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# Impact of supplier technology innovation on supply chain efficiency based on revenue-sharing contract

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**This study constructs a two-period supply chain model consisting of two suppliers and one retailer using a revenue-sharing contract. Considering random investment cost, the impact of supplier competition on innovation strategy is analyzed and the equilibrium strategy of suppliers' technology innovation game as well as the optimal revenue-sharing contract is derived. It is found that technology innovation degree influences supplier competition, technology innovation strategy and the form of the optimal revenue-sharing contract. Supplier innovation can improve retailer's profit, but it may reduce supplier's profit as well as the supply chain efficiency due to the uncertainty of investment cost and supplier competition.**

**Key words:** Technology innovation, revenue-sharing contract, supply chain efficiency, game analysis.

## INTRODUCTION

As corporation competition intensifies and market environment becomes more changeable, the importance of supply chain management keeps growing. Many companies try to optimize supply chain contract to avoid double marginal effect in the price-only contract (Lariviere and Porteus, 2001), so as to achieve supply chain coordination and improve supply chain efficiency. Revenue-sharing contract is one of the supply chain coordination contracts, which has a simple form and wide application in several industries, such as automobile manufacturing industry (Foros et al., 2009), E-commerce (Chen et al., 2010), film production (Palsule-Desai, 2012), video rental

(Cachon and Lariviere, 2005) etc.. When using revenue-sharing contract, the supplier sells the product to the retailer with a lower wholesale price, as the retailer compensates the supplier with a certain ratio of the sales revenue. However, most studies of revenue-sharing contract assume the supplier's production technology remains unchanged, ignoring the impact of supplier technology change on revenue-sharing contract efficiency. As the speed of products upgrade quickens and the lifecycle of production technology reduces, supplier technology innovation is very common in various industries (Bartel et al., 2005).

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In recent years, more and more enterprises increase their R&D investment to strengthen the cost advantage and their role in global supply chain (Nassimbeni and Sartor, 2007; Su et al., 2008). Supplier technology innovation strategy influences production cost and investment cost, which affects supply chain members' profits and the whole supply chain efficiency as well as the form of revenue-sharing contract (Bonaccorsi and Lipparini, 1994; Narayanan and Raman, 2004). What is the optimal form of a revenue-sharing contract considering supplier technology innovation? What is the impact of technology innovation on supply chain efficiency? These are the questions that have not been addressed in previous literature and are the focus of our paper.

In competing environment, the supplier needs to take into account the competitor's behavior in the process of decision making (Altug and Ryzin, 2013). In addition, new technology always has uncertain investment cost and uncertain lifecycle. However, competition and technology cost uncertainty, which has great impact on the revenue-sharing contract efficiency, is not considered in existing studies. In our study, we try to analyze competing suppliers' technology innovation behavior, and further explore the impact of supplier competition and technology change degree on revenue-sharing contract efficiency considering technology cost and technology lifecycle uncertainty. Specifically, in this study we will focus on the following issues: Under a two supplier-one retailer supply chain structure, what is the optimal technology innovation strategy of two competing suppliers using revenue-sharing contract? What is the impact of technology change degree on the competition and profits of the suppliers? What is the optimal revenue-sharing contract? How does supplier technology innovation affect supply chain efficiency?

## Literature Review

Under the price-only contract, supply chain is a decentralized system, where retailer makes the order decision with the target of optimizing his own profit rather than the whole supply chain. Thus, the order quantity under a decentralized supply chain is smaller than that under a centralized one, making the supply chain uncoordinated (Lariviere and Porteus, 2001). Perakis and Roels (2007) provide a quantitative analysis of the supply chain efficiency gap between price-only contract and coordinated contract under different supply chain structures. Revenue-sharing is a coordinated supply chain contract with simple form and is equivalent to many other coordinated supply chain contract. A detailed analysis can be found in Cachon and Lariviere (2005)'s study. For a multi-supplier-one-retailer supply chain structure, revenue-sharing can also achieve supply chain coordination, and increase supply chain each member's profit to obtain a Pareto optimal (Gerchak and Wang,

2004). In a one-supplier-two-retailer supply chain, Kong et al. (2013) explore the potential of revenue-sharing contracts to facilitate information sharing in a supply chain and mitigate the negative effects of information leakage. They find out that the incentives of the supplier and retailers are better aligned under a revenue-sharing contract, as opposed to under a wholesale-price contract. The above research assumes that supplier has a steady technology level, and gets a result that the revenue-sharing parameter (the ratio of retailer's revenue to the whole product sales revenue) has no impact on the supply chain efficiency. However, how to choose an appropriate revenue-sharing parameter is of great importance for enterprises in real life (Yao et al., 2008). Palsule-Desai (2012) has found that the revenue-sharing parameter influences supply chain efficiency, and the optimal revenue-sharing parameter is a function of retailer's whole sales revenue.

Technology innovation can be classified into discrete type and continuous one according to the characteristics of technology innovation process (Xu and Li, 2007). As technology change is always uncertain, thus continuous technology innovation is often characterized by a Markov process (Gjerde et al., 2002; Liu and Özer, 2009), while a discrete technology innovation is depicted by a binomial distribution (Li et al., 2003). When new technology appears in the industry, the supplier makes a decision about whether to adopt the new technology or how many products to produce using the new technology. As specialization division develops, the trend of adopting new technology from an external party becomes more significant, especially in high-tech industries such as telecommunication (Ransbotham and Mitra, 2010; Schmidt and Porteus, 2000). The adoption of new technology is often reflected by the decrease of supplier production cost. With an assumption that new production technology cuts down production cost, Schmidt and Porteus (2000) discuss how to achieve the target of becoming a technology leader in a competitive environment with the lowest cost. Kim (2000) studies the problem of optimizing an incentive mechanism of technology adoption, where the results show that supplier technology innovation can reduce manufacturer's raw material purchasing cost in a supply chain coordinated technology innovation mechanism. Wagner and Bode (2014) focus on the factors that contribute to suppliers' technology innovation through empirical study, and find that contract length and the relationship between the supplier and the retailer may affect supplier's technology innovation strategy.

