

Working Paper SERIES

Date October 23, 2014

WP # 200MSS-068-2010

Contracting for Quality in a Multiple-Level Global Supply Chain

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One of the authors would like to thank the College of Business, University of Texas at San Antonio, for generously providing summer research support for this project.

Contracting for Quality in a Multiple-Level Global Supply Chain

Abstract

Today's global supply chains are inundated with examples where products and components are sourced from manufacturers and suppliers around the world, making quality assurance of the finished products increasingly complex but critical. In this paper, we propose a supply chain framework of a sequential quality management process where the finished product quality depends on the manufacturer quality, which is also affected by component quality. We establish and examine various types of quality incentive mechanisms with implications on efficiency and effectiveness of supply chain quality management. The impact of supply chain structures on supply chain performances in product quality and profitability is closely examined.

Keywords: Incentive mechanism design, supply chain quality, quality assurance, multi-tier supply chain.

JEL Classifications: C700, D210, D820, D860, L140, L150, M110,

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Introduction

Providing quality products to consumers is a challenge to the entire supply chain, and each member of the supply chain needs to contribute to assure product quality from raw materials and components to finished goods (Tagarass and Lee, 1996). Superb product quality establishes consumer value, satisfaction, and loyalty, and provides basis for firm profitability. Under increasing competition, firms have applied various quality management methods in supply chains. For example, corporations such as Motorola, Inc. and GE have implemented Six Sigma programs. BMW has implemented a new computer-aided inspection (CAI) technology to inspect and secure its product quality at its engine manufacturing factory in Steyr, Austria (Higgins, 2003). Intel Corporation has required supplier participation in its quality control system. Despite all the efforts, quality management in supply chains remains mission unaccomplished for many industries, as demonstrated by the recent quality issues publicized by the Mattel toy recalls (cites). The operations management literature has had extensive coverage of quality control and management (cites). However, managing product quality in multi-level supply chains, a reality in many industries, is much less understood and hence the focus of this research.

A key aspect of the quality management challenges in supply chains is the fact that supply chains have become longer and often outsourced globally, as in the case of Mattel. Apple also outsources its hard drive production for to Toshiba Cooperation in Japan. Most other major components of iPod, such as click wheel, lithium battery, media decoder and the controller chip, are all outsourced to contract manufacturers, only to be assembled in China (Varian, 2007). The longer and more complicated supply chains may reduce quality visibility and quality control

throughout the supply chain. Is Apple the next Mattel waiting to happen, or is it doing anything different from Mattel that effectively addresses the challenges in managing supply chain quality?

Quality management literature in operations and supply chain management has shown the effects of input quality on output quality in a supply chain (Lee and Tagaras 1996), and recently research has studied supply chain quality in the context of outsourcing (Donohue 2005?). While the more recent quality literature in supply chain management offers some new insight, the answers to the quality challenges across supply chains are hardly clear. After all, final product quality reflects quality at each individual level of the supply chain and until the entire supply chain is aligned to deliver quality products, outsourced or not, quality problems will be inevitable. What further complicate supply chain quality control, in addition to the lengths and locations of supply chains, are supply chain governance and relationships, which makes aligning supply chains to achieve their quality goals more difficult. Supply chain members with different goals, objectives, and behaviors make conflicting decisions that may hinder any effort to coordinate supply chain quality operations. From a supply chain governance perspective, Mattel chose a different governance structure from Apple, by contracting with toy manufacturers only, while Apple takes stronger control of its supply chains by contracting with both manufacturers and their suppliers. Would this be a reason why iPod is a more reliable product than the Mattel toys? This research studies quality management issues in multi-level supply chains from the perspectives of supply chain governance and relationships. Specifically, we examine supply chain governance structures and quality contracts that allow supply chain members to align their quality improving efforts leading to supply chain performance.

