1}{\eta}\max\{\sigma - \pi_D^s, 0\}\}.$$

Lemma 1 *$CVaR_\eta \pi_D^s$ can be maximized if and only if $\sigma_D^* = (w - c_s - c_k + g)K - \mu g$.*

The proof is presented in Appendix A.

In accordance with Lemma 1, the supplier's CVaR performance function can be rewritten as

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[7] $(x-K)^+ = \int_K^{+\infty}(x-K)f(x)dx = \int_0^{+\infty}(x-K)f(x)dx - \int_0^K (x-K)f(x)dx = \int_0^{+\infty} xf(x)dx - \int_0^{+\infty} Kf(x)dx + \int_0^K (K-x)f(x)dx$
$= \mu - K + \int_0^K (K-x)f(x)dx = \mu - S(K).$

$$H_D^s = CVaR_\eta \pi_D^s = (w - c_s - c_k + g)K - \mu g - \frac{w - c_s + v_s + g}{\eta}\int_0^K F(x)dx. \quad (4)$$

H_D^s is concave regarding K due to $\frac{\partial^2 H_D^s}{\partial K^2} = -\frac{w - c_s + g + v_s}{\eta} f(K) < 0$, and thereby the optimal capacity investment level K_D^* can be characterized by the first-order condition $\frac{\partial H_D^s}{\partial K} = 0$, namely

$$F(K_D^*) = \frac{\eta(w_D - c_s - c_k + g)}{w_D - c_s + v_s + g}. \quad (5)$$

4 Supply chain coordination

According to Cachon (2003), a contract is said to coordinate the supply chain if the supplier's optimal capacity investment level keeps consistent with the optimal capacity investment level of centralized supply chain, and a contract is said to be accepted by the supply chain members if there exists a Pareto improvement, i.e., each firm can earn a positive profit, or at least don't lose money with the coordinating contract. Therefore, we call a contract feasible if it can coordinate the supply chain and has a Pareto improvement.

If wholesale price contract can coordinate the supply chain, i.e., $K_D^* = K_I^*$, and then there exists a condition that must be held as follows:

$$w_D(\eta) = \frac{(p - c_s - c_k + g + v_m)(g + v_s - c_s) - \eta(p - c_s + v_s + g + v_m)(g - c_s - c_k)}{p - c_s - c_k + g + v_m - \eta(p - c_s + v_s + g + v_m)} \quad \text{for} \quad \eta \neq \frac{p - c_s + g + v_m - c_k}{p - c_s + v_s + g + v_m}.$$

Because of $\frac{\partial w_D(\eta)}{\partial \eta} = -\frac{(p - c_s - c_s + g + v_m)(p - c_s + v_s + g + v_m)(c_k + v_s)}{(p - c_s - c_k + g + v_m - \eta(p - c_s + v_s + g + v_m))^2} < 0$, then it holds that $w_D(\eta) \geq w_D(1) = p + v_m > p$. However, this is contradictory to $p > w$. Therefore, the wholesale price contract cannot effectively stimulate the supplier to ramp up capacity investment level, and hence we need to design a reasonable incentive mechanism to improve this situation.

We first consider supply chain coordination with risk diversification contract and then compare risk diversification with several other contracts, i.e., option, payback, capacity reservation and revenue-sharing contracts.

4.1 Risk diversification contract

In order to encourage the supplier to enhance her capacity investment level, both the manufacturer and the supplier agree to a risk diversification contract $(\lambda,\ T)$ before selling season. The first parameter $\lambda(\lambda \in [0,1])$ is the loss sharing ratio and it signifies the supplier's share of loss generated by the deviation of capacity from the manufacturer's order quantity. Thus, the parameter $1-\lambda$ is the loss ratio shared by the manufacturer. The second parameter T is a side payment, which refers to a compensation from the supplier to the manufacturer after the manufacturer shares the loss with the supplier. T can be negative, which means a subsidy can be transferred from the manufacturer to his supplier. Then, in the risk diversification contract, the expected profit of the manufacturer is

$$\pi_a^m = (p - w)S(K) - v_m(x - K)^+ - (1-\lambda)L(w, K) + T, \quad (6)$$

The supplier's expected profit is

$$\pi_a^s = (w - c_s - c_k)K - \lambda L(w,K) - T.$$

Similar to Lemma 1, if $\sigma_a^* = (w - c_s - c_k + \lambda g)K - \mu\lambda g - T$, we have the maximum performance of the supplier under the CVaR criterion as

$$H_a^s = CVaR_\eta \pi_a^s = (w - c_s - c_k + \lambda g)K - \frac{\lambda(w - c_s + v_s + g)}{\eta}\int_0^K F(x)dx - \mu\lambda g - T. \tag{7}$$

H_a^s is concave in K due to $\frac{\partial^2 H_a^s}{\partial K^2} = -\frac{\lambda(w - c_s + g + v_s)}{\eta} f(K) < 0$, and hence the optimal capacity investment level with risk diversification contract is

$$F(K_a^*) = \frac{\eta(w_a - c_s - c_k + \lambda g)}{\lambda(w_a - c_s + v_s + g)}. \tag{8}$$

Proposition 1 *The optimal capacity investment level* K_a^* *is increasing in* η*, and decreasing in* λ.

Proof. $\frac{\partial K_a^*}{\partial \eta} = \frac{1}{f(K_a^*)} \times \frac{w_a - c_s - c_k + \lambda g}{\lambda(w_a - c_s + v_s + g)} > 0$, $\frac{\partial K_a^*}{\partial \lambda} = -\frac{\eta}{f(K_a^*)} \times \frac{w_a - c_s - c_k}{\lambda^2(w_a - c_s + v_s + g)} < 0.$

Proposition1 illustrates that the more loss the manufacturer shares, the higher the optimal capacity investment level of the risk-averse supplier is. As a result, $K_a^*(\lambda) \geq K_a^*(1) = K_D^*$ with an exogenous wholesale price[8], i.e., risk diversification contract can stimulate the growth of investment in supplier's capacity. Let $K_a^* = K_I^*$, then

$$\lambda^* = \frac{\eta(p - c_s + v_s + g + v_m)(w_a - c_s - c_k)}{(p - c_s - c_k + g + v_m)(w_a - c_s + v_s + g) - \eta g(p - c_s + v_s + g + v_m)}. \tag{9}$$

In this situation, the supplier's capacity enables the supply chain system to achieve the best performance. However, this is not the only condition to coordinate supply chain. The risk diversification contract will not be accepted unless each agent's performance is better than the performance from the wholesale price contract. in other words, risk diversification contract would be accepted if Pareto improvement would be realized, i.e.,

$$\begin{cases} H_a^s(w_a, K_I^*, \lambda^*) \geq H_D^s(w_D, K_D^*), \\ \pi_a^m(w_a, K_I^*, \lambda^*) \geq \pi_D^m(w_D, K_D^*). \end{cases} \tag{10}$$

Let

$$T_{\max} = H_D^s(w_a, K_I^*) - H_D^s(w_D, K_D^*) + (1-\lambda^*)L(w_a, K_I^*) + \frac{(1-\eta)(1-\lambda^*)(w_a - c_s + v_s + g)}{\eta}\int_0^{K_I^*} F(x)dx,$$

$$T_{\min} = \pi_D^m(w_D, K_D^*) - \pi_D^m(w_a, K_I^*) + (1-\lambda^*)L(w_a, K_I^*).$$

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[8] In the supply chain system with the risk diversification contract, the wholesale price and the side payment play the same role. They split the performance arbitrarily between the supplier and the manufacturer. Thus, we assume that the wholesale price is the same as the price in the wholesale price contract, and only consider the side payment to adjust the performance between the agents.

Hence, we obtain the feasible range of the side payment by solving (10), which is $T \in [T_{\min}, T_{\max}]$.

