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Supply Chain Quality Management by Contract Design

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1. Introduction

Along with the competition intensity globally, quality management activities should go across the firms' boundaries and be pursued in supply chain environment (Flynn and Flynn 2005; Kaynak and Hartley 2008; Schweinberg 2009; Yeung 2008). Supply chain quality management (SCQM) is the interdisciplinary field between Quality Management (QM) and Supply Chain Management (SCM). SCQM is different from the traditional QM methods such as Statistical Quality Control (SQC), Total Quality Management (TQM) and Quality Management Systems (QMSs), which focus on the implementation of QM in single firm environment. Since one of the QM activities' characteristics in supply chain situation is that each member makes its QM decisions independently, SCQM is the formal coordination and integration of business processes involving all partner organizations in order to create value and achieve satisfaction of intermediate and final customers (Foster 2008; Kaynak and Hartley 2008; Robinson and Malhotra 2005). SCQM emphasizes the coordination of all members' QM activities which are driven by all members' self-interests. In short, SCQM is the effective integration of firms' internal QM activities.

There are many coordination mechanisms to carry out SCQM such as supply chain contracts, information technology, information sharing, and joint decision-making (Corbett et al. 2004; Lee et al. 1997; Robinson and Malhotra 2005). In this chapter we focus on the method of contract design since the implementation of supply chain contracts have the advantages of small cost and convenient operations. It is known that the process of contract design should pay significant attention to all members' self-interest QM activities and the various supply chain environments. Fortunately, game theory is the natural tool to investigate contract design in various situations of SCQM.

We study contract design for SCQM about behavior observability and external failure sharing in a supplier-manufacturer supply chain. In manufacturing supply chains, members' behavior observability and influencing factors to cost sharing of external failure are two main aspects to influence SCQM implementation (Arshinder et al. 2008; Malchi 2003; Reyniers and Tapiero 1995a, b; Sower 2004). The influencing factors to external failure sharing include the verifiability of external failure, the separability of final product architecture, and the member's relationship (Baiman et al. 2000, 2001; Balachandran and Radhakrishnan 2005; Bhattacharyya and Lafontaine 1995; Sila et al. 2006). If some behavior of one member is unobservable to other parties, the member will use this condition as a strategic weapon to improve its own profit. The result of this case may damage other parties as well as the whole supply chain's profit. On the other hand, external failure sharing has directly impact on supply chain's risk sharing. The occurrence of external failure will cause lots of extra cost to the buyers. This kind of cost should be shared by all the members involved in a supply chain. Otherwise, the supply chain is not coordinated and the competitive advantage is ruined.

In this chapter, we employ contract design to pursue SCQM implementation in a manufacturing supply chain. A supplier sells intermediate products to a manufacturer, and the manufacturer inspects the products and processes the "qualified" to be final product. The supplier's production behavior is unobservable to the manufacturer. The analysis is in the view of the manufacturer (the buyer of the supply chain). An external failure sharing mechanism is employed to presents the three influencing factors to external failure sharing which are interactive. Then the circumstance of the supply chain is determined by the observabilities of the manufacturer's inspection and processing, the verifiability of external failure sharing, the separability of final product architecture, and the relationship of two parties. The contracts are designed to guarantee SCQM in different circumstances. The objective of SCQM is to achieve supply chain coordination in this chapter.

The analysis is taken into two steps. In the first step, the first-best achievement is examined in four circumstances characterized only by the observabilities of the manufacturer's inspection and processing. In the second step, contracts for supply chain coordination are designed in circumstances characterized by all of the observability of the manufacturer's inspection and processing and the three influencing factors of external failure sharing. Thirty-two circumstances are divided into two groups based on the two parties' relationship whether the two parties are friends. In this case, the interactions of the three factors of external failure sharing can be illustrated as a tree structure.

Here are the main findings. In the first step, necessary and sufficient conditions in which the first-best solution can be attained are derived in each of the four circumstances. Moreover, it is shown that the observability of the manufacturer's inspection and processing can be investigated separately in the examination of first-best achievement. The unobservable of the manufacturer's inspection is corresponding with the conditions (1) the supplier is not responsible for the external failure caused by the manufacturer's defect, and (2) the supplier's product price and the proportion of customer dissatisfaction that the supplier is responsible for satisfy $\pi / \alpha = ds / (1-s)$ (d is customer satisfaction cost and s is the proportion in which the supplier is responsible for the external failure caused by its own defect). The unobservable of the manufacturer's processing is corresponding with the condition that the final product architecture is separable-but-not-totally.

In the second step, it is concluded that there are five kinds of contracts which guarantee the first-best achievement in the thirty-two circumstances. When the two parties are friends, there are ten circumstances in which contracts are needed to guarantee the first-best achievement; and when the two parties are not friends, there are eight circumstances in which contracts are needed. The relation between circumstances and corresponding contracts is not a one-to-one mapping. Moreover, some contracts are robust to some characteristics of the circumstances. For example, the contract that the manufacturer's inspection quality level is stipulated to the corresponding first-best is robust to the verifiability of external failure, the separability of final product architecture, and the relationship of two parties. Meanwhile, the above contract is a panacea to the eight circumstances in which the first-best solution cannot be achieved without extra contracts when the two parties are not friends. Furthermore, it is shown whether the first-best can be attained based upon the manufacturer's inspection or processing information system installation and how contracts are designed to guarantee the first-best achievement in case that the first-best solution cannot be achieved when some installation is established. Besides, we make a comparison between the results in the literature and in this chapter.

The remainder is organized as follows. Section 2 is literature review. Section 3 is model description. Section 4 is first-best examination of the manufacturer's unobservable inspection and processing. Section 5 is contract design for first-best achievement in circumstances characterized by the manufacturer's behavior observability and the three influencing factors of external failure sharing. The last section is the concluding remarks.