In this research we explore supply chain quality issues in the theoretical lens of incentive contracting. We propose a supply chain framework of a sequential quality management process,

similar to Tagaras and Lee (1996), where the finished product quality depends on the manufacturer quality, which is in turn influenced by component quality. Motivated by various relational forms of outsource manufacturing in supply chains, we establish and examine four types of quality incentive mechanisms that have been implemented in industries to shed light on the efficiency and effectiveness of supply chain quality management. We develop a quality model based on a three-level supply chain, where members of the supply chain make efforts to manage product quality from not only manufacturing but purchasing and procurement as well. This approach contributes to the quality management literature by examining quality management in a multi-level supply chain from the perspective of incentive mechanisms that align supply chain members' interests and behaviors in managing their respective quality processes. This modeling framework extends the previous research (e.g. Lee and Tagaras 1996), and generates important results that provide insightful implications of supply chain behaviors in quality management.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature. In Section 3, we present the general model with unobservable quality enhancement efforts. Four types of contracts are induced in order to improve quality among the supply chain and maximize the brand owner's expected profit. Detailed analysis and discussions are provided in Section 4. Conclusions and future research topics are discussed in Section 5.

LITERATURE REVIEW

In existing literature, several approaches are proposed to raise the product quality. Supplier selection suggests to improve quality from properly selecting qualified suppliers (Seshadri and Zemel 2003; Chen 2004; Cachon and Zhang 2006; Benjaafar et. al, 2007). Lot sizing prefers to determining production and procurement timing and quantities (Yano and Lee 1995; Nahmias

and Moinzadeh 1995; Suerie and Stadtler 2003). Inspection helps quality control by fully or partially inspecting input or output (Lee and Rosenblatt 1987; Porteus 1990; Starbird 1997). Contracts can be used to induce supply chain members to deliver high level quality by providing enough incentives, such as compensation, revenue sharing, price/quantity discount etc (Taylor and Wiggins 1997; Cachon and Lariviere 2005; Tagaras and Lee 1996; Reyniers and Tapiero 1995; Schmitz 2005). In this paper, we apply the incentive contracting theory and propose a multi-level supply chain mechanism to manage product quality. We explore different types of supply chain structures in terms of contracting, information, and decision making.

Tagaras and Lee (1996) analyze both the input component quality and the manufacturing process to investigate the tradeoff between quality and cost in a “vendor-vendee relationship.” They suggest that looking at only the manufacturing process is not sufficient. Input component quality, the manufacturing process and quality costs should be jointly considered in order to secure quality of finished products. This supply chain perspective provides a theoretical foundation for our research where we consider the brand owner, the manufacturer and the component supplier’s contribution to the quality of finished products.

Zhu et al. (2007) focus on interactions between a buyer, which owns the brand and provides the product design, and a supplier, which is in charge of manufacturing process. They argue that the buyer’s investment in supplier’s quality improvement process significantly raises quality level and the profit of both parties. Based on their results, the brand owner is allowed to pay compensations to the manufacturer and the component supplier as a type of quality improvement investment.

Most previous research studies supply chain quality issues based on a two-level supply chain structure, which substantially simplifies supply chain control and decision mechanisms

with regard to quality assurance (Zhu et al.2007, Tagaras and Lee 1996, Taylor and Wiggins, 1997). Many quality challenges, such as those faced by Mattel, in supply chains are present because the structures of supply chains are much more complex and supply chain relationships are much more important than those of a dyad. Schmitz (2005) offers a relevant modeling framework under which a sequential quality management scheme can be studied with quality based incentive contracts. Focusing on allocation of sequentially dependent tasks, Schmitz discusses various contracting structures that may have different implications to effort and performance. Specifically, it is shown that, contrary to the conventional belief, integration of tasks performed by one firm may lead to worse outcomes than separation of tasks performed by multiple firms.

Other potentially relevant literature: recent outsourcing literature, asymmetric information/mixed moral hazard literature, other moral hazard modeling papers in OM.