As (9) holds, the expected profit of the supply chain system is maximized. This is a crucial process in coordinating the supply chain. Another process is allocating the performance between the supplier and the manufacturer after the agents agree the risk diversification contract. To solve this problem, we use the generalized Nash bargaining process (e.g., Sheu, 2016) with the manufacturer's bargaining power $\beta(\beta \in [0,1])$ and the supplier's bargaining power $1-\beta$, and we consider the agents' performance under the wholesale price contract as the benchmark. As such, we can get the bargaining solution by solving the following problem:

$$P(T) = \max_{T \in [T_{\min}, T_{\max}]} (\pi_a^m(w_a, K_I^*, \lambda^*) - \pi_D^m(w_D, K_D^*))^{\beta} (H_a^s(w_a, K_I^*, \lambda^*) - H_D^s(w_D, K_D^*))^{1-\beta}.$$

$P(T)$ is concave regarding T due to $\frac{\partial^2 P(T)}{\partial T^2} = -\beta(1-\beta)(T-T_{\min})^{\beta-2}(T_{\max}-T)^{-\beta-1}(T_{\max}-T_{\min})^2 < 0$, and then the bargaining solution is

$$T^* = \beta T_{\max} + (1-\beta) T_{\min}. \tag{11}$$

When the supplier and the manufacturer agree on the risk diversification contract, the performance of the supply chain system improves ΔT, the supplier gains $(1-\beta)\Delta T$ and the manufacturer gains $\beta \Delta T$,where

$$\begin{aligned}\Delta T = T_{\max} - T_{\min} &= H_D^s(w_a, K_I^*) - H_D^s(w_D, K_D^*) + \pi_D^m(w_a, K_I^*) - \pi_D^m(w_D, K_D^*) \\ &+ \frac{(1-\eta)(1-\lambda^*)(w_a - c_s + v_s + g)}{\eta} \int_0^{K_I^*} F(x)dx.\end{aligned}$$

For illustrating the efficiency of the risk diversification contract, and based on the analysis above, we have the following theorem.

Theorem 1 *In a supply chain consisting of one risk-averse supplier and one risk-neutral manufacturer, the risk diversification contract is feasible if condition (9) holds and* $T \in [T_{\min}, T_{\max}]$. *Meanwhile, we can rationally distribute the newly added performance via* T^* *in the form of (11).*

According to Theorem 1, we indicate that the risk neutral manufacturer need to constantly adjust the loss sharing ratio and the effective range of the side payment to cushion the production capacity investment contradiction between upstream and downstream enterprises. At the same time, the parties should enhance their own bargaining chips (such as product prices, product quality) and further benefit from the negotiation of the valid side payment.

4.2 Alternative contracts

This subsection considers an incentive scheme from various perspectives, including an option contract from the perspective of risk, payback contract and a capacity reservation contract from the perspective of capacity, and a revenue sharing contract from the perspective of revenue. We first show the objective function of the supplier for seeking the profit maximization with the contracts mentioned above under CVaR criterion. Then, we examine whether those contracts are feasible or not. Furthermore, the differences between those contracts and our proposed risk diversification contract are compared in this subsection.

4.2.1 Option contract

When an option contract[9] is agreed by the manufacturer and the supplier. The manufacturer needs to pay the supplier w_{option} per option with the number of options K_{option} except the actual ordering cost. Thus, the total payment satisfies:

$$T_o = \begin{cases} wS(K) + w_{option}K_{option}, K_{option} \le K; \\ wx + w_{option}K, \qquad K_{option} > K, x \le K; \\ wK + w_{option}K, \qquad K_{option} > K, x > K. \end{cases}$$

For simplicity, we suppose the probability of $K_{option} \le K$ is θ_1 and θ_2 denotes the probability of $K_{option} > K$, where both θ_1 and θ_2 belong to $(0,1)$ and satisfy $\theta_1 + \theta_2 = 1$ .Hence, $T_o = wS(K) + w_{option}(\theta_1 K_{option} + \theta_2 K)$.

The expected profit of the manufacturer and the supplier in the option contract can be found in the following equations, respectively.

$$\pi_O^m = (p-w)S(K) - v_m(x-K)^+ - w_{option}(\theta_1 K_{option} + \theta_2 K),$$

$$\pi_O^s = (w - c_s - c_k)K + w_{option}(\theta_1 K_{option} + \theta_2 K) - L(w,K).$$

Similar to Lemma 1, we have $\sigma_O^* = \sigma_D^* + w_{option}(\theta_1 K_{option} + \theta_2 K)$, and the CVaR performance function of the supplier is

$$H_O^s = CVaR_\eta \pi_O^s = H_D^s + w_{option}(\theta_1 K_{option} + \theta_2 K).$$

Here H_O^s is concave regarding K , and hence the optimal capacity investment level with option contract is

$$F(K_O^*) = \frac{\eta(w_O - c_s - c_k + g + \theta_2 w_{option})}{w_O - c_s + v_s + g}.$$

Clearly, we have $K_O^* \ge K_D^*$. Let $K_O^* = K_I^*$; then it follows that

$$w_{option}^* = \frac{1}{\theta_2}\left[\frac{(p - c_s - c_k + g + v_m)(w_O - c_s + v_s + g)}{\eta(p - c_s + v_s + g + v_m)} - w_O + c_s + c_k - g\right].$$

If the coordinating contract has a Pareto improvement with an exogenous wholesale price[10], i.e.,

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[9]Tomlin (2003) investigates the incentive effect of the option contract, but ignores the coordination problem. We extend his model, and consider the situation of excess capacity and unsold capacity, then we investigate the coordination conditions of this contract.

[10] In the supply chain system with the option contract, the wholesale price and K_{option} play the same role. They split the performance arbitrarily between the supplier and the manufacturer. Thus, we assume that the wholesale price is the same as the price in the wholesale price contract, only consider K_{option} to adjust the performance between the agents.

$H_O^s(K_I^*, w_{option}^*) \geq H_D^s(K_D^*)$ and $\pi_O^m(K_I^*, w_{option}^*) \geq \pi_D^m(K_D^*)$ hold, then we can obtain the following equations such as $K_{option} \in [K_{option,\min}, K_{option,\max}]$, with

$$K_{option,\max} = \frac{\pi_D^m(K_I^*) - \pi_D^m(K_I^*)}{\theta_1 w_{option}^*} - \frac{\theta_2}{\theta_1} K_I^*,\ K_{option,\min} = \frac{H_D^s(K_D^*) - H_D^s(K_I^*)}{\theta_1 w_{option}^*} - \frac{\theta_2}{\theta_1} K_I^*.$$

However, K_{option} may be a negative number because there is no guarantee that $K_{option,\max}$ is greater or equal to zero. As a consequence, it is not appropriate to use the option contract, and in contrast, the agents prefer to adopt the risk diversification contract rather than an option contract.

4.2.2 Payback contract

If the manufacturer offers the supplier a payback contract[11], he needs to pay his supplier $wS(K)$ and should be answerable to the excess capacity, where the unit excess capacity compensatory price $\rho(0 \leq \rho < w)$ is given by the manufacturer to the supplier. Thus, the expected profit of the manufacturer and the supplier in the payback contract can be described by the following equations, respectively.

$$\pi_B^m = (p-w)S(K) - v_m(x-K)^+ - \rho(K-x)^+,$$

$$\pi_B^s = (w - c_s - c_k)K - L(w,K) + \rho(K-x)^+.$$

Similar to Lemma 1, we have $\sigma_B^* = \sigma_D^*$, and the CVaR performance function of the supplier is

$$H_B^s = CVaR_\eta \pi_B^s = H_D^s + \frac{\rho}{\eta}\int_0^K F(x)dx.$$

Here H_B^s is concave regarding K due to $\frac{\partial^2 H_B^s}{\partial K^2} = -\frac{w - c_s + g + v_s - \rho}{\eta} f(K) < 0$ for any $\rho < w - c_s + g + v_s$, and hence the optimal capacity investment level with payback contract is

$$F(K_B^*) = \frac{\eta(w_B - c_s + g - c_k)}{w_B - c_s + g + v_s - \rho}.$$

Theorem 2 *The payback contract is feasible under certain conditions.*

Proof. Recall that a contract is feasible if it coordinates the supply chain and has a Pareto improvement. Thus, to obtain the conditions where the payback contract is feasible, we consider the following two possible cases.