2. Literature review

Competition has extended from firm level to supply chain level. The focus of QM is being transferred to external QM, which is referred to SCQM (Foster 2008; Haynak and Haytley 2008; Liker and Choi 2004). SCQM emphasizes the coordination and integration of each party's businesses to increase the whole supply chain's profit as well as each member's profit (Robinson and Malhotra 2005). However, the coordination of SCQM will not be derived naturally. Buyer's unobservable behaviors and external failure sharing are two aspects which significantly influence the coordination in manufacturing supply chains (Baiman et al. 2000, 2001; Balachandran and Radhakrishnan 2005; Hwang et al. 2006; Reyniers and Tapiero 1995a, b; Swinney and Netessine 2009).

The observabilities of a buyer's inspection and processing behaviors have been investigated in two kinds of supply chains. Firstly, Reyniers and Tapiero (1995a, b) consider the unobservable of a buyer's inspection, but the buyer does not process the "qualified" product further. Reyniers and Tapiero (1995b) give the conditions for the first-best achievement. Secondly, Baiman et al. (2000, 2001), Balachandran and Radhakrishnan (2005) and Hwang (2006) consider supply chain in which a buyer inspects a supplier's product and further processes the inspection-qualified product to be final product. These papers only involve the unobservable of the buyer's processing but not the unobservable of the buyer's inspection. Baiman et al. (2000, 2001) give the conditions for the first-best achievement when a supplier has the sole authority in contract design, and Balachandran and Radhakrishnan (2005) and Hwang (2006) give the contract design for the first-best achievement when a buyer has the sole authority. However, the unobservable of a buyer's inspection has not been studied in the case that the buyer processes inspection-qualified product further. On the other hand, the relation between the observabilities of a buyer's inspection and processing has not been investigated in contract design. Maybe there are some interactions between them. In addition, the behavior observability in contract design should be considered in various supply chain environments.

The external failure sharing is influenced by three interactive factors, which are the verifiability of external failure, the separability of final product architecture and the relationship of two parties. In literatures, the three factors are investigated separately. The external failure of a buyer has been studied by modeling in Baiman et al. (2000). In the event of external failure, if the external failure is verifiable, the penalty paid by a supplier to a buyer is based on the external failure caused by the supplier's defect; otherwise, the penalty is based on all external failure. The separability of final product architecture has been investigated by modeling in Baiman et al. (2001). If final product architecture is totally-separable (i.e. the product architecture is modular), the supplier will be responsible for the external failure caused by the supplier; if final product architecture is non-separable (i.e. the product architecture is integrated), the supplier will not be responsible for the external failure (Baiman et al. 2001; Ulrich 1995). Although discussed separately, it is known that the verifiability of external failure and the separability of final product architecture are connected in the proportion of external failure that a supplier is responsible for. Furthermore, the relationship of the two parties of supply chain, which has not been discussed in quality-based supply chain, also connects with the proportion of external failure that a supplier is responsible for. In addition, the above three characteristics of supply chain environment are interacted in contract design. For example, the consideration of the three characteristics has priority, i.e. the contractibility of external failure should be considered firstly. Because the separability of final product architecture and the relationship of the two parties will not influence the proportion of external failure that the supplier is responsible for if the external failure is unverifiable. In this chapter, an external failure-sharing mechanism is employed to connect the three influencing factors and the interactions among the three factors are taken serious in contract design.

In addition, it is worthwhile to note that the observability and the contractibility are different (Tirole 1999). In economic literature, the contractibility is considered as two levels, i.e. observability and verifiability (Tirole 1999; Maskin and Tirole 1999). Since a contractible event must be verified and enforced by a court, an uncontractible event may be observable but not verifiable. However, in the literature of contract design in quality-based supply chain, the unobservable and the uncontractible are always assumed to be the same (Reyniers and Tapiero 1995a, b; Baiman et al. 2000, 2001; Balachandran and Radhakrishnan 2005; Hwang 2006). In this chapter, the observability and verifiability are considered separately if the contractibility is involved. Since the event of external failure is common and observable in the buyer's after-sale of supply chain, the uncontractible of external failure is due to unverifiable. So we take this uncontractible event as "unverifiable".

3. Model description

We consider a supply chain with a risk-neutral supplier and a risk-neutral manufacturer. The supplier provides one unit product for the manufacturer. The supplier's production quality level q_S is the probability that the production fulfills or exceeds the expectation of final customers ($q_S \in [q_S^0, 1)$ and $q_S^0 > 0$), and the supplier's investment $S(q_S)$ satisfies $S(1) = \infty$, $S'(q_S) > 0$, and $S''(q_S) > 0$. The manufacturer will inspect the product once it is received. If the product is defective, the manufacturer can inspect to be "unqualified" with probability δ ($\delta \in [0, \delta^1]$ and $\delta^1 < 1$), and the inspection cost $I(\delta)$ satisfies $I(1) = \infty$, $I'(\delta) > 0$, and $I''(\delta) > 0$. The inspection-unqualified product will be delivered back to the supplier. Otherwise, the manufacturer will process the product into final product and sell to customers. The manufacturer's processing quality level q_M is the probability that the processing fulfills or exceeds the expectation of final customers ($q_M \in [q_M^0, 1)$ and $q_M^0 > 0$), and the processing cost $M(q_M)$ satisfies $M(1) = \infty$, $M'(q_M) > 0$, and $M''(q_M) > 0$. Since the manufacturer's inspection is imprecise, the external failure will occur. The cost of external failure not only includes the final product price, but also customer dissatisfaction (Heagy 1991; Ittner et al. 1999; Kumar et al. 1998; Sower 2004). The supplier is responsible for α

percent of customer dissatisfaction cost d. In addition, supplier's product price is π, the final product price is Π. Without loss of generality, the price of the supplier's raw material is 0 (Balachandran and Radhakrishnan 2005; Hwang et al. 2006).