MODEL DEVELOPMENT

In this paper, we consider a supply chain of three levels: a brand owner that owns a brand and outsources manufacturing to a contract manufacturer, who produces the final product with components purchased and procured from a component supplier. The brand owner assumes the bargaining power and controls the supply chain quality by offering quality specific contracts. Following the prior literature such as Tagaras and Lee (1996), Balanchandran and Radhakrishnan (2005), and Hwang, Radhakrishnan and Su (2006), the quality of the final product depends on the quality performance of both the manufacturing and purchasing and procurement processes. The rest of the section discusses the details of this modeling framework.

Product Quality Process and Costs in the Supply Chain

The quality of the finished product is the outcome of two sequential supply chain tasks: the component input and the manufacturing process. Such processes are performed by the supplier and the manufacturer who are risk neutral and the outcome depends on effort exerted by the two supply chain parties. The effort levels are unobservable to the brand owner who is also risk neutral. The brand owner requires the manufacturer to provide x units of the product; in turn the manufacturer requires the supplier to provide xy units of the component. Without loss of generality, we set $x = 1$ and $y = 1$. Following the frameworks of Hwang, et al. (2006) and Balanchandran and Radhakrishnan (2005), we model the supplier's quality effort, q , as the probability that the component performs the desired functions with $q \in (0,1)$ and corresponding quality cost of $S(q)$. To keep the model simple we let the quality level to be either high or low, $q \in \{q_H, q_L\}$ with $\Delta q = q_H - q_L > 0$ and corresponding quality cost $\{S_H, S_L\}$ with $S_L = 0$ (low quality is normalized as the equivalent of no-quality) and $\Delta S = S_H - S_L > 0$. Similarly, the manufacturer's quality effort, $p \in \{p_H, p_L\}$ ($\Delta p = p_H - p_L > 0$), is the probability that its work performs the desired functions with corresponding quality cost $\{M_H, M_L\}$ ($M_L = 0$ and $\Delta M = M_H - M_L > 0$ by normalizing the cost at manufacturer's low quality effort to 0). The manufacturer's and the supplier's quality are assumed to be independent, i.e., the probability that the finished product performs the desired function is given by pq without inspections [see, e.g., Balanchandran and Radhakrishnan (2005)].

The manufacturer inspects the incoming components. The inspection technology does not reject a good unit, and it does not identify all defective units either. Specifically, on the manufacturer's inbound process, the probability of identifying a defective unit is denoted as θ_M , leading to the expected component rejection rate as $(1 - q_i)\theta_M$ for $i = H, L$. Thus the amount of

product produced with “good work but bad components” by the manufacturer is

$(1 - q_i)(1 - \theta_M)p_j$ for $i, j = H, L$, while the amount of product produced with “bad work” by the manufacturer is $[q_i + (1 - q_i)(1 - \theta_M)](1 - p_j)$, leading to the total amount of unqualified product or external failure rate at the final consumer as $e_{ij} = [1 - p_j q_i - (1 - q_i)\theta_M]$.

On the other hand, the brand owner uses an exogenously specified technology to investigate each external failure and identifies the cause for the external failure as supplier’s or the manufacturer’s fault (Balanchandran and Radhakrishnan, 2005). The technology might not be perfect either. In particular, the proportions of external failures that the investigation technology identifies as the supplier’s (S) and manufacturer’s (M) faults are respectively

$$e_S = a(1 - q_i)(1 - \theta_M) + (1 - h)(1 - p_j)q_i, \text{ and} \quad (1)$$

$$e_M = (1 - a)(1 - q_i)(1 - \theta_M) + h(1 - p_j)q_i, \quad (2)$$

where $a \in (0, 1]$ and $h \in [0, 1]$. Here “ a ” is the probability that the supplier is correctly held responsible for the external failures (because of unqualified components), while “ h ” is the probability that the manufacturer is (correctly) held responsible for his poor work despite good component provided. That is, the investigation technology could identify the supplier’s fault (unqualified components) as the manufacturer’s fault, or vice versa. The parameters $\{a, h\}$ denotes the precision of the investigation technology, with higher a and higher h indicating higher precision. Since manufacturer’s inspection cost and the brand owner’s investigation cost are fixed costs given that they are not a decision, we normalize them to 0 without the loss of generality.