If the payback contract can coordinate the supply chain, i.e., $K_B^* = K_I^*$, then it follows that

$$\rho^* = w_B - c_s + g + v_s - \frac{\eta(w_B - c_s + g - c_k)(p - c_s + g + v_m + v_s)}{p - c_s + g + v_m - c_k},\ \eta \in (\max\{\eta_1, 0\}, 1],$$

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[11]Özer and Wei (2006) show that an appropriate payback agreement can coordinate channel under symmetric forecast information. We consider a scenario that exists lost sales and a risk averse supplier by using this payback contract, and discuss the feasible of a Pareto improvement for this contract.

where $\eta_1 = \dfrac{(-c_s + g + v_s)(p - c_s + g + v_m - c_k)}{(w_B - c_s + g - c_k)(p - c_s + g + v_m + v_s)}$.

If the coordinating contract has a Pareto improvement, i.e., $H_B^s(w_B, K_I^*, \rho^*) \geq H_D^s(w_D, K_D^*)$ and $\pi_B^m(w_B, K_I^*, \rho^*) \geq \pi_D^m(w_D, K_D^*)$ hold, then we have that

$$\rho^* \in [\rho_{\min}, \rho_{\max}],$$

where $\rho_{\min} = \dfrac{\eta[H_D^s(w_D, K_D^*) - H_D^s(w_B, K_I^*)]}{(K_I^* - x)^+}$, $\rho_{\max} = \dfrac{\pi_D^m(w_B, K_I^*) - \pi_D^m(w_D, K_D^*)}{(K_I^* - x)^+}$.

This completes the proof.

From Theorem 2, we have that the supplier and the manufacturer can achieve a win-win status if using the payback contract, while the same results can be shown in the risk diversification contract by Theorem 1. Now, there exists an interesting question: what kind of contract do agents would prefer to accept, the payback contract or the risk diversification contract? We set

$$T_c = H_D^s(w_a, K_I^*) - H_D^s(w_B, K_I^*) + (1-\lambda^*)L(w_a, K_I^*) + \frac{(1-\lambda^*)(1-\eta)(w_a - c_s + g + v_s) - \rho^*}{\eta}(K_I^* - x)^+,$$

$$T_d = \pi_D^m(w_B, K_I^*) - \pi_D^m(w_a, K_I^*) + (1-\lambda^*)L(w_a, K_I^*) - \rho^*(K_I^* - x)^+.$$

Thus, clearly, we have $\pi_a^m \geq \pi_B^m$ and $H_a^s \geq H_B^s$ due to $T_{\max} \geq T_c \geq T \geq T_d \geq T_{\min}$ with $w_B = w_a$ (see Table 1). Therefore, agents would be prone to choose the risk diversification contract.

Tabel 1: The quantity of agents' performances between payback contract and risk diversification contract under different range of side payment

Participants	Payback contract		Risk diversification contract	The range of side payment
Manufacturer	π_B^m	>	π_a^m	$T > T_c$
	π_B^m	=	π_a^m	$T = T_c$
	π_B^m	<	π_a^m	$T < T_c$
Supplier	H_B^s	>	H_a^s	$T < T_d$
	H_B^s	=	H_a^s	$T = T_d$
	H_B^s	<	H_a^s	$T > T_d$

4.2.3 Capacity reservation contract

Under the capacity reservation model[12], the manufacturer pays the supplier not merely the actual purchase cost $wS(K)$ but also the cost calculated through the per unit τ multiplying the number of capacity K. The expected profits of the manufacturer and the supplier can be characterized by the functions below, respectively.

$$\pi_R^m = (p - w)S(K) - v_m(x - K)^+ - \tau K,$$

[12] Özer and Wei (2006) also consider a capacity reservation contract under risk neutral situation, we expand their model with lost sales and excess capacity under a risk averse scenario.

$$\pi_R^s = (w - c_s - c_k)K - L(w,K) + \tau K.$$

Similar to Lemma 1, we have $\sigma_R^* = \sigma_D^* + \tau K$, and the CVaR performance function of the supplier is

$$H_R^s = CVaR_\eta \pi_R^s = H_D^s + \tau K.$$

The optimal capacity investment level with the capacity reservation contract is given by

$$F(K_R^*) = \frac{\eta(w_R - c_s + g - c_k + \tau)}{w_R - c_s + g + v_s}.$$

If the capacity reservation contract can coordinate the supply chain, then we have τ^* satisfies

$$\tau^* = \frac{(w_R - c_s + g + v_s)(p - c_s + g + v_m - c_k)}{\eta(p - c_s + g + v_m + v_s)} - w_R + c_s - g + c_k. \tag{11}$$

If the coordinating contract has a Pareto improvement, i.e., $\pi_R^m(w_R, K_I^*, \tau^*) \geq \pi_D^m(w_D, K_D^*)$ and $H_R^s(w_R, K_I^*, \tau^*) \geq H_D^s(w_D, K_D^*)$, then it follows that $\tau^* \in [\tau_{\min}, \tau_{\max}]$, where

$$\tau_{\max} = \frac{\pi_D^m(w_R, K_I^*) - \pi_D^m(w_D, K_D^*)}{K_I^*}, \tau_{\min} = \frac{H_D^s(w_D, K_D^*) - H_D^s(w_R, K_I^*)}{K_I^*}.$$

We rewrite the equation (11) as $w_R = P(\tau)$, where $P(\tau)$ is a function about τ . Then we replace w_R with $P(\tau)$ in $\tau \leq \tau_{\max}$ and $\tau \geq \tau_{\min}$, and we have $\tau_{\max}^* \geq \tau$ and $\tau \geq \tau_{\min}^*$. However, it may be false that $\tau_{\max}^* \geq \tau_{\min}^*$, which we show in the Numerical Studies. Otherwise, by comparing the risk diversification contract and the capacity reservation contract, we set

$$T_g = H_D^s(w_a, K_I^*) - H_D^s(w_R, K_I^*) - \tau^* K_I^* + (1 - \lambda^*)[L(w_a, K_I^*) + \frac{(1-\eta)(w_a - c_s + g + v_s)}{\eta}(K_I^* - x)^+],$$

$$T_h = \pi_D^m(w_R, K_I^*) - \pi_D^m(w_a, K_I^*) - \tau^* K_I^* + (1 - \lambda^*) L(w_a, K_I^*).$$

Thus, we have $\pi_a^m \geq \pi_R^m$ and $H_a^s \geq H_R^s$ due to $T_{\max} \geq T_g \geq T \geq T_h \geq T_{\min}$ with $w_R = w_a$ .Whereupon, risk diversification contract would be more likely to be accepted by agents than a capacity reservation contract.

4.2.4 Revenue sharing contract

From the perspective of revenue, the manufacturer decides to provide his supplier a revenue sharing contract[13] with the purpose of stimulating the supplier to ramp up capacity investment. In the revenue sharing contract, $1 - \phi(\phi \in [0,1])$ of the manufacturer's income is transferred to the supplier, and the manufacturer's and the supplier's expected profits can be described as follows:

[13]Panda (2014); Li et al (2016) etc., point out a revenue sharing contract can coordinate the supply chain in a newsvendor model with various scenarios. We try to introduce this mechanism into capacity investment problem, and consider the supply chain coordination with the revenue sharing contract.

$$\pi_{\Phi}^{m} = \phi(pS(K) - v_m(x-K)^+) - wS(K),$$

$$\pi_{\Phi}^{s} = (1-\phi)[pS(K) - v_m(x-K)^+] + (w - c_s - c_k)K - L(w,K).$$

Similar to Lemma 1, we have $\sigma_{\Phi}^{*} = \sigma_{D}^{*} + (1-\phi)[(p+v_m)K - \mu v_m]$, and the CVaR performance function of the supplier is

$$H_{\Phi}^{s} = CVaR_{\eta}\pi_{\Phi}^{s} = H_{D}^{s} + (1-\phi)[(p+v_m)(K - \frac{(K-x)^+}{\eta}) - \mu v_m].$$

Here H_{Φ}^{s} is concave regarding K due to $\frac{\partial^2 H_{\Phi}^{s}}{\partial K^2} = -\frac{(1-\phi)(p+v_m) + w - c_s + g + v_s}{\eta} f(K) < 0$, and hence the optimal capacity investment level with revenue sharing contract is

$$F(K_{\Phi}^{*}) = \frac{\eta[(1-\phi)(p+v_m) + w_{\Phi} - c_s + g - c_k]}{(1-\phi)(p+v_m) + w_{\Phi} - c_s + g + v_s}.$$

Let $K_{\Phi}^{*} = K_{I}^{*}$, then the following condition holds,

$$\eta = \frac{(p - c_s + g + v_m - c_k)[(1-\phi)(p+v_m) + w_{\Phi} - c_s + g + v_s]}{(p - c_s + g + v_m + v_s)[(1-\phi)(p+v_m) + w_{\Phi} - c_s + g - c_k]}.$$

Note here that $\eta \in (0,1]$ and thus the revenue sharing contract can coordinate the supply chain with $\phi^{*} \in [0, \frac{w_{\Phi}}{p+v_m}]$.

