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# 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.



## 1. Introduction

Newsboy products, such as electronic products, automobiles and fashions 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 a plenty of solid evidence showing 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. For instance, Solectron, a major electronics supplier in the world, had

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$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 whichthe supplier is 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 usedin 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., 2016), supply chain planning (e.g., Soleimani and Govindan, 2014), and supply chain coordination (e.g., He and Zhao, 2012). 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, uses CVaR for the risk management.

However, the existing capacity investment literatures only consider the supplier is risk neutral, so an interesting question naturally arises: what will happen to the capacity investment decision when the supplier's risk aversion is considered?

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

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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.

[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.