Multi-Level Supply Chain Quality Contracts

In a supply chain of multiple levels, contracting to assure quality becomes much more difficult than in a dyadic supply chain. To the extent to which the finished product quality depends on both manufacturing process and component quality, quality contracts offered by the brand owner needs to deliver incentives not only to the manufacturer but to the supplier, directly or indirectly, as well. A common approach to design incentive mechanisms in such supply chains, both in theory (Schmitz 2005) and in practice (such as Mattel), is to consider a separate “side contract” between the manufacturer and the supplier detailing quality requirements and corresponding compensations for the component. Given this manufacturer-supplier contract, the brand owner can choose to implement various grand contracts that imply different level of decision control and information visibility. Specifically, we examine four contracting structures commonly observed in industries along two dimensions: the brand owner contracting with both the manufacturer and the supplier in a “centralized” manner vs. the brand owner contracting with the manufacturer only in a “decentralized” or sequential way; the supply chain relationships characterized as short term transactional vs. long term relational. The combinations of such contracting choices offer useful insight into how effective and efficient a supply chain quality management process can be under different supply chain contracting and governance structures.

In order to focus on the above issues, we make a few assumptions to facilitate the development of the model. First of all, we focus on the cases where the brand owner prefers both the manufacturer and the supplier to make effort to improve quality at their respective level. While such assumption is commonly made in a two-level supply chain, it is not necessarily a natural extension to a multi-level supply chain. It is conceivable that if the component turns out to be of inferior quality, it may make economical sense for the manufacturer to not salvage it, or for the brand owner to recover it under a contract. However, we assume it is to the brand owner’s

best interest to assure high quality regardless of outcome for the long-term benefit. Second, we assume all members of the supply chain are risk neutral. This assumption significantly simplifies model development while allowing us to concentrate on the issues on hand. Most of the related literature is based on risk-averse agents (the manufacturer and/or the supplier), and we expect that most of our findings will hold in nature if risk-aversion is incorporated. Third, depending on the nature of the supply relationship (transactional vs. relational), quality contracts are bounded by limited liability of the supply chain members, e.g. the manufacturer and the supplier. This assumption restricted the power of the brand owner to penalize the rest of supply chain for low levels of product quality in short term transactional relationships. Such restriction is often observed in global supply chains when different members of the supply chain are subject to different legal requirements and regulations across nations. In long term relational contracts, the brand owner would have more legal venues and time flexibility to penalize the supplying parties when inferior products or components are delivered.

The brand owner pays the manufacturer for each unit of finished product with three different prices depending on the outcome of the product: w if no failure; w_M if the external failure is identified as manufacturer's fault; and w_S if the external failure is identified as supplier's fault. Similarly, depending on the outcome of component inspection the supplier is paid the amount of c_1 if the component passes the inspection, but c_0 if the component does not pass the inspection.

The brand owner interacts with the manufacturer through the following sequence of events:

- (1) The brand owner and the manufacturer agree on the unit price of the product $\{w, w_M, w_S\}$.
- (2) The manufacturer chooses quality enhancement effort $\{p\}$.

- (3) The brand owner receives the finished good from the manufacturer and sells it to the consumer for r per unit of finished product. But if the product fails, the consumer returns it for full refund and the brand owner incurs the external failure cost of $(r+l)$.
- (4) If the finished product incurs no failure in the market, the brand owner pays w to the manufacturer. For each unit of failures, the manufacturer investigates the fault, but pays w_M if the external failure is identified as manufacturer's fault and w_S if identified as supplier's fault.