If the coordinating contract has a Pareto improvement, then it follows that

$$\pi_{\Phi}^{m}(w_{\Phi}, K_{I}^{*}, \phi^{*}) \geq \pi_{D}^{m}(w_D, K_{D}^{*}) \quad \text{and} \quad H_{\Phi}^{s}(w_{\Phi}, K_{I}^{*}, \phi^{*}) \geq H_{D}^{s}(w_D, K_{D}^{*}).$$

Thus $\phi^{*} \geq \frac{\pi_{D}^{m}(w_D, K_{D}^{*}) + w_{\Phi}S(K_{I}^{*})}{pS(K_{I}^{*}) - v_m(x - K_{I}^{*})^+} = \phi_1$. However, we have $\phi_1 > \frac{w_{\Phi}}{p+v_m}$, which contradicts to $\phi^{*} \leq \frac{w_{\Phi}}{p+v_m}$. It follows that a revenue sharing contract is infeasible.

Based on the theoretical analysis above, we have shown the advantages of our proposed risk diversification contract over the alternative contracts and thus the following theorem holds.

Theorem 3 *Compared with the other contracts (including option, payback, capacity reservation and revenue sharing contract), agents would prefer to adopt the risk diversification contract for dealing with the capacity investment problem in the supply chain consisting of a risk-averse supplier and a risk-neutral manufacturer from the perspective of realizing supply chain coordination and achieving the Pareto improvement.*

Theorem 3 indicates that both agents can benefit more via the risk diversification contract when provided a number of supply chain contracts, which can be applied to effectively solve the capacity conflicts between upstream and downstream enterprises. That is, we provide a significant managerial reference for the managers for choosing the advantageous way when facing a series of related contracts.

5 Risk diversification contract under the asymmetrical demand information

In this section, we consider a risk diversification contract model where the demand information is asymmetrical. In practice, information is often privately held by one member of the supply chain. The informed party may use her information to improve her profits even at the expense of the other party. Hence, the uninformed party has a reason not to believe in the information (true or false) provided. This possibility precludes credible information sharing.

In this scenario, both parties learn the customer demand x which has CDF $F(\cdot)$ and PDF $f(\cdot)$. The manufacturer has the private information about demand forecast ξ. The supplier can always ask the manufacturer to provide her forecast information. Besides, the supplier resorts to a prior belief and considers ξ to be a zero-mean continuous random variable that takes values in $[\underline{\xi}, \overline{\xi}]$ with CDF $\Psi(\cdot)$ and PDF $\psi(\cdot)$, which is common knowledge. To recap, the supplier's demand forecast information is $x+\xi$ where x has CDF $F(\cdot)$ and ξ has CDF $\Psi(\cdot)$. On the other hand, the manufacturer's forecast information is $x+\xi$, where ξ is deterministically known and x has CDF $F(\cdot)$. Hence, the demand forecast information is asymmetric.

By choosing a risk diversification contract, similar to Section 4.1, the manufacturer defines her expected profit, the supplier's CVaR performance function as

$$\pi_{a,\xi}^{m} = (p-w)\min\{K, x+\xi\} - v_m(x+\xi-K)^+ - (1-\lambda)L(w,K,\xi) + T,$$

$$CVaR_{\eta}\pi_{a,\xi}^{s} = (w-c_s-c_k+\lambda g)K - \frac{\lambda(w-c_s+v_s+g)}{\eta}\int_{\underline{\xi}}^{\overline{\xi}}\int_0^{K-\xi}(K-\xi-x)dF(x)d\Psi(\xi) - \mu\lambda g - T,$$

where $L(w,K,\xi) = (w-c_s+v_s)(K-x-\xi)^+ + g(x+\xi-K)^+$.

Then, the optimal capacity investment level $K_{a,\xi}^*$ satisfies

$$\frac{\eta(w-c_s-c_k+\lambda g)}{\lambda(w-c_s+v_s+g)} = \int_{\underline{\xi}}^{\overline{\xi}} F(K_{a,\xi}^* - \xi)\psi(\xi)d\xi.$$

Particularly, when $T=0$ and $\lambda=1$, the risk diversification contract can degrade into the wholesale price contract. Then, in the wholesale price contract, the manufacturer's expected profit is $\pi_{D,\xi}^{m} = \pi_{a,\xi}^{m}\big|_{\lambda=1,T=0}$, and the supplier's CVaR performance function is $CVaR_{\eta}\pi_{D,\xi}^{s} = CVaR_{\eta}\pi_{D,\xi}^{s}\big|_{\lambda=1,T=0}$. Thus, the optimal capacity investment level $K_{D,\xi}^*$ satisfies

$$\frac{\eta(w-c_s-c_k+\lambda g)}{w-c_s+v_s+g} = \int_{\underline{\xi}}^{\overline{\xi}} F(K_{D,\xi}^* - \xi)\psi(\xi)d\xi.$$

Now we have that both the wholesale price contract and the risk diversification contract have the optimal decisions. Why do agents accept the latter? In other words, the risk diversification contract would be accepted if both parties gain a higher performance than that from the wholesale price contract, i.e.,

$$\begin{cases} CVaR_\eta \pi^s_{a,\xi}(w_a, K^*_{a,\xi}) \geq CVaR_\eta \pi^s_{D,\xi}(w_D, K^*_{D,\xi}), \\ \pi^m_a(w_a, K^*_{a,\xi}) \geq \pi^m_D(w_D, K^*_D). \end{cases}$$

Therefore, we can obtain $T \in [T_{\min,\xi}, T_{\max,\xi}]$ by solving the equation set above, where

$$\begin{aligned} T_{\max,\xi} = {} & CVaR_\eta \pi^s_{D,\xi}(w_a, K^*_{a,\xi}) - CVaR_\eta \pi^s_{D,\xi}(w_D, K^*_{D,\xi}) + (1-\lambda)L(w_a, K^*_{a,\xi}, \xi) \\ & + \frac{(1-\eta)(1-\lambda)(w_a - c_s + v_s + g)}{\eta} \int_{\underline{\xi}}^{\bar{\xi}} \int_0^{K-\xi} (K - \xi - x) dF(x) d\Psi(\xi), \end{aligned}$$

$$T_{\min,\xi} = \pi^m_{D,\xi}(w_D, K^*_{D,\xi}) - \pi^m_{D,\xi}(w_a, K^*_{a,\xi}) + (1-\lambda)L(w_a, K^*_{a,\xi}, \xi).$$

As the risk diversification contract leads to agents' performance increased under the asymmetrical demand information if $T \in [T_{\min,\xi}, T_{\max,\xi}]$. Another interesting question involved is what happens if the added performance is allocated between the parties with the risk diversification contract? To deal with this problem, we consider the manufacturer's bargaining power $\beta (\beta \in [0,1])$ and the supplier's bargaining power $1-\beta$, then we can rationally distribute the newly added performance via

$$T^*_\xi = \beta T_{\max,\xi} + (1-\beta) T_{\min,\xi},$$

where T^*_ξ is the solution of the Nash bargaining model

$$\max_{T \in [T_{\min,\xi}, T_{\max,\xi}]} (\pi^m_a(w_a, K^*_{a,\xi}) - \pi^m_D(w_D, K^*_{D,\xi}))^\beta (CVaR_\eta \pi^s_a(w_a, K^*_{a,\xi}) - CVaR_\eta \pi^s_D(w_D, K^*_{D,\xi}))^{1-\beta}.$$