From the description, the probability of an external failure is $E=(1-q_S)(1-\delta)+(1-q_M)q_S$, where $(1-q_S)(1-\delta)$ is due to the supplier's poor production and the manufacturer's incorrect inspection and $(1-q_M)q_S$ is due to the manufacturer's poor processing. In this chapter, we employ an external failure-sharing mechanism to decide the supplier's share, which wholly represents the verifiabibity of external failure, the separability of the final product architecture, and the relationship of the two parties. Specifically, the supplier's share of the external failure is $E_S=s(1-\delta)(1-q_S)+m(1-q_M)q_S$, where s ($0\le s\le 1$) be the proportion that the supplier takes the responsibility of $(1-q_S)(1-\delta)$, and m ($0\le m\le 1$) be the proportion that the supplier takes the responsibility of $(1-q_M)q_S$. The parameter s, which is related with the verifiability of external failure and the separability of the final product architecture, is determined by an objective judgment machine. The parameter m, which is related with the verifiability of external failure and the relationship of the two parties, is determined by the agreement of the two parties. If the external failure is unverifiable, the supplier will not be responsible for the external failure ($s=0$ and $m=0$); otherwise, the supplier will be responsible for. In case that the external failure is verifiable, the supplier's share of external failure depends on two factors: the final product architecture and the two parties' relationship. For the parameter s, if the architecture is totally-separable, $s=1$; if the architecture is non-separable, $s=0$; if the architecture is separable-but-not-totally, $0<s<1$. For the parameter m, if the two parties are not friends or if the two parties are friends and the final product architecture is totally-separable, $m=0$; if the two parties are friends and if the final product architecture is not-totally-separable, $0<m\le 1$.

4. First-best examinations about manufacturer's unobservable behaviors

First of all, we give the first-best outcome. According to model description, the manufacturer's profit is

$$P^M(q_S,q_M,\delta,\pi,m,\alpha)=(\Pi-\pi)[1-\delta(1-q_S)]-(\Pi+d)E+(\pi+\alpha d)E_S-I(\delta)-M(q_M),$$

the supplier's profit is

$$P^S(q_S,q_M,\delta,\pi,m,\alpha)=\pi[1-\delta(1-q_S)]-(\pi+\alpha d)E_S-S(q_S),$$

and the whole profit of the supply chain is

$$P(q_S,q_M,\delta,\pi,m,\alpha)=\Pi[1-\delta(1-q_S)]-(\Pi+d)E-I(\delta)-S(q_S)-M(q_M).$$

The problem of First-Best of supply chain is $\underset{0<q_S,q_M,\delta<1}{Maximize}\ P(q_S,q_M,\delta)$. Suppose that $(\Pi+d)q_S^0>M'(q_M^0)$ and $\Pi q_S^0-d(1-q_M^0)>S'(q_S^0)$, there is an interior solution $\{q_S^*,q_M^*,\delta^*\}$ satisfies

$$P_{q_M} = (\Pi + d)q_S - M'(q_M) = 0\,, \tag{1}$$

$$P_\delta = d(1 - q_S) - I'(\delta) = 0\,, \tag{2}$$

$$P_{q_S} = -d\delta + (\Pi + d)q_M - S'(q_S) = 0\,. \tag{3}$$

(Referred on Balachandran and Radhakrishnan 2005).

There are four circumstances characterized by the observability of the manufacturer's behaviors, which depend on the observability of the inspection or the processing. The decision-making processes of the circumstances can be considered in two stages by game-theoretical thinking (Rasmusen 1989; Fudenberg and Tirole 1991; Wei 2001). In the first stage, the manufacturer makes an offer of contract to the supplier. If the supplier takes the offer, the processes go into the next stage in which the two parties optimize their profits by manipulating the variables $\{q_S, q_M, \delta\}$ respectively.

The first-best solution can be attained if the supply chain is integrated, i.e. the optimal value $\{\hat{q}_S, \hat{q}_M, \hat{\delta}\}$ of decentralized supply chain is coincident with the first-best $\{q_S^*, q_M^*, \delta^*\}$.

Circumstance 1 The manufacturer's inspection and processing are both unobservable to the supplier. In the second stage, the manufacturer decides the inspection level δ and the processing quality level q_M, and the supplier decides the production quality level q_S simultaneously and independently. Therefore, the manufacturer's optimization problem is

$$\underset{0<q_S, q_M, \delta<1; \pi, \alpha>0}{Maximize} \quad P^M(q_S, q_M, \delta, \pi, \alpha) \tag{A}$$

subject to

$$P^M_{q_M}(q_S, q_M, \delta, \pi, \alpha) = 0\,, \tag{B}$$

$$P^M_{\delta}(q_S, q_M, \delta, \pi, \alpha) = 0\,, \tag{C}$$

$$P^S_{q_S}(q_S, q_M, \delta, \pi, \alpha) = 0\,, \tag{D}$$

$$P^S(q_S, q_M, \delta, \pi, \alpha) \geq v\,. \tag{E}$$

Equations (B) and (C) are incentive-compatible constraints since the supplier does not observe the manufacturer's q_M and δ. Equation (D) is an incentive-compatible constraint since the manufacturer does not observe the supplier's q_S. Equation (E) is a participation constraint ensuring a minimum profit v for the supplier. We have the following result. (All proofs are provided in the appendix.)

Proposition 1 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. The first-best solution can be attained if and only if (a) the supplier is not responsible for the manufacturer's external failure caused by the manufacturer's defect i.e. $m = 0$; (b) the final product architecture is separable-but-not-totally, i.e. $0 < s < 1$; and (c) the supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi / \alpha = ds / (1 - s)$.

The conditions (a) and (c) can be achieved by contract design, while the condition (b) is objective one of supply chain. Based on condition (a), the manufacturer should not make the supplier hold responsible for the external failure caused by the supplier's own defect. Based on condition (c), the manufacturer should not fiercely reduce the supplier's product price, which will damage the total interest of supply chain. Specifically, (1) the more the Proposition of customer dissatisfaction the supplier is responsible for, (2) the more customer dissatisfaction, or (3) the more the final product's architecture is separable, the higher the supplier's product price.