In real life, suppliers often compete with each other to obtain orders from the retailer, thus to choose an appropriate supplier is an important decision for the retailer (Xia et al., 2008). Ho et al. (2010) provide a review about the research on supplier selection, which has found that supplier production cost and wholesale price are critical factors in the process of supplier selection. Suppliers are often characterized by operation performance terms of

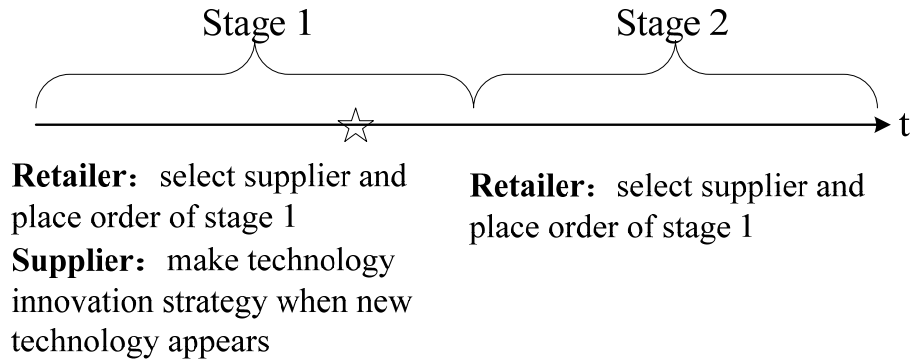


Figure 1. Sequence of event.

cost, delivery time, service level, or quality (Qian, 2014). In competitive circumstances, innovation is the key to the survival of enterprises and in recent ten years, to recognize a supplier with high innovation ability is an important task for the retailers (Schiele, 2006). In addition, supplier’s investment on technology innovation and his innovation capability are also key factors in the retailer’s supplier selection process (Petroni and Panciroli, 2002).

Although supplier technology innovation has a big impact on supply chain coordination and supply chain efficiency; so far scholars have used the assumption that supplier has unchanged production technology in their study on revenue-sharing contract. The studies on supplier technology innovation are mainly focusing on the coordination and optimization of supplier technology innovation mechanism, with few researches discussing the impact of competing suppliers’ technology innovation on revenue-sharing contract. Different from the above studies, we would like to investigate the issue about how will the two factors, which are supplier competition and supplier technology innovation degree, affect the suppliers’ equilibrium technology innovation strategies and the supply chain revenue-sharing contract efficiency.

**Model and analysis**

**Model description**

Considering a two-stage supply chain model with two suppliers (supplier  $N$  and supplier  $S$ ), who have different initial production technology levels and one retailer. In each stage, the retailer places an order on one of the two suppliers. Assume in the first stage supplier  $N$  is the technology leader, who has lower unit production cost, that is  $c_N < c_S$ , where  $c_N$  and  $c_S$  are unit production cost of supplier  $N$  and supplier  $S$  in the first stage, respectively. The inverse market demand function is  $p = a - q$ , where  $p$  is the product sales price of the retailer,  $a > 0$  is the potential market demand and  $q$  is retailer’s product order

quantity. The sequence of event in the model is shown in Figure 1, where  $\star$  stands for supplier’s new production technology, with a certain probability.

At the beginning of the first stage, the retailer selects his supplier and makes the order quantity decision  $q_1$  for stage one. Retailer’s supplier selection decision is shown by equation (1).

$$y_1 = \begin{cases} 1, & \text{if retailer's first-stage supplier is } S; \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

In the first stage, supplier’s new production technology appears with probability  $\gamma$ , where  $\gamma \in [0,1]$ , and the corresponding technology investment is a random variable  $\kappa$ , with probability density function and cumulative distribution function being  $f(\cdot)$  and  $F(\cdot)$ , respectively.  $\kappa \in [0, H]$  and the maximum value of random investment cost is, with the realization of investment cost being  $K$ . According to the realized investment cost  $K$ , supplier  $i (i = N, S)$  makes technology innovation strategy shown as equation (2).

$$x_i = \begin{cases} 1, & \text{if supplier } i \text{ adopts new technology;} \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

If supplier adopts new production technology, the unit production cost reduces by  $\delta$ , where  $0 < \delta < c_N$ , and expends the corresponding investment cost  $K$ . According to supplier’s technology innovation strategy, at the beginning of the second stage, the retailer chooses the supplier for the second stage and makes the order decision  $q_2$ . Retailer’s supplier selection decision for the second stage is shown by equation (3).

$$y_2 = \begin{cases} 1, & \text{if retailer's second-stage supplier is } S; \\ 0, & \text{otherwise.} \end{cases} \quad (3)$$

**Supplier’s technology innovation strategy**

Cachon and Lariviere (2005)’s study shows that when using revenue-sharing contract, the condition of supply chain coordination is supplier  $i$ ’s wholesale price  $w_i$  and its unit production cost  $c_i$  satisfy equation (4) as follows,  $i = N, S$ ,

$$w_i = \phi c_i \tag{4}$$

where  $\phi \in [0,1]$  is revenue-sharing parameter (the ratio of retailer’s revenue to the product’s whole sales revenue). The supply chain profit allocation to the retailer and the supplier is also decided by  $\phi$ ; which means that the ratio of retailer’s profit to the supply chain profit is also decided by  $\phi$ .

In the first stage, as supplier  $N$  has lower unit production cost, thus according to equation (4), supplier  $N$ ’s wholesale price is lower than that of supplier  $S$ , that is  $w_N = \phi c_N < \phi c_S = w_S$ . Thus, in the first stage, the retailer chooses supplier  $N$ , that is  $y_1 = 0$ . The first stage profit of the retailer and supplier  $N$  is shown by equations (7) and (6) as follows,

$$\pi_r(q_1) = \phi R(q_1) - w_N q_1 = \phi [(a - q_1)q_1 - c_N q_1] \tag{5}$$

$$\pi_s^N(q_1) = (1 - \phi)R(q_1) + w_N q_1 - c_N q_1 = (1 - \phi)[(a - q_1)q_1 - c_N q_1] \tag{6}$$

where  $R(q_1) = p q_1 = (a - q_1)q_1$  is the whole sales revenue of the products. The first order derivative of  $\pi_r(q_1)$  to  $q_1$  is shown by equation (7).

$$\partial \pi_r(q_1) / \partial q_1 = \phi (a - 2q_1 - c_N) \tag{7}$$

As  $\pi_r(q_1)$  is a concave function, using the first order condition we get the retailer’s optimal order quantity of the first stage  $q_1 = (a - c_N) / 2$ . Correspondingly, we get the first stage profits of the retailer, supplier  $N$  and the whole supply chain, which are shown by equations (8) and (10).

$$\pi_r = \phi (a - c_N)^2 / 4 \tag{8}$$

$$\pi_s^N = (1 - \phi) (a - c_N)^2 / 4 \tag{9}$$

$$\pi_{sc} = (a - c_N)^2 / 4 \tag{10}$$

If new production technology does not appear at the end of the first stage, that is  $\gamma = 0$ , the retailer will surely continue to choose supplier  $N$  in the second stage, that is  $y_2 = 0$ ; on the contrary, if new technology appears in the first stage, that is  $\gamma > 0$ , two suppliers will then make their technology innovation strategies, which are denoted by

$x_i$  ( $i = S, N$ ), and the retailer will make his second stage supplier selection decision  $y_2$ . The following proposition shows two suppliers’ equilibrium technology innovation strategies and retailer’s optimal supplier selection decision of the second stage.