Obviously, the supplier's performance is decreasing in β and $K^*_{a,\xi} \geq K^*_{D,\xi}$, another crucial process is the coordination of supply chain. Considering the integrated firm bases its component capacity decision on the point forecast ξ and the remaining market uncertainty, we obtain the whole supply chain system's expected profit as $\pi_{I,\xi} = CVaR_\eta \pi^s_{a,\xi} \hat{}_{\eta=1} + \pi^m_{a,\xi}$, and its' optimal capacity decision as

$$K^*_{I,\xi} = F^{-1}\left(\frac{p - c_s - c_k + g + v_m}{p - c_s + v_s + g + v_m}\right) + \xi.$$

The supplier's capacity choice under asymmetric information $K^*_{a,\xi}$ is not a function of ξ. Without credible forecast information sharing, the supplier cannot adjust the capacity to account for the manufacturer's private forecast. It leads to the equation that $K^*_{a,\xi} = K^*_{I,\xi}$ holds for some certain conditions. That is, the supply chain can be coordinated only under certain conditions. An example below is shown to illustrate the supply chain coordination with the risk diversification contract under the asymmetrical demand information.

We set x to follow uniform distribution $x \sim U[0, M]$, and ξ to follow uniform distribution $\xi \sim U[-N, N]$, where M and N are positive constants. Then the whole supply chain's optimal capacity is

$K_{I,\xi}^{*}=(\frac{p-c_s-c_k+g+v_m}{p-c_s+v_s+g+v_m})M+\xi$. The supplier's optimal capacity with the risk diversification contract is

$K_{a,\xi}^{*}=\frac{\eta(w-c_s-c_k+\lambda g)M}{\lambda(w-c_s+v_s+g)}$. Thus, under a special scenario that $\xi=0$, the risk diversification contract can coordinate the supply chain if equation (9) holds.

Through the above analysis, under the asymmetrical demand information, although it cannot ensure the coordination of the supply chain with the risk diversification contract, this contract has a Pareto improvement which leads to a higher performance for both agents. Meanwhile, according to agents' bargaining power, this contract can accomplish the distribution of the performance appropriately under certain conditions by negotiating the side payment. This implies that in some ways, the risk diversification contract can promote the long-term effective cooperation between the supplier and the manufacturer.

6 Sensitivity analysis of parameters

In this section, we compare performance of all contracts considered in this paper under the symmetrical demand information. We use our previous analytical results and some numerical investigations discussed later to outline a possible choice of contract selection strategy. We demonstrate their pact of the exogenous variables, including risk aversion coefficient, losses of unsold capacity and shortage cost, on the feasibility of contacts. We alter one of the three exogenous variables, and keeping the other two variables unchanged. For instance, we let losses of unsold capacity and shortage cost fixed, changing risk aversion coefficient to investigate how it affects the alter contracts, which is shown in section 6.1.

6.1 The influence of risk aversion coefficient

The supplier's risk aversion can describe the phenomenon that he doubts or he may even deny himself about the prospect of future events. However, in the existing capacity investment studies, the decisions makers trusted their own sense and keep risk neutral attitudes. One interesting question is naturally followed that how the risk aversion affects the agents with difference contracts?

To have the answer, we suppose the customer demand follows uniform distribution $x\sim U[0,500]$ and the other parameters follow that $p=15$, $c_k=5$, $c_s=3$, $v_s=v_m=g=1$. Then, in the centralized supply chain, we have the optimal capacity investment level $K_I^{*}=300$. In contrast, in the wholesale price contract, for earning a positive profit, the supplier should offer a wholesale price $w>8$. By setting $w_D=10$, we then have the optimal capacity investment level which satisfies $K_D^{*}=500\eta/3<K_I^{*}$. Thus, the manufacturer may offer other contracts for encouraging the supplier to ramp up capacity investment.

First, we consider the proposed risk diversification contract with an exogenous wholesale price $w_a=10$. According to Fig.2, we can observe that the more risk averse the supplier is or the more loss the supplier share, the less the capacity investment of the supplier is. Fig.2 shows that the risk diversification contract can coordinate the supply chain if the curved section $M_0N_0:5\eta(2+\lambda)=27\lambda$ holds as well. Fig.3 exhibits the impact of the degree of risk aversion on the side payment with the coordinating risk diversification contract, and shows three info below. In domain A, the supplier's CVaR performance with the wholesale price contract is higher than that with the risk diversification contract; however, the manufacturer's expected profit with the wholesale price contract is less than or equal to that with the risk diversification contract; In domain C, the supplier's CVaR performance with the wholesale price contract is less than or equal to that with the risk diversification contract; however, the manufacturer's expected profit with the wholesale price contract is higher than that with the risk diversification contract; In domain B, both the supplier's CVaR performance and the manufacturer's expected profit with the risk diversification contract are higher than or equal to that with the wholesale price contract . From the info of Fig.3, it indicates the coordinating risk diversification contract has a Pareto improvement with $T\in[T_{\min},T_{\max}]$. In other words, the risk diversification contract is feasible.

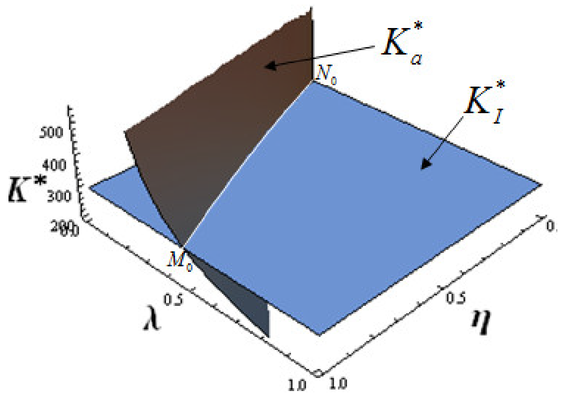

Fig. 2: Impact of η and λ on the optimal capacity investment level with risk diversification contract

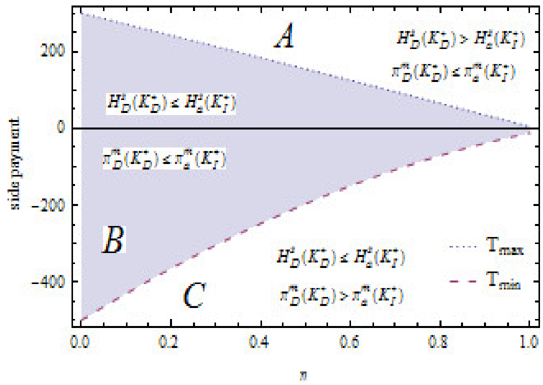

Fig. 3: Impact of η on side payment

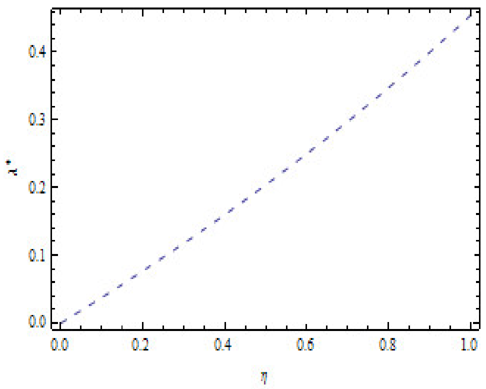

Fig. 4: Impact of η on λ^*

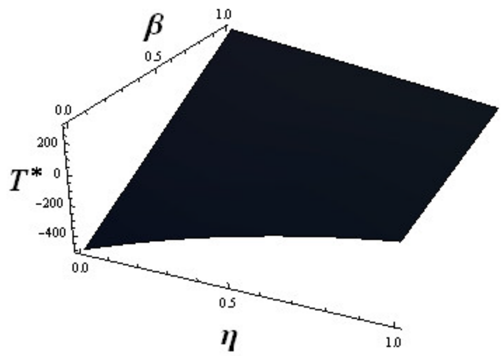

Fig. 5: The impact on side payment of the supplier's risk aversion measure and the manufacturer's bargaining power