Depending on the decentralization vs. centralization control scheme to be implemented, the manufacturer (in decentralization) or brand owner (in centralization) contracts with the supplier through the following sequence of events:

- (5) The manufacturer (or brand owner) and the supplier agree on the unit component price $\{c_1, c_0\}$. The manufacturer under decentralization commits to $\{p\}$ based on its contract with the brand owner.
- (6) The supplier chooses quality enhancement effort $\{q\}$.
- (7) The manufacturer gets the component from the supplier and inspects it. Under centralization the brand owner relies on the inspection information relayed from the manufacturer to compensate the supplier. If the component is identified as good, the manufacturer (or brand owner) pays c_1 to the supplier. If the unit is identified as defective, the supplier is only paid the amount of c_0 .
- (8) The manufacturer then makes the committed quality effort in its production work (p) , and sells the finished product to the brand owner.

Hence, the expected profits for the supplier (S), the manufacturer (M) and the brand owner (B) can be given as follows. In particular, under decentralization, they are

$$\begin{aligned}\pi_S(c_1, c_0 | q_i, p_j, \theta_M) &= c_1 [1 - (1 - q_i)\theta_M] + c_0(1 - q_i)\theta_M - S_i \\ &= c_1 - (c_1 - c_0)(1 - q_i)\theta_M - S_i,\end{aligned}\quad (3)$$

$$\begin{aligned}\pi_M(c_1, c_0, w, w_M, w_S | q_i, p_j, \theta_M) \\ = wp_j q_i + w_M e_M + w_S e_S - c_1 + (c_1 - c_0)(1 - q_i)\theta_M - M_j,\end{aligned}\quad \text{and}\quad (4)$$

$$\pi_B(w, w_M, w_S | q_i, p_j, \theta_M) = rp_j q_i - le_{ij} - [wp_j q_i + w_M e_M + w_S e_S].\quad (5)$$

For centralization, they are

$$\pi_S(c_1, c_0, w_S | q_i, p_j, \theta_M) = c_1 - (c_1 - c_0)(1 - q_i)\theta_M - S_i + w_S e_S,\quad (6)$$

$$\pi_M(w, w_M | q_i, p_j, \theta_M) = wp_j q_i + w_M e_M - M_j,\quad \text{and}\quad (7)$$

$$\begin{aligned}\pi_B(c_1, c_0, w, w_M, w_S | q_i, p_j, \theta_M) \\ = rp_j q_i - le_{ij} - [wp_j q_i + w_M e_M + w_S e_S] - c_1 + (c_1 - c_0)(1 - q_i)\theta_M.\end{aligned}\quad (8)$$

The following evaluates the four different supply chain quality management structures.

Decentralization in a Transaction-Based Supply Chain

In capturing the key features of a decentralized supply chain governance structure, we define the contracting scheme as follows: the brand owner offers a quality contract only to the manufacturer, which then contracts with the component supplier for component quality given the contract with the brand owner. On the other hand, in a supply chain which is characterized as short term transaction-based relationship, each downstream party could not fully penalize the upstream party for defective items delivered and may only withhold the payment at most. They will be captured by the limited liability constraints stated below. As a whole, the manufacturer commits p_H to the supplier (not known to the brand owner) and solves the following single moral hazard problem M(d),

$$\max_{\{c_1, c_0\}} \pi_M(c_1, c_0, w, w_M, w_S | q_H, p_H, \theta_M)$$

$$\text{s.t.} \quad \pi_S(c_1, c_0 | q_H, p_H, \theta_M) \geq \pi_S(c_1, c_0 | q_L, p_H, \theta_M), \quad (9)$$