**Proposition 1.** When  $\gamma > 0$ , the equilibrium technology innovation strategies of the two suppliers depend on two suppliers’ initial production technology gap  $c_S - c_N$ , technology innovation degree  $\delta$  and the realized investment cost  $K$ ,

(i) If  $\delta \geq c_S - c_N$ , the equilibrium technology innovation strategies of the two suppliers are shown by equation (11),

$$(x_S, x_N) = \begin{cases} (0,1), & \text{if } 0 \leq K \leq M_1; \\ \text{mixed strategy,} & \text{if } M_1 \leq K \leq M_2; \\ (0,0), & \text{otherwise.} \end{cases} \tag{11}$$

where the mixed strategy is shown by equation (12),

$$(x_S, x_N) = \begin{cases} (1,1), & \text{with probability } p_S p_N; \\ (1,0), & \text{with probability } p_S (1 - p_N); \\ (0,1), & \text{with probability } (1 - p_S) p_N; \\ (0,0), & \text{with probability } (1 - p_S)(1 - p_N). \end{cases} \tag{12}$$

Retailer’s corresponding second stage supplier selection decision is shown by equation **Error! Reference source not found.**,

$$y_2 = \begin{cases} 1, & \text{if } (x_S, x_N) = (1,0); \\ 0, & \text{otherwise.} \end{cases} \tag{13}$$

(ii) If  $0 < \delta < c_S - c_N$ , the equilibrium technology innovation strategies of the two suppliers are shown by equation (14),

$$(x_S, x_N) = \begin{cases} (0,1), & \text{if } 0 \leq K \leq M_1; \\ (0,0), & \text{otherwise.} \end{cases} \tag{14}$$

Retailer’s corresponding second stage supplier selection decision is shown by equation  $y_2 = 0$ , where

$$M_1 = \frac{(1 - \phi)}{4} [(a - c_N + \delta)^2 - (a - c_N)^2], M_2 = \frac{(1 - \phi)}{4} (a - c_S + \delta)^2,$$

$$p_N = \frac{(a - c_S + \delta)^2 - 4K / (1 - \phi)}{(a - c_S + \delta)^2},$$

$$p_S = \frac{(a - c_N)^2 - (a - c_N + \delta)^2 + 4K / (1 - \phi)}{(a - c_N)^2}.$$

**Proof.** Retailer’s supplier selection decision and the profits of supply chain members of the second stage under different supplier technology innovation strategy combination are shown in Table 1. Two suppliers’

**Table 1.** Retailer's supplier selection decision and supply chain members' profits of the second stage.

	$x_N = 1$	$x_N = 0$	
$x_S = 1$	$y_2 = 0$ $\pi_r = \phi(a - c_N + \delta)^2 / 4$ $\pi_s^S = -K$ $\pi_s^N = (1 - \phi)(a - c_N + \delta)^2 / 4 - K$	If $\delta \geq c_S - c_N$ , $y_2 = 1$	$\pi_r = \phi(a - c_S + \delta)^2 / 4$ $\pi_s^S = (1 - \phi)(a - c_S + \delta)^2 / 4 - K$ $\pi_s^N = 0$
		If $\delta < c_S - c_N$ , $y_2 = 0$	$\pi_r = \phi(a - c_N)^2 / 4$ $\pi_s^S = -K$ $\pi_s^N = (1 - \phi)(a - c_N)^2 / 4$
$x_S = 0$	$y_2 = 0$ $\pi_r = \phi(a - c_N + \delta)^2 / 4$ $\pi_s^S = 0$ $\pi_s^N = (1 - \phi)(a - c_N + \delta)^2 / 4 - K$	$y_2 = 0$ $\pi_r = \phi(a - c_N)^2 / 4$ $\pi_s^S = 0$ $\pi_s^N = (1 - \phi)(a - c_N)^2 / 4$	

equilibrium technology innovation strategies depend on initial production technology gap  $c_S - c_N$ , technology innovation degree  $\delta$  and the realized investment cost  $K$ , which are discussed as follows.

(1) If  $\delta \geq c_S - c_N$ , supplier's technology innovation strategy depends on investment cost  $K$ . As  $a \geq c_S + 2\delta \geq 3c_S - 2c_N \geq 2c_S - c_N$ ; it is easy to find that  $M_1 \leq M_2$ .

For  $0 \leq K < M_1$ , the equilibrium technology innovation strategy is  $(x_S, x_N) = (0, 1)$ ; for  $M_1 \leq K < M_2$ , the equilibrium technology innovation strategy is a mixed strategy. Assume supplier  $S$  adopts new technology ( $x_S = 1$ ) with probability  $p_S \in [0, 1]$ , while supplier  $N$  adopts new technology ( $x_N = 1$ ) with probability  $p_N \in [0, 1]$ . According to the definition of Nash equilibrium, supplier  $i$  gets the same profit under strategy  $x_i = 0$  or strategy  $x_i = 1$ , where  $i = S, N$ . Thus we can get two equations shown as (15) and (16).

$$-4Kp_N + [(1 - \phi)(a - c_S + \delta)^2 - 4K](1 - p_N) = 0 \tag{15}$$

$$(1 - \phi)(a - c_N + \delta)^2 - 4K = (1 - p_S)(1 - \phi)(a - c_N)^2 \tag{16}$$

Solving equation (15) and equation (16), the expression of  $p_S$  and  $p_N$  are as shown in proposition 1.

For  $K \geq M_2$ , the equilibrium technology innovation strategy is  $(x_S, x_N) = (0, 0)$ .

If  $\delta \geq c_S - c_N$ , technology change degree is relatively large. Retailer's supplier selection decision is made according to two supplier's technology innovation strategies. When the equilibrium technology innovation strategy is  $(x_S, x_N) = (1, 0)$ , retailer's supplier selection

decision of the second stage is  $y_2 = 1$ ; otherwise,  $y_2 = 0$ .

(2) If  $0 < \delta < c_S - c_N$ , supplier's technology innovation strategy also depends on investment cost  $K$ .

For  $0 \leq K < M_1$ , the two suppliers' equilibrium technology innovation strategy is  $(x_S, x_N) = (0, 1)$ .