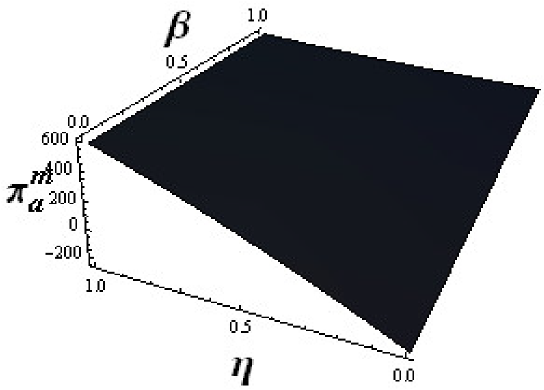

Fig. 6: The impact on the manufacturer's expected profit of the supplier's risk aversion measure and the manufacturer's bargaining power

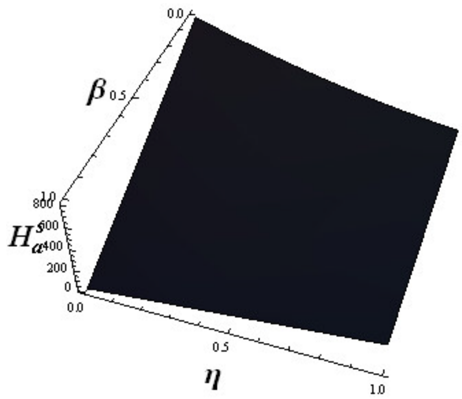

Fig.7: The impact on the supplier's CVaR performance of the supplier's risk aversion measure and the manufacturer's bargaining power

In the feasible risk diversification contract, Fig.4 shows that the more risk averse the supplier is, the less loss the supplier shares. Fig.5 demonstrates the side payment from the supplier to the manufacturer is monotonically increasing (or decreasing, or unchanging) in the supplier's risk aversion measure and increasing in the manufacturer's bargaining power β .Fig.6 states the manufacturer's expected profit are both increasing in η and β, respectively.Fig.7 illustrates the supplier's CVaR performance is monotonically increasing (or decreasing, or unchanging) in η and decreasing in β.

Although the risk diversification contract can handle the capacity contradiction efficiently, there exists a series of alternative contracts for dealing with the capacity investment problem. Why would agents like to adopt the risk diversification contract instead of others? In the following part, we first investigate the feasibility of the option, payback, capacity reservation and revenue sharing contract, respectively, and then compare those contracts with the proposed risk diversification contract, respectively.

In the option contract, for simplicity, we suppose the probability of options amount being above or below the capacity investment level is the same and the wholesale price is exogenous that $w_O = 10$. Then the option contact can coordinate the supply chain if $5\eta(3+0.5w_{option}) = 27$ holds. For all η, Fig.8 manifests the expected profit of the manufacturer with the coordinating option contract is greater than that with the wholesale price contract if $K_{option} < -122.22$. However, the design of the option contract is valid with $K_{option} > 0$. Thereby, the coordinating option contract has no Pareto improvement, i.e., the option contract is infeasible.

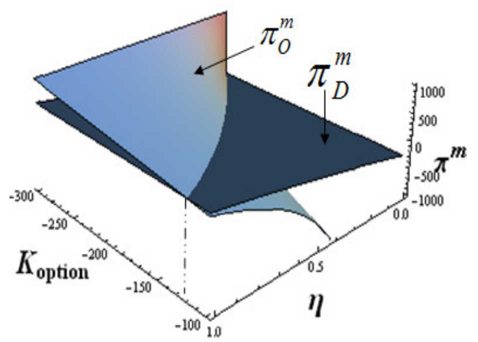

Fig. 8: Impact of η and K_{option} on π_O^m and π_D^m

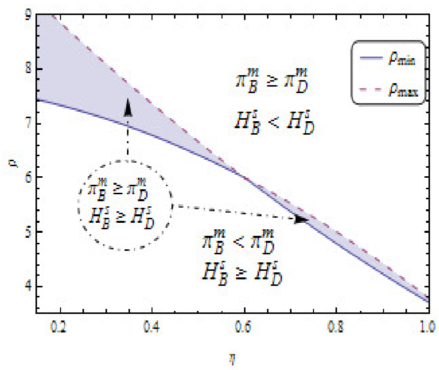

Fig. 9: Impact of η on ρ with the coordinating payback contract

No matter how the risk aversion coefficient change, a coordinating payback contract has a Pareto improvement, namely the manufacturer's expected profit and the supplier's CVaR performance with payback contract are higher than that with wholesale price contract, if $\rho \in [\rho_{\min}, \rho_{\max}]$ (see Fig.9). Take $\rho^* = 0.5(\rho_{\min} + \rho_{\max})$, it holds that $T_{\max} > T_c \geq T_d > T_{\min}$ for all η (see Fig.10). The supplier's CVaR performance with risk diversification contract is higher than that with payback contract under $T < T_c$ (see Fig.11); the manufacturer's expected profit with risk diversification contract is higher than that with payback contract under $T > T_d$ (see Fig.12). Thus, combining Fig.10 to Fig.12, agents would agree upon the same contract, namely the risk diversification contract, if $T \in [T_d, T_c]$.

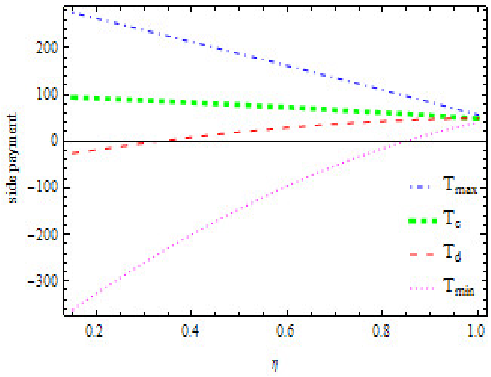

Fig. 10: Impact of η on the side payment

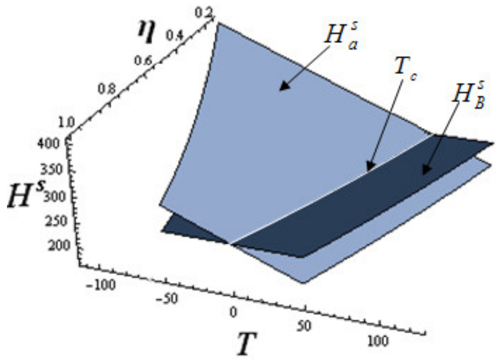

Fig. 11: Impact of T and η on the supplier's CVaR performance with risk diversification contract and that with payback contract

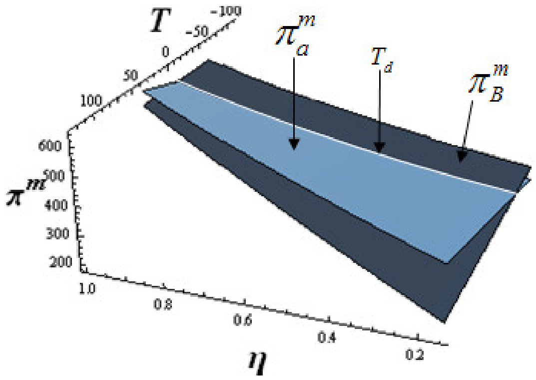

Fig. 12: Impact of T and η on the manufacturer's expected profit with risk diversification contract and that with payback contract

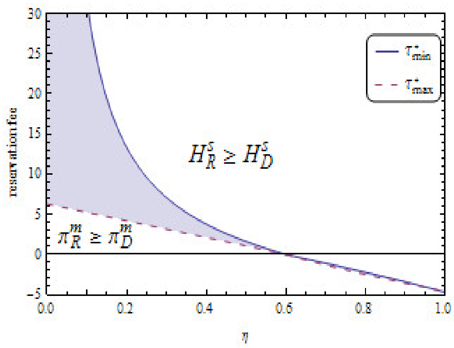

Fig. 13: Impact of η on the reservation fee with capacity reservation contract

A coordinating capacity reservation contract has a Pareto improvement, if both agents' performances with capacity reservation contract are higher than that with wholesale price contract. Fig.13 shows that the supplier's CVaR performance with capacity reservation contract is higher than that with wholesale price contract if $\tau > \tau^*_{\min}$; the manufacturer's expected profit with capacity reservation contract is higher than that with wholesale price contract if $\tau < \tau^*_{\max}$. However, $\tau^*_{\min} > \tau^*_{\max}$ regarding η (see 13). That is, the capacity reservation contract is infeasible.