Circumstance 2 The manufacturer's inspection is unobservable to the supplier while the processing is observable. The second stage is divided into two steps: firstly, the manufacturer decides the processing quality level q_M which the supplier observes; secondly, the manufacturer and the supplier simultaneously move to decide the inspection level δ and the production quality level q_S. Therefore the manufacturer's optimization problem is

$$\underset{0<q_S,q_M,\delta<1;\pi,\alpha>0}{Maximize} \quad P^M(q_S,q_M,\delta,\pi,\alpha) \tag{A}$$

subject to

$$P_{\delta}^M(q_S,q_M,\delta,\pi,\alpha)=0\,, \tag{C}$$

$$P_{q_S}^S(q_S,q_M,\delta,\pi,\alpha)=0\,, \tag{D}$$

$$P^S(q_S,q_M,\delta,\pi,\alpha)\geq v\,. \tag{E}$$

Note that the incentive-compatible constraint (B) is not included in contrast to Circumstance 1, which is because the supplier will utilize the decision about q_M to maximize its profit. The following Proposition holds.

Proposition 2 Suppose that the manufacturer's processing is observable to the supplier while the inspection is unobservable. The first-best solution can be attained if and only if (b) the final product architecture is separable-but-not-totally, i.e. $0<s<1$; and (c) the supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi/\alpha=ds/(1-s)$.

According to Proposition 1 and 2, we have the following corollary.

Corollary 1 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. The first-best solution can be attained if (b) the final product architecture is separable-but-not-totally, i.e. $0<s<1$; (c) the supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi/\alpha=ds/(1-s)$; and (d) the manufacturer's processing quality level q_M is stipulated to be the first-best q_M^* in the contract.

Circumstance 3 The manufacturer's inspection is observable to the supplier while the processing is unobservable. The second stage is: firstly, the manufacturer decides the inspection level δ which the supplier observes; secondly, the manufacturer and the supplier decide the processing quality level q_M and the production quality level q_S simultaneously and independently. Therefore, the manufacturer's optimization problem is

$$\underset{0<q_S,q_M,\delta<1;\pi,\alpha>0}{Maximize} \quad P^M(q_S,q_M,\delta,\pi,\alpha) \tag{A}$$

subject to

$$P^M_{q_M}(q_S,q_M,\delta,\pi,\alpha)=0\,, \tag{B}$$

$$P^S_{q_S}(q_S,q_M,\delta,\pi,\alpha)=0\,, \tag{D}$$

$$P^S(q_S,q_M,\delta,\pi,\alpha)\ge v\,. \tag{E}$$

Note that the incentive-compatible constraint (C) is not included in contrast to CIRCUMSTANCE 1 and the argument is similar to the one in CIRCUMSTANCE 2. The first-best achievement in Circumstance 3 is characterized by the following Proposition. (Balachandran and Radhakrishnan (2005) derives the same result when $0<s\le 1$.)

Proposition 3 Suppose that the manufacturer's inspection is observable to the supplier while the processing is unobservable. The first-best solution can be attained if and only if (a) the supplier is not responsible for the manufacturer's external failure caused by the manufacturer's defect, i.e. $m=0$.

According to Proposition 1 and 3 we have

Corollary 2 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. The first-best solution can be attained if (a) the supplier is not responsible for the manufacturer's external failure caused by the manufacturer's defect, i.e. $m=0$; and (e) the manufacturer's inspection quality q_S is stipulated to be the first-best δ^* in the contract.

Circumstance 4 The manufacturer's inspection and processing are both observable to the supplier. The second stage is: firstly, the manufacturer decides the inspection level δ and processing quality level q_M, which the supplier observes; secondly, the supplier decides the production quality level q_S. Therefore the manufacturer's optimization problem is

$$\underset{0<q_S,q_M,\delta<1;\pi,\alpha>0}{Maximize} \quad P^M(q_S,q_M,\delta,\pi,\alpha) \tag{A}$$

subject to

$$P^S_{q_S}(q_S,q_M,\delta,\pi,\alpha)=0\,, \tag{D}$$

$$P^S(q_S,q_M,\delta,\pi,\alpha)\ge v\,. \tag{E}$$

Note that the two incentive-compatible constraints (B) and (C) are not included in contrast to Circumstance 1. We have the following Proposition. (Balachandran and Radhakrishnan (2005) derives the same result when $0<s\le 1$.)

Proposition 4 Suppose that the manufacturer's inspection and processing are both observable to the supplier. The first-best solution can be attained without extra condition.

From Proposition 1, 2, 3, and 4, we have

Corollary 3 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. The first-best solution can be attained if (d) the manufacturer's processing quality level q_M is stipulated to be the first-best q_M^*, and (e) the manufacturer's inspection quality level δ is stipulated to be the first-best δ^* in the contract.

Corollary 4 Suppose that the manufacturer's processing is observable to the supplier while her inspection is unobservable. The first-best solution can be attained if (e) the manufacturer's inspection quality level δ is stipulated to be the first-best δ^* in the contract.

Corollary 5 Suppose that the manufacturer's inspection is observable to the supplier while her processing is unobservable. The first-best solution can be attained if (d) the manufacturer's processing quality level q_M is stipulated to be the first-best q_M^* in the contract.

From Proposition 1, 2, 3 and 4, it is found that the observability of the manufacturer's inspection and processing can be investigated separately. Specifically, we have the following observation.

Observation 1 The observabilities of the manufacturer's inspection and processing can be investigated separately in analyses of the first-best achievement. If the manufacturer's processing is unobservable, the condition (b) should be considered in contract design, if necessary. If the manufacturer's inspection is unobservable, the conditions (a) and (c) should be considered in contract design, if necessary.

5. Contract design in circumstances characterized by influencing factors

In this section, contract design is pursued in circumstances characterized by the combinations of the manufacturer's behavior (including inspection and processing) observability and the three influencing factors of external failure sharing, i.e., the verifiability of the manufacturer's external failure, the separability of the final product architecture, and the relationship of the two parties.

Before contract design, some issues should be illustrated. Firstly, the verifiability of external failure should be considered prior to the separablility of the final product architecture and the relationship of the two parties. Only if the external failure is verifiable, the other two factors will be taken into account. Secondly, the separablility of the final product architecture and the relationship of the two parties are interactive and do not have priority. Thirdly, the observabilities of the manufacturer's behaviors are independent of the three characteristics of supply chain environment. Fourthly, from Observation 1, the observabilities of the inspection and the processing are separable in supply chain quality management.