For  $K \geq M_1$ , the two suppliers' equilibrium technology innovation strategy is  $(x_S, x_N) = (0, 0)$ .

If  $0 < \delta < c_S - c_N$ , technology change degree is relatively small, thus supplier  $S$  will not adopt new technology. No matter whether supplier  $N$  adopts new technology, the retailer gets higher profit from supplier  $N$ ; thus retailer's supplier selection decision of the second stage is  $y_2 = 0$ .

From proposition 1 we find that when technology innovation degree is small, even if supplier  $N$  does not adopt new technology and supplier  $S$  adopts new technology, supplier  $N$  can still keep the technology leading advantage. Thus, supplier  $N$  only needs to trade off between investment cost and revenue to decide whether to adopt new technology. However, when technology innovation degree is big, supplier  $N$  needs to consider supplier competition in the process of making technology innovation strategy. Particularly, when investment cost is in the range of  $M_1 \leq K < M_2$ , supplier  $S$  adopts new technology with probability  $p_S(1 - p_N)$  while supplier  $N$  does not adopt new technology, which makes supplier  $S$  the technology leader, and the retailer will choose supplier  $S$  for the second stage. Considering the competition threat of supplier  $S$ , supplier  $N$  will thus make an irrational technology innovation decision, that is adopting new technology to guarantee the sales opportunity for the second stage even if investment cost is bigger than the revenue brought by the new technology.

According to suppliers' equilibrium technology innovation strategies, with the consideration of random

investment cost and the probability of technology change, the two-stage profits of supply chain members and the supply chain two-stage efficiency are shown by proposition 2.

**Proposition 2.** Considering a revenue-sharing contract with supplier technology change. When  $\delta \geq c_S - c_N$ , the two-stage profits of the retailer, supplier  $N$  and supplier  $S$  are shown as equations (17) and (19), and the supply chain two-stage efficiency is shown by equation (20).

$$\begin{aligned} \Pi_r = & \frac{\phi(a-c_N)^2}{2} + \frac{\phi\gamma\delta(2a-2c_N+\delta)^2}{4(a-c_S+\delta)^2} F(M_1) - \frac{8\phi\gamma(2a-c_S-c_N+\delta)(c_N+\delta-c_S)}{[(1-\phi)(a-c_N)(a-c_S+\delta)]^2} \int_{M_1}^{M_2} F(x)xdx \\ & + \frac{\phi\gamma\delta(2a-2c_N+\delta)}{4} F(M_2) - \frac{\phi\gamma(c_S-c_N)(2a-c_S-c_N+2\delta)(a-c_S+\delta)^2}{4(a-c_N)^2} F(M_2) \\ & + \frac{\phi\gamma\delta(2a-2c_N+\delta)}{(1-\phi)(a-c_N)^2} \int_{M_1}^{M_2} F(x)dx \end{aligned} \quad (17)$$

$$\Pi_s^N = \frac{(1-\phi)}{2}(a-c_N)^2 + \gamma \int_0^{M_2} F(x)dx - \frac{(1-\phi)\gamma}{4} [(a-c_S)^2 - 2\delta(c_S-c_N)] F(M_2) \quad (18)$$

$$\Pi_s^S = 0 \quad (19)$$

$$\Pi_{sc} = \Pi_r + \Pi_s^N \quad (20)$$

When  $0 < \delta < c_S - c_N$ , the two-stage profits of the retailer, supplier  $N$  and supplier  $S$  are shown as equation (21) to equation (23), and the supply chain two-stage efficiency is shown by equation (24).

$$\Pi_r = \frac{\phi(a-c_N)^2}{2} + \frac{\phi\gamma\delta(2a-2c_N+\delta)}{4} F(M_1) \quad (21)$$

$$\Pi_s^N = (1-\phi)(a-c_N)^2 / 2 + \gamma \int_0^{M_1} F(x)dx \quad (22)$$

$$\Pi_s^S = 0 \quad (23)$$

$$\Pi_{sc} = \frac{(a-c_N)^2}{2} + \frac{\phi\gamma\delta(2a-2c_N+\delta)}{4} F(M_1) + \gamma \int_0^{M_1} F(x)dx \quad (24)$$

**Proof** According to proposition 1, when  $\delta \geq c_S - c_N$ , the two-stage profits of the retailer and two competing suppliers depend on investment cost, which are shown from equation (25) to equation (27).

$$\pi_r = \begin{cases} \frac{\phi}{4} [(2-\gamma)(a-c_N)^2 + \gamma(a-c_N+\delta)^2], & \text{if } 0 \leq K < M_1; \\ \frac{\phi}{4} [(2-\gamma)(a-c_N)^2 + \gamma p_N(a-c_N+\delta)^2] + \frac{\phi\gamma}{4} p_S(1-p_N)(a-c_S+\delta)^2 \\ + \frac{\phi\gamma}{4} (1-p_S)(1-p_N)(a-c_N)^2, & \text{if } M_1 \leq K < M_2; \\ \frac{\phi}{2} (a-c_N)^2, & \text{if } M_2 \leq K < H. \end{cases} \quad (25)$$

$$\pi_s^N = \begin{cases} \frac{(1-\phi)}{4} [(2-\gamma)(a-c_N)^2 + \gamma(a-c_N+\delta)^2] - \gamma K, & \text{if } 0 \leq K < M_2; \\ \frac{(1-\phi)}{2} (a-c_N)^2, & \text{if } M_2 \leq K < H. \end{cases} \quad (26)$$

$$\pi_s^S = \begin{cases} p_S(1-p_N)[(1-\phi)(a-c_S+\delta)^2 / 4 - K], & \text{if } M_1 \leq K < M_2; \\ 0, & \text{otherwise.} \end{cases} \quad (27)$$

Therefore, when  $\delta \geq c_S - c_N$ , the two-stage profits of the retailer and two suppliers under revenue-sharing contract are shown as equations (28) and (30).

$$\begin{aligned} \Pi_r = & \frac{\phi}{4} \int_0^{M_1} [(2-\gamma)(a-c_N)^2 + \gamma(a-c_N+\delta)^2] dF(x) + \frac{\phi}{2} \int_{M_2}^H (a-c_N)^2 dF(x) \\ & + \frac{\phi}{4} \int_{M_1}^{M_2} [(2-\gamma)(a-c_N)^2 + \gamma p_N(a-c_N+\delta)^2 + \gamma p_S(1-p_N)(a-c_S+\delta)^2] dF(x) \\ & + \frac{\phi}{4} \int_{M_1}^{M_2} \gamma(1-p_S)(1-p_N)(a-c_N)^2 dF(x) \\ \Pi_s^N = & \int_0^{M_2} \left\{ \frac{(1-\phi)}{4} [(2-\gamma)(a-c_N)^2 + \gamma(a-c_N+\delta)^2] - \gamma x \right\} dF(x) + \frac{(1-\phi)}{2} \int_{M_2}^H (a-c_N)^2 dF(x) \end{aligned} \quad (28)$$

$$\Pi_s^S = \int_{M_1}^{M_2} p_S(1-p_N) \left[ \frac{(1-\phi)}{4} (a-c_S+\delta)^2 - x \right] dF(x) \quad (30)$$