A revenue sharing contract can coordinate the supply chain if $\eta \in (0.75,1]$ (see Fig.14). However, in interval $\eta \in (0.75,1]$, the expected profit of the manufacturer with the coordinating revenue contract is less than that with the wholesale price contract (see Fig.15). In other words, the manufacturer has no motivation to offer a coordinating revenue sharing contract.

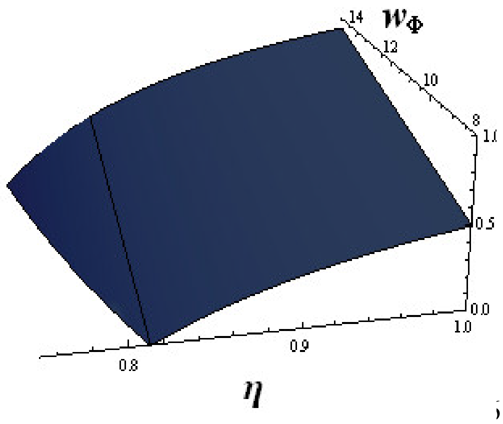

Fig.14: Impact of η and w_Φ on ϕ^* under a coordinating revenue sharing contract

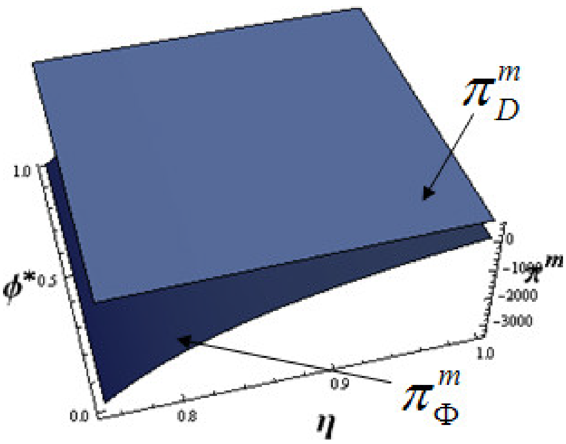

Fig.15: Impact of η and ϕ^* on the manufacturer' expected profit with revenue sharing contract and that with wholesale price contract

Based on the analysis above, no matter how the risk aversion coefficient change, the risk diversification contract has a wider range of application than other finite contracts.

6.2 The influence of the losses of unsold capacity and shortage cost

In this section, we consider the impact of the losses of unsold capacity and shortage cost on the agents' optimal performance with alternative contracts. In Table 2 and Table 3, we alter the losses of unsold capacity and shortage cost, respectively, with the other variables remaining unchanged. The performance of agents with the payback contract (or the risk diversification contract) are both higher than that with the wholesale price contact. However, the manufacturer's expected profit with the finite contracts (including option, capacity reservation and revenue sharing contract) are all less than that with the wholesale price contract. Meanwhile, the agents' performance with the risk diversification contract are both higher than that with the payback contract under certain condition. In other words, comparing to the wholesale price contract, the manufacturer would not to offer a contract, such as option, capacity reservation and revenue sharing contract, that lower his profit. And the agents prefer to adopt the risk diversification contract and the payback contract.

By a closer analysis, Table 2 and Table 3 further show that the agents with the risk diversification contract can gain a higher performance than that with the payback contract. For example, when $v_s = h = 1$, the supplier and the manufacturer can achieve a mutually beneficial outcome with the risk diversification contract if $-71.2 \le T \le 315.2$. And both agents can get a higher performance with the risk diversification contract than that with the payback contract if $45.5 \le T \le 65.2$. Obviously, the interval $[45.5, 65.2]$ is belong to the interval $[-71.2, 315.2]$, that is, the supply chain members prefer to applicate the risk diversification contract to increase performance.

Table 2: Impact of the losses of unsold capacity on agents' performance

v_s	π_D^m	H_D^s	π_a^m	H_a^s	π_O^m	π_B^m	H_B^s	π_R^m	π_Φ^m
0	515.0	-25.0	582.2+T	289.9-T	-43.1-3.5 K_{option}	618.2	232.3	-43.1	-2476.9
0.5	477.5	-38.2	547.3+T	276.8-T	-81.2-4.0 K_{option}	588.1	216.2	-81.2	-2148.5
1	**443.3**	**-50.0**	**514.5+T**	**265.2-T**	-115.0-3.7 K_{option}	**560.0**	**200.0**	-115.0	-1905.6
1.5	412.1	-60.5	484.1+T	255.6-T	-145.4-3.9 K_{option}	534.2	185.2	-145.8	-1719.3
2	383.6	-70.0	455.4+T	245.1-T	-171.3-4.1 K_{option}	509.1	172.3	-171.2	-1570.1

$x \sim U[0,500]$, $p = 15$, $c_k = 5$, $c_s = 3$, $v_m = g = 1$, $w = 10$, $\eta = 0.8$

Table 3: Impact of the supplier's shortage cost on agents' performance

g	π_D^m	H_D^s	π_a^m	H_a^s	π_O^m	π_B^m	H_B^s	π_R^m	π_Φ^m
0	290.0	100.0	550.0+T	285.7-T	-86.7-3.7 K_{option}	550.0	285.7	-86.7	-1475.4
0.5	372.8	22.1	531.9+T	275.0-T	-99.7-3.7 K_{option}	556.0	241.4	-99.7	-1679.5
1	**443.3**	**-50.0**	**514.5+T**	**265.2-T**	-115.0-3.7 K_{option}	**560.0**	**200.0**	-115.0	-1905.6
1.5	503.9	-117.1	497.2+T	256.2-T	-132.6-3.8 K_{option}	562.1	161.3	-132.6	-2155.9
2	556.4	-180.0	480.5+T	247.9-T	-152.3-3.8 K_{option}	562.5	125.0	-152.3	-2433.0

$x \sim U[0,500]$, $p = 15$, $c_k = 5$, $c_s = 3$, $v_m = v_s = 1$, $w = 10$, $\eta = 0.8$

In summary, we considered those contracts mentioned above in the supply chain consisted of a risk averse supplier and a risk neutral manufacturer, with the assumption that the customer information is symmetrical. Considering that the realization of supply chain coordination and Pareto improvement is regarded as a prerequisite for the feasibility of contract, and the risk diversification contract has higher market acceptance.

7 Discussion and conclusion

Due to the worry that investment cost may not recover, generally the supplier has no willingness to ramp up her capacity investment level, which further causes the manufacturer to shrink his enterprise scale due to the limited capacity of his supplier. Therefore, the manufacturer hopes to stimulate the supplier to invest his capacity through designing an incentive mechanism. In order to deal with this capacity contradiction, this paper considers a supply chain consisted of a risk neutral manufacturer and a risk averse supplier, and investigates the capacity investment problem with an uncertain demand via CVaR criterion. Consequently, we obtain the following main results.

Firstly, we provide a risk diversification contract with two parameters λ and T, as loss sharing ratio λ is responsible for the supply chain coordination and side payment T can achieve the Pareto improvement, obtain Nash bargaining solution, and then realize the reasonable distribution of the profits. Secondly, we address a contract selection criteria: a feasible contract which can distribute the profits reasonably could be accepted by agents, while a contract is said to be feasible if it realizes supply chain coordination and Pareto improvement. Meanwhile, a contract has a reasonable profit allocation scheme if it obtains an arbitrary Nash bargaining solution.

Under symmetrical demand information, this paper points out that an option, capacity reservation and revenue sharing contract cannot effectively solve the capacity contradiction; however, an effective solution to this contradiction exists in the payback contract model and the risk diversification contract model, respectively. Compared with the risk diversification contract and the payback contract, it demonstrates that agents with the risk diversification contract can gain a higher performance than that with the payback contract due to the existence of side payment. Therefore, it indicates that the risk diversification contract is more advantageous than the others.