We divide the circumstances into two groups to discuss: friends or not-friends. In each group, there are four factors influencing contract design, i.e. the observability of the manufacturer's inspection, the observability of the manufacturer's processing, the verifiability of the external failure, and the separability of the final product architecture. It is important that there are only two relations between the four factors – independent and hierarchical. In this case, the braches of the four factors are depicted in Figure 1. The manufacturer's inspection has two nodes: MI_O^N (unobservable) and MI_O (observable). The manufacturer's processing has two nodes: MP_O^N (unobservable) and MP_O (observable). The combination of the verifiability of the manufacturer's external failure and the separability of the final product architecture has three end-nodes: $ME_V + A_{T+N}$ (the manufacturer's external failure is verifiable and the final product architecture is totally separable or non-separable, i.e. $s=1$ or $s=0$), $ME_V + A_{S-T}$ (the manufacturer's external failure is verifiable and the final product architecture is separable-but-not-totally, i.e. $0 < s < 1$) and ME_V^N (the manufacturer's external failure is unverifiable, i.e. $E_S = 0$).

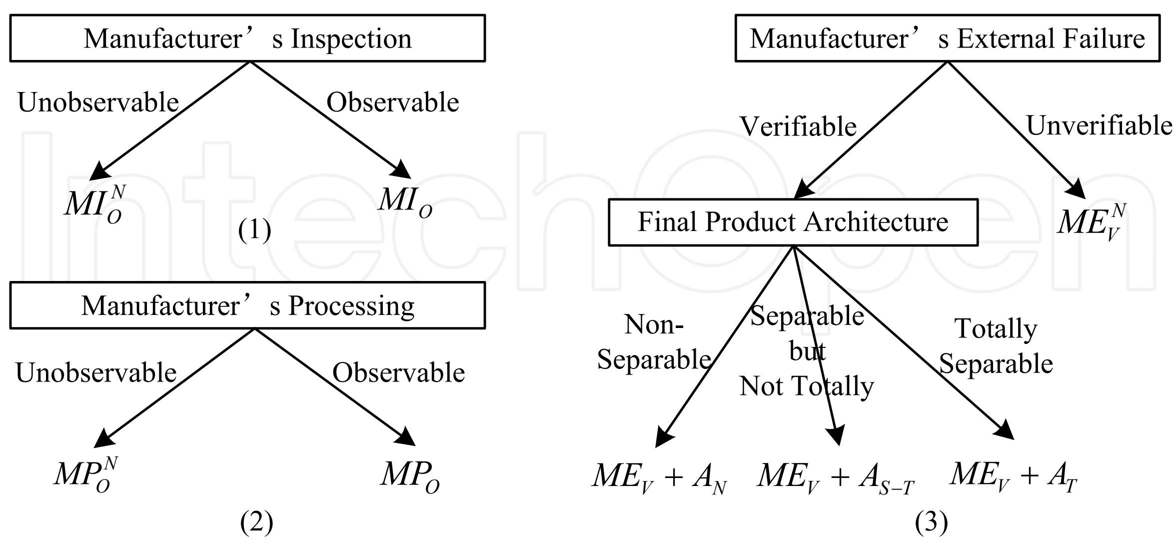

Fig. 1. The branches of the observability of the manufacturer's inspection, the observability of the manufacturer's processing, the verifiability of external failure, and the separability of the final product architecture

There are sixteen different circumstances characterized by the combinations of end-notes in Figure 1. According to Proposition 1-4 and Corollary 1-4, contracts by stipulating which the first-best solution is achieved in different circumstances are exhibited in Table 1. The items of contracts are:

1. The external failure which is caused by the manufacturer's defect but the supplier is responsible for is zero, i.e. $m = 0$.
2. The supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi / \alpha = ds / (1-s)$.
3. The manufacturer's inspection quality level δ is the first-best δ^*.
4. The manufacturer's processing quality level q_M is the first-best q_M^*.

For example, if the supply chain in Circumstance 1 of Table 1, Contract [2+4] guarantees first-best achievement according to Proposition 1. Note that the contracts listed in Table 1 are the ones which encompass the least items. Otherwise there are much more satisfied contracts. For instance, Contract [3+4] is suitable for every circumstance according to Proposition 4.

There are five kinds of contracts, i.e. contracts [2], [3], [4], [2+4] and [3+4], to guarantee first-best achievement. When the two parties are friends, there are ten circumstances in which first-best solution is achieved by extra contracts; and when the two parties are not friends, there are eight circumstances. The relation of the circumstances and the contracts is not a one-to-one mapping. When the two parties are friends, the reasons that the first-best can be attained without contract in the other four circumstances are (a) the manufacturer's inspection is observable to the supplier, the external failure is verifiable, and the final product architecture is totally separable (Circumstances 11 and 15); (b) the manufacturer's inspection is observable and the manufacturer's external failure is unverifiable (Circumstance 12 and 16); or (c) the manufacturer's inspection and processing are both

CIRCUMSTANCES	CONTRACTS	
	Friends	Not-Friends
1. $MI_O^N + MP_O^N + ME_V + A_N$	[3+4]	[3]
2. $MI_O^N + MP_O^N + ME_V + A_{S-T}$	[2+4], [3+4]	[2], [3]
3. $MI_O^N + MP_O^N + ME_V + A_T$	[3]	[3]
4. $MI_O^N + MP_O^N + ME_V^N$	[3]	[3]
5. $MI_O^N + MP_O + ME_V + A_N$	[3]	[3]
6. $MI_O^N + MP_O + ME_V + A_{S-T}$	[2], [3]	[2], [3]
7. $MI_O^N + MP_O + ME_V + A_T$	[3]	[3]
8. $MI_O^N + MP_O + ME_V^N$	[3]	[3]
9. $MI_O + MP_O^N + ME_V + A_N$	[4]	–
10. $MI_O + MP_O^N + ME_V + A_{S-T}$	[4]	–
11. $MI_O + MP_O^N + ME_V + A_T$	–	–
12. $MI_O + MP_O^N + ME_V^N$	–	–
13. $MI_O + MP_O + ME_V + A_N$	–	–
14. $MI_O + MP_O + ME_V + A_{S-T}$	–	–
15. $MI_O + MP_O + ME_V + A_T$	–	–
16. $MI_O + MP_O + ME_V^N$	–	–

Table 1. The circumstances and the corresponding contracts when the two parties are friends or not friends

observable to the supplier (Circumstance 13-15). When the two parties are not friends, there is only one reason to guarantee first-best achievement without contract. The reason is that the manufacturer's inspection is observable to the supplier.