$$\pi_S(c_1, c_0 | q_H, p_H, \theta_M) \geq 0, \quad (10)$$

$$c_1, c_0 \geq 0. \quad (11)$$

Here (9) is the incentive compatibility constraint [IC(S)] for the supplier to make the high quality enhancement effort, while (10) is the supplier's individual rationality constraint [IR(S)] to participate in such contract. (11) are considered the limited liability constraints, because the manufacturer may not pay the supplier with defective components. Solving (9), we have

$$c_1 - (c_1 - c_0)(1 - q_H)\theta_M - S_H \geq c_1 - (c_1 - c_0)(1 - q_L)\theta_M - S_L, \text{ or}$$

$$c_1 \geq \theta_M \Delta S / \Delta q + c_0. \quad (12)$$

From (9) and (11), (10) is automatically implied, because

$$c_1 - (c_1 - c_0)(1 - q_H)\theta_M - S_H \geq c_1 [1 - (1 - q_L)\theta_M] + c_0(1 - q_L)\theta_M - S_L \geq 0. \quad (13)$$

Since the objective function of the manufacturer is linear in c_1 and c_0 , the optimal solution is given by the binding constraint (12) and $c_0^d = 0$, leading to $c_1^d = \theta_M \Delta S / \Delta q$ (superscript “d” denotes “decentralization”) and

$$\begin{aligned} & \pi_M(c_1^d, c_0^d, w, w_M, w_S | q_i, p_j, \theta_M) \\ &= w p_j q_i + w_M e_M + w_S e_S - c_1^d + (c_1^d - c_0^d)(1 - q_i)\theta_M - M_j \\ &= w p_j q_i + [w_M(1 - a) + w_S a](1 - q_i)(1 - \theta_M) + [w_M h + w_S(1 - h)](1 - p_j)q_i \\ & \quad - c_1^d [1 - (1 - q_i)\theta_M] - M_j. \end{aligned} \quad (14)$$

The brand owner solves the problem B(d):

$$\max_{\{w, w_M, w_S\}} \pi_B(w, w_M, w_S | q_H, p_H, \theta_M)$$

$$\text{s.t.} \quad \pi_M(c_1^d, c_0^d, w, w_M, w_S | q_H, p_H, \theta_M) \geq \pi_M(c_1^d, c_0^d, w, w_M, w_S | q_H, p_L, \theta_M), \quad (15)$$

$$\pi_M(c_1^d, c_0^d, w, w_M, w_S | q_H, p_H, \theta_M) \geq 0, \quad (16)$$

$$w, w_M, w_S \geq 0, \quad (17)$$

where (15)~(17) are respectively the manufacturer's the incentive compatibility [IC(M)], individual rationality [IR(M)], and limited liability constraints where the brand owner is similarly limited in the extent that he could penalize the manufacturer for external product failures in a relational supply chain. Solving (15):

$$\begin{aligned} & wp_H q_H + [w_M(1-a) + w_S a](1-q_H)(1-\theta_M) + [w_M h + w_S(1-h)](1-p_H)q_H \\ & - c_1^d [1 - (1-q_H)\theta_M] - M_H \\ & \geq wp_L q_H + [w_M(1-a) + w_S a](1-q_H)(1-\theta_M) + [w_M h + w_S(1-h)](1-p_L)q_H \\ & - c_1^d [1 - (1-q_H)\theta_M] - M_L \end{aligned}$$

$$\text{i.e., } w - [w_M h + w_S(1-h)] \geq M_H / (q_H \Delta p). \quad (18)$$

From IR(M) in (16):

$$\begin{aligned} & wp_H q_H + [w_M(1-a) + w_S a](1-q_H)(1-\theta_M) + [w_M h + w_S(1-h)](1-p_H)q_H \\ & - c_1^d [1 - (1-q_H)\theta_M] - M_H \\ & = wp_H q_H + w_M [(1-a)(1-q_H)(1-\theta_M) + h(1-p_H)q_H] + w_S [a(1-q_H)(1-\theta_M) + (1-h)(1-p_H)q_H] \\ & - c_1^d [1 - (1-q_H)\theta_M] - M_H \geq 0. \end{aligned} \quad (19)$$

As $c_1^d = \theta_M \Delta S / \Delta q$, we have two scenarios here:

(I) If $\{[1 - (1-q_H)\theta_M] \theta_M S_H / \Delta q + M_H\} / p_H \geq M_H / \Delta p$, then IR in (16) is binding and the

first best solution for B(d) is achieved for a wide range of solution sets $\{w, w_M, w_S\}$.