When  $0 < \delta < c_S - c_N$ , the two-stage profits of the retailer and two suppliers also depend on investment cost, which are shown in equations (31) and (33).

$$\pi_r = \begin{cases} \frac{\phi}{4} [(2-\gamma)(a-c_N)^2 + \gamma(a-c_N+\delta)^2], & \text{if } 0 \leq K < M_1; \\ \frac{\phi}{2} (a-c_N)^2, & \text{if } M_1 \leq K < H. \end{cases} \quad (31)$$

$$\pi_s^N = \begin{cases} \frac{(1-\phi)}{4} [(2-\gamma)(a-c_N)^2 + \gamma(a-c_N+\delta)^2] - \gamma K, & \text{if } 0 \leq K < M_1; \\ \frac{(1-\phi)}{2} (a-c_N)^2, & \text{if } M_1 \leq K < H. \end{cases} \quad (32)$$

$$\pi_s^S = 0 \quad (33)$$

Thus, when  $0 < \delta < c_S - c_N$ , the two-stage profits of the retailer and two suppliers under revenue-sharing contract are shown as equations (34) and (36).

$$\Pi_r = \frac{\phi}{4} \int_0^{M_1} [(2-\gamma)(a-c_N)^2 + \gamma(a-c_N+\delta)^2] dF(x) + \frac{\phi}{2} \int_{M_1}^H (a-c_N)^2 dF(x) \quad (34)$$

$$\Pi_s^N = \int_0^{M_1} \left\{ \frac{(1-\phi)}{4} [(2-\gamma)(a-c_N)^2 + \gamma(a-c_N+\delta)^2] - \gamma x \right\} dF(x) + \frac{(1-\phi)}{2} \int_{M_1}^H (a-c_N)^2 dF(x) \quad (35)$$

$$\Pi_s^S = 0 \quad (36)$$

From proposition 2 we find that, as supplier  $N$ 's potential competitor, under a certain condition, supplier  $S$  will replace supplier  $N$ , become the technology leader and obtain the second stage order opportunity. Therefore, a competitive environment will affect the technology leader's technology innovation strategy, and influence supply chain efficiency. For supplier  $N$ , in order to guarantee the sales opportunity of the second stage, when investment cost is bigger than revenue, he still will adopt new technology with a rather big probability. For example, when  $M_1 \leq K < M_2$ , new technology cost is bigger than revenue, considering the competition of supplier  $S$ , supplier  $N$  still adopts new technology with probability  $p_N$ . As for the retailer, supplier competition increases supplier  $N$ 's technology innovation probability,

which can improve retailer's expected profit. Therefore, the aim of retailer's supplier evaluation and selection process is to intensify supplier competition so as to improve his own profit. From the above analysis, we can also find that the competition between suppliers plays a positive part in the improvement of supply chain product technology.

As competing suppliers' technology innovation behavior has impact on revenue-sharing contract efficiency, we would like to find out the optimal contract form (the optimal revenue-sharing parameter) in this circumstance so as to improve the supply chain efficiency.

**Corollary 1.** There exists an optimal revenue-sharing parameter  $\phi^*$  which makes revenue-sharing contract achieve the highest efficiency in supplier technology change environment; and when technology change degree is small ( $0 < \delta < c_s - c_N$ ), revenue-sharing contract efficiency decreases in  $\phi$  with the optimal revenue-sharing parameter being  $\phi^* = 0$ .

**Proof.** According to proposition 2, when technology change degree is small, revenue-sharing contract efficiency is shown as equation (37).

$$\Pi_{sc} = \frac{(a - c_N)^2}{2} + \frac{\phi\gamma\delta(2a - 2c_N + \delta)}{4} F(M_1) + \gamma \int_0^{M_1} F(x) dx \quad (37)$$

Take the first order derivative of  $\Pi_{sc}$  to  $\phi$ , we get the result shown as equation (38).

$$\frac{\partial \Pi_{sc}}{\partial \phi} = -\frac{\phi\gamma\delta^2(2a - 2c_N + \delta)^2}{16} f(M_1) < 0 \quad (38)$$

Thus, when technology change is small, revenue-sharing contract efficiency is a decreasing function of  $\phi$  and thus the optimal revenue-sharing parameter is  $\phi^* = 0$ .

When technology change degree is big, revenue-sharing contract efficiency is shown as equation (39).

$$\begin{aligned} \Pi_{sc} = & \frac{(a - c_N)^2}{2} + \frac{\phi\gamma\delta^2(2a - 2c_N + \delta)^2}{4(a - c_s + \delta)^2} F(M_1) + \frac{\gamma\delta[2\phi a - 2c_N + \phi\delta + (2 - 2\phi)c_s] - (1 - \phi)\gamma(a - c_s)^2}{4} F(M_2) \\ & - \frac{\phi\gamma(c_s - c_N)(2a + 2\delta - c_s - c_N)(a - c_s + \delta)^2}{4(a - c_N)^2} F(M_2) - \frac{8\phi\gamma(2a - c_s - c_N + \delta)(c_N + \delta - c_s)}{(1 - \phi)^2(a - c_N)^2(a - c_s + \delta)^2} \int_{M_1}^{M_2} F(x) dx \\ & + \frac{\phi\gamma\delta(2a - 2c_N + \delta)}{(1 - \phi)(a - c_N)^2} \int_{M_1}^{M_2} F(x) dx + \gamma \int_0^{M_2} F(x) dx \end{aligned} \quad (39)$$

Therefore, the revenue-sharing contract efficiency  $\Pi_{sc}$  is a function of revenue-sharing parameter  $\phi$ , and thus exists the optimal revenue-sharing parameter  $\phi^*$ , which can be found from the first order condition of equation (39).