Some contracts are robust to the changes of some of three circumstance characteristics. When the two parties are friends, Contract [3+4] is robust to the separability of the final product architecture in circumstances that the manufacturer's inspection and processing are both unobservable to the supplier and the final product architecture is not totally separable (Circumstance 1 and 2); Contract [3] is robust to the verifiability of the manufacturer's external failure and the separability of the final product architecture in circumstances that only the manufacturer's inspection is unobservable to the supplier (Circumstance 4-8); Contract [3] is robust between the verifiable external failure and totally separable final product architecture (Circumstance 3) and the unverifiable external failure (Circumstance 3); and Contract [4] is robust between the nonseparable and separable-but-not-totally final product architectures in circumstances that only the manufacturer's inspection is observable to the supplier and the external failure is verifiable (Circumstance 9 and 10). When the two parties are not friends, contract [3] is robust to the observability of the processing, the verifiability of the external failure, and the separability of the final product architecture in circumstances except the ones that The first-best can be attained without contract. Contract [3] is used much more times than other contracts. When the two parties are not friends Contract [3] is a panacea to achieve the first-best solution. meanwhile, contract [3] is robust to the verifiability of external failure, the separability of the final product architecture, and the relationship of the two parties in circumstances that only the inspection is unobservable, and robust between between the verifiable external failure and totally separable final product architecture and the unverifiable external failure and between the friend and not-friend relations in circumstances that the inspection and processing are both unobservable.

Compared with the group in which the two parties are friends, there are several changes in groups that the two parties are not friends. Circumstances 9 and 10 guarantee first-best achievement without contracts. Meanwhile, it is plausible that the difference between the two groups is that item [4] is not included in the contract when the two parties are not friends in the same circumstances (Circumstances 1, 2, 9, and 10). However, that the item [4] is stipulated in the contract is not directly related with the situation that the two parties are friends. The reason of this phenomenon is: when the two parties are not friends ($m = 0$) the first-best can be attained by contract [1+2] (Circumstance 2), contract [1+3] (Circumstances 1), and contract [1] (Circumstance 9 and 10), and the circumstances 1, 2, 9, and 10 all guarantee item [1].

5.1 Information system installation

IT and supply chain contracts are two key approaches to supply chain management (Arshinder et al. 2008; Li and Wang 2007; Saraf et al. 2007). The derived results can give further comments on information system installation in supply chain. The circumstances that the manufacturer's inspection and processing are both unobservable to the supplier are always the original type of supply chains. The firms should make tradeoffs between information system installation and contract design to implement supply chain management. The circumstances that the inspection or the processing is observable refer to the situations that one of the information systems is installed. In Table 1, if the manufacturer's inspection and processing systems are both installed in the supply chain, the first-best solution can be attained without contract; otherwise, the first-best solution cannot be attain without contract. To conclude, we have the following proposition.

Proposition 5 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. If installing an inspection information system in circumstances that the two parties are friends, The first-best can be attained without contract when the external failure is unverifiable or when the external failure is verifiable and the final product architecture is totally separable; contract [4] is needed to guarantee the first-best achievement when the external failure is verifiable and the final product architecture is not totally separable. If installing an inspection information system in circumstances that the two parties are not friends, supply chain can be achieved without contract in any circumstance. If installing a processing information system, supply chain can be achieved by contract [3] in any circumstance and by contract [2] only in circumstance [6].

Therefore, information system installation should be accomplished by contract design, and the managers of supply chain management should pay more attention to relation between information technology and SC coordination. Otherwise, the objective of information system installation will not be achieved and the firm's enthusiasm will be turned down.

5.2 Result comparison with other studies

In the following, we make a specific comparison with the result in Baiman et al. (2000, 2001), which also involve the observability of the buyer's inspection, the verifiability of external failure, and the separability of the final product architecture separately.

When the manufacturer's processing is observable and the external failure is verifiable, Baiman et al. (2000) show that the first-best solution is achieved (Proposition 2a); however, Table 1 shows that the first-best solution is achieved with extra contracts if the manufacturer's inspection is unobservable (Circumstances 5-7) or without extra contract if the inspection is observable (Circumstances 13-15).

When the manufacturer's processing is unobservable, the manufacturer's inspection is observable, and external failure is verifiable, Proposition 3 in Baiman et al. (2000) and Proposition 4 in Baiman et al. (2001) show that the first-best solution is achieved; however, Table 1 shows that the first-best solution is achieved without extra contract if the two parties are not friends (Circumstances 9-16 in Not-Friends group) or if the two parties are friends and the final product architecture is totally-separable (Circumstance 11 in Friends Group), or with extra contract if the two parties are friends and the final product architecture is not-totally-separable (Circumstances 9 and 10 in Friends group).

When the final product architecture is non-separable, Proposition in Baiman et al. (2001) shows that the first-best solution cannot be achieved, but Table 1 shows that the first-best solution can be attained without extra contract if the manufacturer's inspection is observable and with extra contract if the inspection is unobservable.

It is worthwhile to note that the above comparisons are just arguments by modeling approaches to SCC. The results are based on different assumptions of the quality-based supply chain.

6. Concluding remarks

Contract design for SCQM is discussed in a manufacturing supply chain. It is shown that supplier and manufacturer in some circumstances must stipulate some items in contract to guarantee coordination in SCQM, while other circumstances guarantee coordination without extra contract. Furthermore, information system installation is an alternative approach to coordination in those circumstances that need extra contracts to guarantee coordination. The exact information system should be chosen based on characteristics of the circumstances.