One of them would be

$$\{w^d = \{[1 - (1-q_H)\theta_M] \theta_M \Delta S / \Delta q + M_H\} / (q_H p_H), w_M^d = 0, w_S^d = 0\}$$

where the profits for brand owner, manufacturer and supplier are respectively

$$\pi_B^{d*} = rp_H q_H - l[1 - p_H q_H - (1 - q_H)\theta_M] - \{[1 - (1 - q_H)\theta_M]\theta_M S_H / \Delta q + M_H\}, \quad (20)$$

$$\pi_M^{d*} = [1 - (1 - q_H)\theta_M]\theta_M S_H / \Delta q + M_H - S_H[1 - (1 - q_H)\theta_M]\theta_M / \Delta q - M_H = 0, \quad (21)$$

$$\pi_S^{d*} = S_H \{[1 - (1 - q_H)\theta_M]\theta_M / \Delta q - 1\}. \quad (22)$$

(II) $\{[1 - (1 - q_H)\theta_M]\theta_M S_H / \Delta q + M_H\} / p_H < M_H / \Delta p$, then IC(M) in (15) is binding while

IR(M) is not, leading to the second best solution as

$\{w^d = \{M_H / (q_H \Delta p), w_M^d = 0, w_S^d = 0\}$ and the profits for brand owner, manufacturer

and supplier are respectively

$$\pi_B^{d-} = rp_H q_H - l[1 - p_H q_H - (1 - q_H)\theta_M] - p_H M_H / \Delta p < \pi_B^*, \quad (23)$$

$$\pi_M^{d-} = M_H [p_H / \Delta p - 1] - S_H [1 - (1 - q_H)\theta_M]\theta_M / \Delta q > \pi_M^* = 0, \quad (24)$$

$$\pi_S^{d-} = S_H \{[1 - (1 - q_H)\theta_M]\theta_M / \Delta q - 1\} = \pi_S^*. \quad (25)$$

Decentralization in a Relation-Based Supply Chain

In a supply chain structure characterized as long-term and relational, each downstream party could afford the time flexibility and legal resources to fully penalize the upstream party for defective items delivered. Thus the problem of the manufacturer and the brand owner are similar to above without the limited liability constraints. In particular, the manufacturer's problem M(d) without (11) leads to a first best solution with binding (9) and (10) constraints [IC(S) and IR(S)],

leading to $c_1 - c_0 = \theta_M S_H / \Delta q$, and the supplier's profit as

$$\pi_S^{d+}(c_1, c_0 | q_H, p_H, \theta_M) = c_1 - (c_1 - c_0)(1 - q_H)\theta_M - S_H = 0. \quad (26)$$

Thus,

$$c_1^d = (1 - q_H)\theta_M \theta_M S_H / \Delta q + S_H, \quad (27)$$

$$c_0^d = (1 - q_H)\theta_M\theta_M S_H / \Delta q + S_H - \theta_M S_H / \Delta q = \theta_M S_H / \Delta q [(1 - q_H)\theta_M + \Delta q / \theta_M - 1] < 0. \quad (28)$$

Thus

$$\begin{aligned} \pi_M(c_1^d, c_0^d, w, w_M, w_S | q_H, p_j, \theta_M) &= wp_j q_H + w_M e_M + w_S e_S - S_H - M_j \\ &= wp_j q_H + [w_M(1 - a) + w_S a](1 - q_H)(1 - \theta_M) + [w_M h + w_S(1 - h)](1 - p_j)q_H - S_H - M_j. \end{aligned} \quad (29)$$