From corollary 3 we find that when technology change degree is small, supplier  $N$  makes a cautious and rational technology innovation decision without considering the competition of supplier  $S$ . Theoretically, to

achieve the highest contract efficiency, the best revenue-sharing parameter is  $\phi^* = 0$ , with the aim of encouraging supplier  $N$  to adopt new technology. That explains the improvement of supplier production technology plays a critical role to the increase of supply chain efficiency. When technology change degree is big, however, revenue-sharing parameter has impact on supplier's technology innovation strategy, thus influences supply chain efficiency. In the following section, we will provide a detailed numerical analysis about the optimal revenue-sharing parameter and its impact on supply chain efficiency when the technology change degree is big.

### Numerical analysis

From the analysis of section 3, we find that supplier's technology innovation behavior influences revenue-sharing contract efficiency. In this section, we would like to investigate the impact of new technology appearance probability, revenue-sharing parameter and potential market demand on supplier's technology innovation behavior and supply chain efficiency. As technology investment cost is uncertain, we will do the numerical analysis when  $\kappa$  follows a uniform distribution, that is  $\kappa \sim U[0, H]$  and an exponential distribution, that is  $\kappa \sim e(\lambda)$ , respectively. In addition, as technology change degree influences supplier's technology innovation strategies, thus we will analyze the problem when technology change degree is small, that is  $0 < \delta < c_s - c_N$  as well as technology change is big, that is  $\delta \geq c_s - c_N$ . As the analysis in section 3 shows that supplier  $S$ 's expected profit is 0, thus in this section we concentrate on the profits of supplier  $N$  and the retailer. For brief expression, the supplier in this section stands for supplier  $N$ .

### Impact of supplier technology innovation on supply chain members and revenue-sharing contract efficiency

The parameters in the numerical analysis are as follows,  $c_s = 15$ ,  $c_N = 12$ ,  $\delta = 8$  (big technology innovation),  $\delta = 2$  (small technology innovation),  $\lambda = 0.005$ ,  $H = 1000$  (From several groups of numerical studies we find that when parameters change we can still get the results).

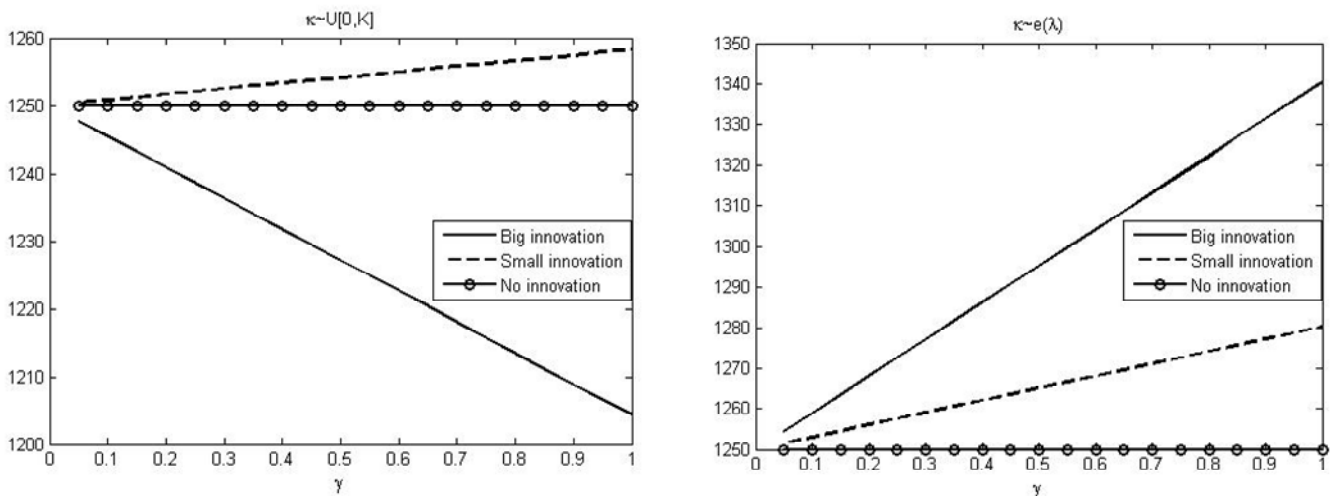
Tables 2 and 3 show the profits of supplier and retailer as well as the supply chain efficiency, using revenue-sharing contract when revenue-sharing parameter is big ( $\phi = 0.8$ ) and small ( $\phi = 0.2$ , respectively). We can find that supplier technology innovation is always beneficiary to the retailer, while it may decrease supplier's profit and the whole supply chain efficiency

**Table 2.** Impact of supplier technology innovation on revenue-sharing contract when  $\lambda=0.8$ .

	$\kappa \in U[0, H]$		$\kappa \in e(\lambda)$		No technology innovation
	Big technology innovation	Small technology innovation	Big technology innovation	Small technology innovation	
Supplier's profit	227	231	227	223	230
Retailer's profit	936	922	1126	923	921
Supply chain efficiency	1163	1153	1353	1146	1151

**Table 3.** Impact of supplier technology innovation on revenue-sharing contract when  $\lambda=0.2$ .

	$\kappa \in U[0, H]$		$\kappa \in e(\lambda)$		No technology innovation
	Big technology innovation	Small technology innovation	Big technology innovation	Small technology innovation	
Supplier's profit	864	923	927	923	922
Retailer's profit	245	231	297	232	230
Supply chain efficiency	1109	1154	1224	1155	1152



**Figure 2.** Impact of new technology appearance probability on supply chain efficiency.

(We obtain the same conclusion by altering the parameters several times). This is because if supplier adopts new technology, the production cost decreases. When using revenue-sharing contract, the wholesale price then also reduces and the retailer can increase market demand by cutting down the sales price of the product, thus increasing the expected profit the retailer. However, due to the supplier's irrational technology investment strategy caused by supplier competition, in some circumstances, the investment cost exceeds revenue, resulting in a lower supply chain efficiency and less supplier's expected profit.