Two issues are highlighted in the manufacturing supply chain. The observability of the buyer's inspection is highlighted in supply chains such that the buyer further processes the supplier's product to be final product. The result is different from the case that the buyer does not further process the supplier's product. If the buyer's inspection is unobservable, the supplier will be exposed to moral hazard. Moreover, the extra conditions in which the first-best solution is achieved are different from the ones in supply chains such that the buyer does not process the supplier's product further. In this chapter, the situation that the manufacturer's inspection is unobservable is corresponding with two extra conditions: (1) the supplier is not responsible for the external failure caused by the manufacturer's defect, and (2) the supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi / \alpha = ds / (1-s)$.

The interactions between the external failure's verifiability, the final product architecture's separability, and the two parties' relationship are also highlighted. The three factors do not independently influence the contract design. Only if the external failure is verifiable, the other two factors will be taken into account. The final product architecture's separability and the two parties' relationship have the same hierarchy and have interactive influences. In this chapter, an external failure-sharing mechanism is employed to connect the three factors.

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8. Appendix

This Proof of Proposition 1: It is only to prove that the solution of maximization problem coincides with the first-best solution if and only if the conditions are satisfied in the circumstance.

The Lagrangian for the maximization problem in Circumstance 1 of Section 4 is $L = P^M + \lambda_1 P^M_{q_M} + \lambda_2 P^M_\delta + \lambda_3 P^S_{q_S} + \mu(P^S - v)$ with λ_1, λ_2, λ_3 and μ as Lagrange multipliers on constraints (B), (C), (D), and (E). The first-order conditions of the Lagrangian are

$$L_{q_M} = (\Pi + d)q_S - (\pi + \alpha d)mq_S - M'(q_M) - \lambda_1 M''(q_M) + \lambda_3 m(\pi + \alpha d) + \mu m q_S(\pi + \alpha d) = 0\,, \quad \text{(A1)}$$

$$L_\delta = [\pi(1-s) + d(1-\alpha s)](1-q_S) - I'(\delta) - \lambda_2 I''(\delta) + [\lambda_3 - (1-q_S)\mu][\pi - s(\pi + \alpha d)] = 0\,, \quad \text{(A2)}$$

$$\begin{aligned} L_{q_S} &= (\Pi - \pi)\delta - (\Pi + d)(\delta - q_M) + (\pi + \alpha d)[m(1-q_M) - s(1-\delta)] + \lambda_1[\Pi + d - m(\pi + \alpha d)] \\ &-\lambda_2[\pi(1-s) + d(1-\alpha s)] - \lambda_3 S''(q_S) + \mu\{\pi\delta + (\pi + \alpha d)[s(1-\delta) - m(1-q_M)] - S'(q_S)\} = 0 \end{aligned}\,, \quad \text{(A3)}$$

$$\begin{aligned} L_\pi &= [(\mu - 1)(1-q_S) - \lambda_3](1-s)(1-\delta) + [(\mu-1)q_S + \lambda_3][1 - m(1-q_M)] \\ &-\lambda_1 m q_S + \lambda_2(1-s)(1-q_S) = 0 \end{aligned} \quad \text{(A4)}$$

$$L_\alpha = [(\mu-1)(1-q_S) - \lambda_3]s(1-\delta) + [(\mu-1)q_S + \lambda_3]m(1-q_M) + \lambda_1 m q_S + \lambda_2 s(1-q_S) = 0\,. \quad \text{(A5)}$$

Let $\{\hat{q}_M, \hat{q}_S, \hat{\delta}, \hat{\alpha}, \hat{\pi}\}$ be the solution of the maximization problem.

On the one hand, if the first-best solution is achieved, $\hat{q}_S$, $\hat{q}_M$ and $\hat{\delta}$ must satisfy (B0), (C0), and (D0). Comparing (B), (C) with (B0), (C0), we have $\pi = (\pi + \alpha d)s$ and $m(\pi + \alpha d) = 0$. Since $\pi > 0$, then $m = 0$, $0 < s < 1$, and $\pi / \alpha = ds/(1-s)$.

On the other hand, the only thing we have to prove is that if $m = 0$, $0 < s < 1$, and $\pi / \alpha = ds/(1-s)$ then $\lambda_1, \lambda_2, \lambda_3 = 0$ and $\mu = 1$. Because if $\lambda_1, \lambda_2, \lambda_3 = 0$ and $\mu = 1$ exist $L = P - v$ and the first-best solution is derived. Firstly Plugging $m = 0$ into (A1) and comparing with (B) we have $\lambda_1 = 0$ since $M''(q_M) > 0$, and plugging $\pi / \alpha = ds/(1-s)$ into (A2) and comparing with (C), we have $\lambda_2 = 0$ since $I''(\delta) > 0$. Secondly, plugging (D), (D0), and $\lambda_1, \lambda_2 = 0$ into (A3) we have $\lambda_3 = 0$ since $S''(q_S) > 0$. Finally, plugging $m = 0$ and $\lambda_1, \lambda_2, \lambda_3 = 0$ into (A4) we have $\mu = 1$ since $0 < s < 1$. At this moment, (A3) is also satisfied.