Note that there are only one supplier and one manufacturer exist in the supply chain we considered, so an interesting direction for further research is to represent the competition scenes (e.g., Guan and Chen, 2016; Ye et al, 2016; Chen et al, 2017). Furthermore, in actual trading, as the time goes on, the production cost may be changed (e.g., Jian et al., 2015), however, our study establishes on the assumption that the cost of production is fixed. Therefore, another direction is to explore the impact of time on optimal capacity investment decisions.

Acknowledgements

This research was supported in part by the National Natural Science Foundation of China (Grant No. 71273124). The authors would like to thank the Editor and the anonymous referees for their helpful comments and suggestions, which significantly improved the paper. The authors also benefit from discussion with Professor Jiuh-Biing Sheu at National Taiwan University and Professor Bintong Chen at University of Delaware. In addition, we thank Professor Stan Uryasev at University of Florida for providing us the real application cases of CVaR in the financial industry and Professor Shuaian Wang at Hong Kong Polytechnic University for providing valuable comments.

Appendix A. Proof of Lemma 1.

The supplier's CVaR utility function with wholesale price contract can state as

$$CVaR_\eta \pi_D^s = \sigma - \frac{1}{\eta}\int_0^K (\sigma + (v_s + c_k)K + \mu g - (w - c_s + v_s + g)x)^+ dF(x) - \frac{1}{\eta}\int_K^{+\infty} (\sigma - (w - c_s - c_k + g)K + \mu g)^+ dF(x).$$

Let $\sigma_1 = -(v_s + c_k)K - \mu g$, $\sigma_2 = (w - c_s - c_k + g)K - \mu g$. We divide the domain of σ into three intervals to discuss,

$$\frac{\partial CVaR_\eta \pi_D^s}{\partial \sigma}=\begin{cases}1, & \sigma \le \sigma_1,\\ 1-\frac{1}{\eta}F[\frac{\sigma+(v_s+c_k)K+\mu g}{w-c_s+v_s+g}], & \sigma_1<\sigma<\sigma_2,\\ 1-\frac{1}{\eta}, & \sigma>\sigma_2.\end{cases}$$

It is obvious that $CVaR_\eta \pi_D^s$ is left-continuous in σ at the point σ_2. And for any $\delta > 0$,

$$|CVaR_\eta \pi_D^s(\sigma+\delta)-CVaR_\eta \pi_D^s(\sigma)|_{\sigma=\sigma_2}=\frac{\delta(1-\eta)}{\eta}\le\frac{\delta}{\eta}.$$

Hence $CVaR_\eta \pi_D^s$ is right-continuous in σ at the point σ_2, and thereby $CVaR_\eta \pi_D^s$ is continuously differentiable in σ at the point σ_2.

Noting that $\frac{\partial CVaR_\eta \pi_D^s}{\partial \sigma}<0$ for $\sigma>\sigma_2$. If $\frac{\partial CVaR_\eta \pi_D^s}{\partial \sigma}>0$ for $\sigma<\sigma_2$, then there exists a point $\sigma^*=\sigma_2$ such that $\frac{\partial CVaR_\eta \pi_D^s}{\partial \sigma}\Big|_{\sigma=\sigma_2}=0$. And noting that $\frac{\partial CVaR_\eta \pi_D^s}{\partial \sigma}=1>0$ for $\sigma\le\sigma_1$. Now we need to demonstrate that $\frac{\partial CVaR_\eta \pi_D^s}{\partial \sigma}>0$ for $\sigma_1\le\sigma<\sigma_2$.

Suppose $\frac{\partial CVaR_\eta \pi_D^s}{\partial \sigma}\Big|_{\sigma=[\sigma_2]^-}=1-\frac{1}{\eta}F(K)\le 0$, thus $K\ge F^{-1}(\eta)$, and there exists $\sigma^*(K)$ subject to $1-\frac{1}{\eta}F[\frac{\sigma+(v_s+c_k)K+\mu g}{w-c_s+v_s+g}]=0.$

This suggests

$$\sigma_0^*=(w-c_s+v_s+g)F^{-1}(\eta)-(v_s+c_k)K-\mu g,$$

$$CVaR_\eta \pi_D^s(\sigma_0^*(K))=(w-c_s+v_s+g)[F^{-1}(\eta)]-(v_s+c_k)K-\mu g-\frac{w-c_s+v_s+g}{\eta}\int_0^{F^{-1}(\eta)}[F^{-1}(\eta)-x]dF(x).$$

Obviously, $\frac{\partial CVaR_\eta \pi_D^s(\sigma_0^*(K))}{\partial K}=-(v_s+c_k)<0$. Consequently, can we maximize the $CVaR_\eta \pi_D^s(\sigma_0^*(K))$ at the point $K^*=F^{-1}(\eta)$. However, this is contradictory to $K>F^{-1}(\eta)$ for $\sigma_1\le\sigma<\sigma_2$. Therefore, $\frac{\partial CVaR_\eta \pi_D^s}{\partial \sigma}>0$ for $\sigma_1\le\sigma<\sigma_2$.

Accordingly, we know the optimal value of σ in the definition of CVaR satisfies,

$$\sigma_D^*=\sigma_2=(w-c_s-c_k+g)K-\mu g.$$

Appendix B. **Proof of the feasible region of the risk diversification contract.**

As a contract feasible if it can coordinate the supply chain and has a Pareto improvement.

We first consider the risk diversification contract can coordinate the supply chain, i.e., $K_I^*=K_a^*$. Then, we combine equation (2), equation (8) and the continuity property of $F(x)$, it obtains that equation (9).

We second consider the risk diversification contract has a Pareto improvement.

We substitute $K=K_D^*$ and $w=w_D$ into equation (3) and equation (4), respectively. Then, the equation (3) can be written as $\pi_D^m(w_D,K_D^*)=(p-w_D)S(K_D^*)-v_m(x-K_D^*)^+$. The equation (4) can be changed as

$$H_D^s(w_D,K_D^*)=(w_D-c_s-c_k+g)K_D^*-\mu g-\frac{w_D-c_s+v_s+g}{\eta}\int_0^{K_D^*}F(x)dx.$$

We substitute $K = K_I^*$, $w = w_a$ and $\lambda = \lambda^*$ into equation (6) and equation (7), respectively. Then, the equation (6) can be modified as $\pi_a^m(w_a, K_I^*, \lambda^*) = \pi_D^m(w_a, K_I^*) - (1-\lambda^*)L(K_I^*) + T$. The equation (7) can be overtyped as $H_a^s(w_a, K_I^*, \lambda^*) = H_D^s(w_a, K_I^*) + (1-\lambda)L(w_a, K_I^*) + \dfrac{(1-\eta)(1-\lambda^*)(w_a - c_s + v_s + g)}{\eta}\int_0^{K_I^*} F(x)dx - T$.

Thus, we solve the inequation $H_a^s(w_a, K_I^*, \lambda^*) \geq H_D^s(w_D, K_D^*)$, it holds that

$$T \leq H_D^s(w_a, K_I^*) - H_D^s(w_D, K_D^*) + (1-\lambda^*)L(w_a, K_I^*) + \frac{(1-\eta)(1-\lambda^*)(w_a - c_s + v_s + g)}{\eta}\int_0^{K_I^*} F(x)dx = T_{\max}.$$

We solve the inequation $\pi_a^m(w_a, K_I^*, \lambda^*) \geq \pi_D^m(w_D, K_D^*)$, the following inequation holds

$$T \geq \pi_D^m(w_D, K_D^*) - \pi_D^m(w_a, K_I^*) + (1-\lambda^*)L(w_a, K_I^*) = T_{\min}.$$

Note that $T_{\max} - T_{\min} > 0$, hence, when $T \in [T_{\min}, T_{\max}]$, the risk diversification contract has a Pareto improvement.

Therefore, the risk diversification contract's feasible region can be regard as equation (9) and $T \in [T_{\min}, T_{\max}]$.

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