**Impact of parameters on revenue-sharing contract efficiency**

**Impact of new technology appearance probability**

Impact of new technology appearance probability on revenue-sharing contract efficiency is shown in Figure 2. As it can be seen, when technology innovation is small, competition does not exist between suppliers; therefore, technology innovation will improve supply chain efficiency, which is a function of new technology appearance probability. When technology innovation is big, impact of



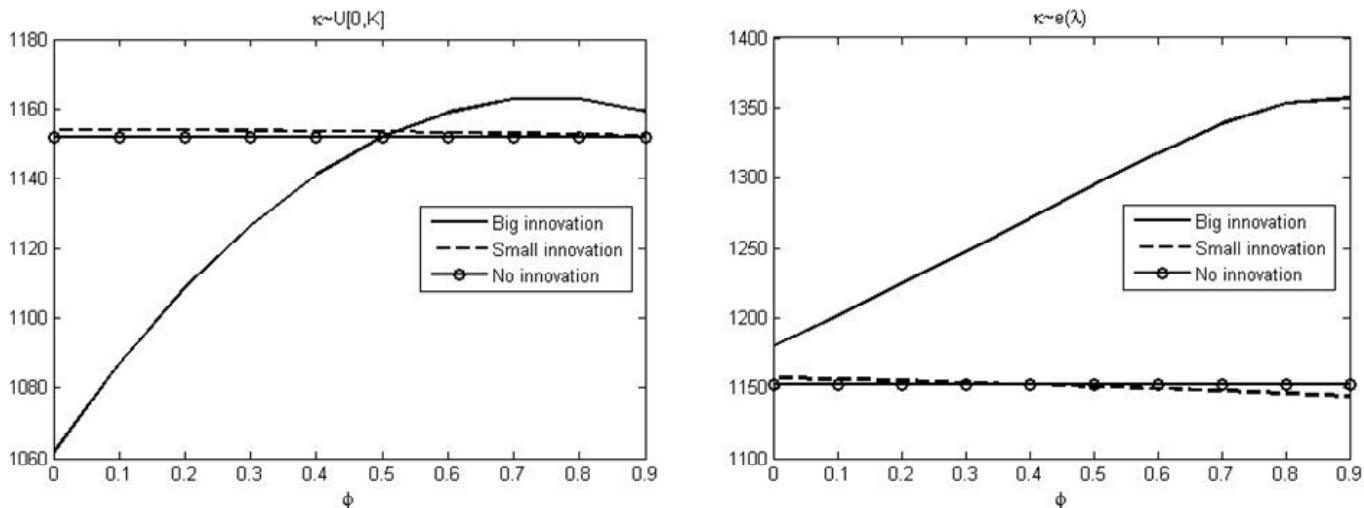


Figure 3. Impact of revenue-sharing parameter on supply chain efficiency.

new technology appearance probability on revenue-sharing contract efficiency is influenced by investment cost probability distribution. When investment cost follows an exponential distribution, supply chain efficiency is an increasing function of new technology appearance probability; while when investment cost follows a uniform distribution, supplier technology innovation decreases supply chain efficiency and supply chain efficiency is a decrease function of new technology appearance probability.

Therefore, a small degree of technology innovation is not influenced by investment cost and can improve supply chain efficiency; on the contrary, when technology innovation degree is big, supplier competition exists and impact of supplier  $N$ 's irrational technology innovation decision on supply chain efficiency is affected by investment cost. When investment cost follows exponential distribution, new technology brings revenue that exceeds the investment cost, thus technology innovation can improve supply chain efficiency; while when investment cost follows uniform distribution, investment cost exceeds the revenue brought by the new technology, resulting in a lower supply chain efficiency.

**Impact of revenue-sharing parameter**

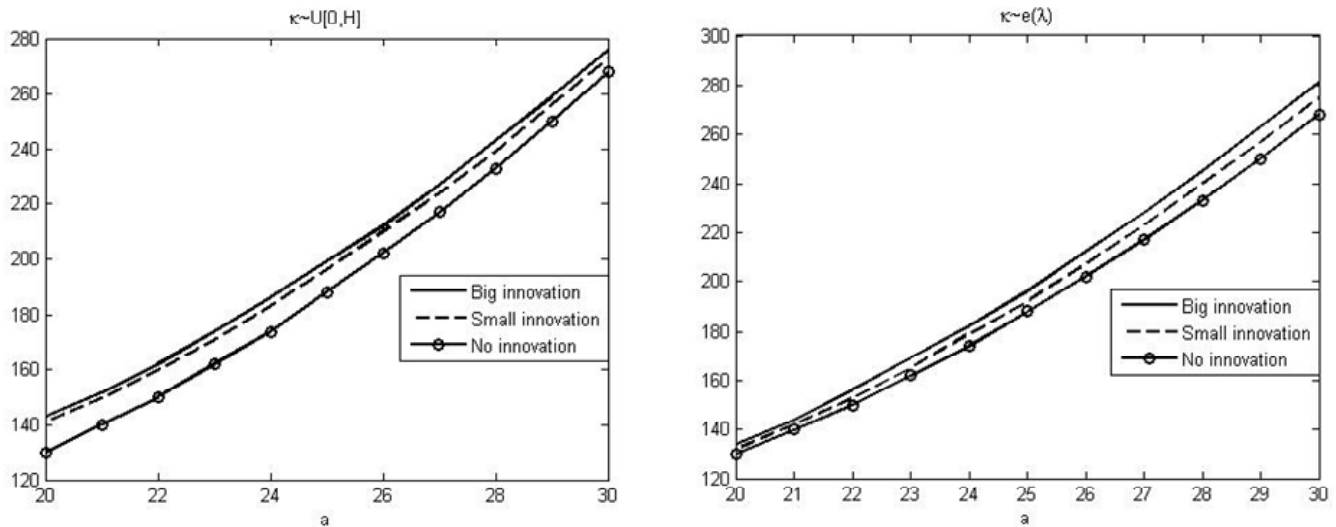
Impact of revenue-sharing parameter on revenue-sharing contract efficiency is shown in Figure 3. It can be found in the figure that revenue-sharing parameter has similar impact on supply chain efficiency under different investment cost distribution function. When technology innovation degree is relatively big, supply chain efficiency is a concave function of revenue-sharing parameter; while when technology innovation degree is small, supply chain

efficiency decreases in revenue-sharing parameter. A small technology change eliminates the competition between suppliers, and from corollary 1, we find that supply chain efficiency is a decreasing function of revenue-sharing parameter. This is because when supplier competition does not exist, supplier makes a careful technology innovation strategy; thus when supplier has higher revenue, he will be more active to adopt new technology, resulting in higher supply chain efficiency.

When technology innovation degree is relatively big, competition exists between suppliers. By numerical analysis, we find that the optimal revenue-sharing parameter is in the range of  $\phi^* \in (0,1)$ . In competing environment, in order to avoid supplier  $N$ 's irrational investment and the corresponding cost, the revenue-sharing parameter should not be set too high; meanwhile, the revenue-sharing parameter should not be too low, so as to inspire the supplier to adopt new technology. Therefore, the optimal revenue-sharing parameter  $\phi^*$  is decided by trading-off between the investment cost caused by irrational investment and the opportunity cost caused by giving up adopting new technology.

**Impact of potential market demand**

Impact of potential market demand on revenue-sharing contract efficiency is shown in Figure 4. As it is shown by the figure, when investment cost follows different distribution functions, the revenue-sharing contract efficiency always improves as the potential market demand increases. In addition, supplier technology innovation can improve supply chain efficiency, which also increases as technology innovation degree increases.