Proof of Proposition 2: The Lagrangian for the maximization problem in Circumstance 2 of Subsection 4.1 is $L = P^M + \lambda_2 P_\delta^M + \lambda_3 P_{q_S}^S + \mu(P^S - v)$ with λ_2, λ_3, and μ as Lagrange multipliers on constraints (C), (D), and (E). The first-order conditions of the Lagrangian are

$$L_{q_M} = (\Pi + d)q_S - (\pi + \alpha d)mq_S - M'(q_M) + \lambda_3 m(\pi + \alpha d) + \mu m q_S(\pi + \alpha d) = 0\,, \quad \text{(A6)}$$

$$L_\delta = [\pi(1-s) + d(1-\alpha s)](1-q_S) - I'(\delta) - \lambda_2 I''(\delta) + [\lambda_3 - (1-q_S)\mu][\pi - s(\pi + \alpha d)] = 0\,, \quad \text{(A7)}$$

$$\begin{aligned} L_{q_S} &= (\Pi - \pi)\delta - (\pi + d)(\delta - q_M) + (\pi + \alpha d)[m(1-q_M) - s(1-\delta)] - \lambda_2[\pi(1-s) + d(1-\alpha s)] \\ &\quad -\lambda_3 S''(q_S) + \mu\{\pi\delta + (\pi + \alpha d)[s(1-\delta) - m(1-q_M)] - S'(q_S)\} = 0, \end{aligned} \quad \text{(A8)}$$

$$L_\pi = [(\mu-1)(1-q_S) - \lambda_3](1-s)(1-\delta) + [(\mu-1)q_S + \lambda_3][1 - m(1-q_M)] + \lambda_2(1-s)(1-q_S) = 0 \quad \text{(A9)}$$

$$L_\alpha = [(\mu-1)(1-q_S) - \lambda_3]s(1-\delta) + [(\mu-1)q_S + \lambda_3]m(1-q_M) + \lambda_2 s(1-q_S) = 0\,. \quad \text{(A10)}$$

Let $\{\hat{q}_M, \hat{q}_S, \hat{\delta}, \hat{\alpha}, \hat{\pi}\}$ be the solution of the maximization problem.
We only prove that if $0 < s < 1$ and $\pi / \alpha = ds / (1-s)$ then $\lambda_2, \lambda_3 = 0$ and $\mu = 1$. Firstly, plugging $\pi / \alpha = ds / (1-s)$ into (A7) and comparing with (C) we have $\lambda_2 = 0$. Secondly, plugging (D), (D0) and $\lambda_2 = 0$ into (A8) we have $\lambda_3 = 0$. Finally, plugging $\lambda_2, \lambda_3 = 0$ into (A9) and (A10) we have $(\mu-1)(1-q_S)(1-s)(1-\delta) + (\mu-1)q_S[1 - m(1-q_M)] = 0$ and $(\mu-1)(1-q_S)s(1-\delta) + (\mu-1)q_S m(1-q_M) = 0$. The two equations imply $(\mu-1)[(1-q_S)(1-\delta) + q_S] = 0$. Then $\mu = 1$, since $0 < q_S < 1$ and $\delta < 1$.

Proof of Corollary 1: The process of proof is tantamount to solve two maximization problems

$$\underset{0<q_S,\delta<1;\pi,\alpha>0}{Maximize} \quad P^M(q_S, q_M^*, \delta, \pi, \alpha) \quad \text{(A)}$$

subject to

$$P_\delta^M(q_S, q_M^*, \delta, \pi, \alpha) = 0\,, \quad \text{(C)}$$

$$P_{q_S}^S(q_S, q_M^*, \delta, \pi, \alpha) = 0\,, \quad \text{(D)}$$

$$P^S(q_S, q_M^*, \delta, \pi, \alpha) \geq v\,. \quad \text{(E)}$$

According to the proof of Proposition 3, the solution of the above problem coincides with the first-best solution.

Proof of Proposition 3: The Lagrangian for the maximization problem in Circumstance 3 is $L = P^M + \lambda_1 P_{q_M}^M + \lambda_3 P_{q_S}^S + \mu(P^S - v)$ with λ_1, λ_3, and μ as Lagrange multipliers on constraints (B), (D), and (E). Let $\{\hat{q}_M, \hat{q}_S, \hat{\delta}, \hat{\alpha}, \hat{\pi}\}$ be the solution of the maximization problem. We only prove that if $m = 0$ then $\lambda_2, \lambda_3 = 0$ and $\mu = 1$.

Following the similar steps we have that if $m = 0$ then $\lambda_1, \lambda_3 = 0$. It leaves to prove that $\mu = 1$. From the first-order conditions of the Lagrangian we have

$$L_{\pi} = (\mu - 1)[(1 - q_S)(1 - s)(1 - \delta) + q_S] = 0\ , \tag{A11}$$

$$L_{\alpha} = (\mu - 1)(1 - q_S)s(1 - \delta) = 0\ . \tag{A12}$$

If $s = 0$ we have $(\mu - 1)[(1 - q_S)(1 - \delta) + q_S] = 0$ from (A11), while if $s = 1$ we have $L_{\alpha} = (\mu - 1)(1 - q_S)(1 - \delta) = 0$ from (A12). Hence it holds that $\mu = 1$.

Proof of Proposition 4: The Lagrangian for the maximization problem in Circumstance 4 is $L = P^M + \lambda_3 P^S_{q_S} + \mu(P^S - v)$ with λ_3 and μ as Lagrange multipliers on constraints (D) and (E). By following the similar track as in the proof of proposition 3 we are able to obtain $\lambda_3 = 0$ and $\mu = 1$.

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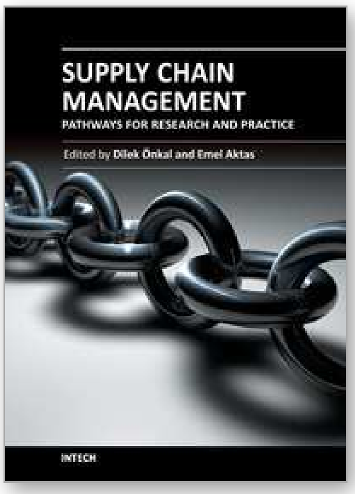

Supply Chain Management - Pathways for Research and Practice

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Challenges faced by supply chains appear to be growing exponentially under the demands of increasingly complex business environments confronting the decision makers. The world we live in now operates under interconnected economies that put extra pressure on supply chains to fulfil ever-demanding customer preferences. Relative attractiveness of manufacturing as well as consumption locations changes very rapidly, which in consequence alters the economies of large scale production. Coupled with the recent economic swings, supply chains in every country are obliged to survive with substantially squeezed margins. In this book, we tried to compile a selection of papers focusing on a wide range of problems in the supply chain domain. Each chapter offers important insights into understanding these problems as well as approaches to attaining effective solutions.

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