**Figure 4.** Impact of potential market demand on supply chain efficiency.

Besides, impact of supplier technology innovation on supply chain efficiency becomes more significant as the potential market becomes larger. This shows that for different sizes of market demand, supplier technology innovation can always improve supply chain efficiency, which also increases in technology innovation degree.

## Conclusion

This study analyzes the impact of competing supplier technology innovation on the revenue-sharing contract efficiency. A two supplier-one retailer two-stage supply chain model is constructed with different initial technology levels of the two suppliers. The equilibrium technology innovation strategies of two suppliers and the optimal revenue-sharing contract are analyzed. In addition, we discuss impact of new technology appearance probability, revenue-sharing parameter and potential market demand on supply chain efficiency. The results show that when technology innovation degree is big, suppliers need to trade-off between investment cost and revenue and make decision with the consideration of competition between the suppliers, which may decrease supply chain efficiency. However, when technology innovation degree is relatively small, there is no need to consider supplier competition, and technology innovation is always beneficial to supply chain efficiency. Different with the existing research, this study shows that the revenue-sharing parameter affects the supply chain efficiency of revenue-sharing contract when considering supplier technology innovation and the optimal revenue-sharing parameter is influenced by the degree of technology change. Therefore, it is necessary to make an appropriate revenue allocation scheme considering different degree of technology innovation, so as to improve supply

chain efficiency. It should be pointed out that we do not consider the downstream supply chain competition; thus the future studies should be on a supply chain consisting of multiple retailers and the impact of supplier technology innovation on revenue-sharing contract efficiency. In addition, the impact of technology innovation on other forms of supply chain contract, such as sales-rebate contract, buy-back contract, etc. is also a research direction worth studying.

## Conflict of Interests

The author(s) have not declared any conflict of interests.

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## REFERENCES

- Altug MS, Ryzin G (2013). Product quality selection: Contractual agreements and supplier competition in an assemble-to-order environment. *Int. J. Prod. Economics* 141(2):626-638.
- Bartel A, Lach S, Sichernan N (2005). Outsourcing and technological change. National Bureau of Economic Research, <http://www.nber.org/papers/w11158>.
- Bonaccorsi A, Lipparini A (1994). Strategic partnerships in new product development: an Italian case study. *J. Prod. Innov. Manage.* 11(2):134-145.
- Cachon GP, Lariviere MA (2005). Supply chain coordination with revenue-sharing contracts: Strengths and limitations. *Manage. Sci.* 51(1):30-44.
- Chen J, Cheng H, Lin I (2010). On channel coordination under price-

- dependent revenue-sharing: can eBay's fee structure coordinate the channel & quest. *J. Oper. Res. Soc.* 62(11):1992-2001.
- Foros Ø, Hagen KP, Kind HJ (2009). Price-dependent profit sharing as a channel coordination device. *Manage. Sci.* 55(8):1280-1291.
- Gerchak Y, Wang Y (2004). Revenue-Sharing vs. Wholesale-Price Contracts in Assembly Systems with Random Demand. *Prod. Oper. Manage.* 13(1):23-33.
- Gjerde KAP, Slotnick SA, Sobel MJ (2002). New product innovation with multiple features and technology constraints. *Manage. Sci.* 48(10):1268-1284.
- Ho W, Xu X, Dey PK (2010). Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *Eur. J. Oper. Res.* 202(1):16-24.
- Kim B (2000). Coordinating an innovation in supply chain management. *Eur. J. Oper. Res.* 123(3):568-584.
- Kong G, Rajagopalan S, Zhang H (2013). Revenue sharing and information leakage in a supply chain. *Manage. Sci.* 59(3):556-572.
- Lariviere MA, Porteus EL (2001). Selling to the newsvendor: An analysis of price-only contracts. *Manuf. Service Oper. Manage.* 3(4):293-305.
- Li S, Loulou R, Rahman A (2003). Technological progress and technology acquisition: Strategic decision under uncertainty. *Prod. Oper. Manage.* 12(1):102-119.
- Liu H, Özer Ö (2009). Managing a product family under stochastic technological changes. *Int. J. Prod. Econ.* 122(2):567-580.
- Narayanan V, Raman A (2004). Aligning incentives in supply chains. *Harvard Bus. Rev.* 82(11):94-102.
- Nassimbeni G, Sartor M (2007). Sourcing in China: a typology. *Int. J. Prod. Econ.* 107(2):333-349.
- Palsule-Desai OD (2012). Supply chain coordination using revenue-dependent revenue sharing contracts. *Omega* 41(4):780-796.
- Perakis G, Roels G (2007). The price of anarchy in supply chains: Quantifying the efficiency of price-only contracts. *Manage. Sci.* 53(8):1249-1268.
- Petroni A, Panciroli B (2002). Innovation as a determinant of suppliers' roles and performances: an empirical study in the food machinery industry. *Eur. J. Purchasing Supply Manage.* 8(3):135-149.
- Qian L (2014). Market-based supplier selection with price, delivery time, and service level dependent demand. *Int. J. Prod. Econ.* 147:697-706.
- Ransbotham S, Mitra S (2010). Target age and the acquisition of innovation in high-technology industries. *Manage. Sci.* 56(11):2076-2093.
- Schiele H (2006). How to distinguish innovative suppliers? Identifying innovative suppliers as new task for purchasing. *Ind. Market. Manage.* 35(8):925-935.
- Schmidt GM, Porteus EL (2000). Sustaining technology leadership can require both cost competence and innovative competence. *Manuf. Service Oper. Manage.* 2(1):1-18.
- Su Q, Shi JH, Lai SJ (2008). Study on supply chain management of Chinese firms from the institutional view. *Int. J. Prod. Econ.* 115(2):362-373.
- Wagner SM, Bode C (2014). Supplier relationship-specific investments and the role of safeguards for supplier innovation sharing. *J. Oper. Manage.* 32(3):65-78.
- Xia Y, Chen B, Kouvelis P (2008). Market-based supply chain coordination by matching suppliers' cost structures with buyers' order profiles. *Manage. Sci.* 54(11):1861-1875.
- Xu SH, Li Z (2007). Managing a single-product assemble-to-order system with technology innovations. *Manage. Sci.* 53(9):1467-1485.
- Yao Z, Leung SC, Lai K (2008). The effectiveness of revenue-sharing contract to coordinate the price-setting newsvendor products' supply chain. *Supply Chain Management: Int. J.* 13(4):263-271.