Similarly, the brand owner's problem B(d) is now solved without the liability constraints (17)

and yields the first best solution with the binding IR(M) in (16), while the IC(M) in (15) does not

have to be binding. This suggests a multiple optimal solution set. One optimal solution with the

binding IC(M) can be solved by setting $w_S = 0$ in

$$w - [w_M h + w_S(1 - h)] = \Delta M / (q_H \Delta p), \quad (30)$$

$$\pi_M^{d+}(c_1^d, c_0^d, w, w_M, w_S | q_H, p_j, \theta_M)$$

$$\begin{aligned} &= wp_H q_H + w_M [(1 - a)(1 - q_H)(1 - \theta_M) + h(1 - p_H)q_H] \\ &+ w_S [a(1 - q_H)(1 - \theta_M) + (1 - h)(1 - p_H)q_H] - S_H - M_H = 0. \end{aligned} \quad (31)$$

Hence

$$\begin{aligned} w^d &= \{ [(1 - a)(1 - q_H)(1 - \theta_M) + h(1 - p_H)q_H] M_H / (q_H \Delta p) + hS_H + hM_H \} / \\ &[(1 - a)(1 - q_H)(1 - \theta_M) + hq_H], \end{aligned} \quad (32)$$

$$w_M^d = [S_H + M_H - M_H / \Delta p] / [(1 - a)(1 - q_H)(1 - \theta_M) + hq_H]. \quad (33)$$

$$\pi_B^{d+} = rp_H q_H - l[1 - p_H q_H - (1 - q_H)\theta_M] - [S_H + M_H]. \quad (34)$$

Centralization in a Transaction-Based Supply Chain

In a centralization scheme, the brand owner contracts directly with both the manufacturer and the

component supplier. This contracting approach resembles the one used in supply chains such as

Apple's and Toyota's. Another example is General Motors' tiered supply chain network, which

allows GM to bypass its Tier 1 suppliers and to contract directly with its smaller Tier 2 suppliers

(Sherefkin and Barkholz, 2009). The supplier and manufacturer are unaware of each other's

quality commitment, but assume that it would be p_H and q_H respectively, given that this is the interested direction of the brand owner and the existence of the direct contract with manufacturer.

Thus, in a short term transaction-based relationship, the brand owner solves the following problem B(c):

$$\max_{\{c_1, c_0, w, w_M, w_S\}} \pi_B(c_1, c_0, w, w_M, w_S | q_i, p_j, \theta_M)$$

$$\text{s.t.} \quad \pi_M(w, w_M | q_H, p_H, \theta_M) \geq \pi_M(w, w_M | q_H, p_L, \theta_M), \quad (35)$$

$$\pi_M(w, w_M | q_H, p_H, \theta_M) \geq 0, \quad (36)$$

$$w, w_M \geq 0, \quad (37)$$

$$\pi_S(c_1, c_0, w_S | q_H, p_H, \theta_M) \geq \pi_S(c_1, c_0, w_S | q_L, p_H, \theta_M), \quad (38)$$

$$\pi_S(c_1, c_0, w_S | q_H, p_H, \theta_M) \geq 0, \quad (39)$$

$$c_1, c_0, w_S \geq 0, \quad (40)$$

where $\{\pi_B, \pi_M, \pi_S\}$ are given in (6)~(8). As in decentralization, here (35) and (38) are the incentive-compatibility constraints for the manufacturer and the supplier to exert quality enhancement efforts in their respective processes. Similarly, (36) and (39) are participation constraints IR(M) and IR(S) that require both the manufacturer and the supplier to make nonnegative returns when making quality efforts. The problem can be decomposed into two sub-problems involving $\{c_1, c_0, w_S\}$ with (38)~(40) and $\{w, w_M\}$ with (35)~(37) respectively.

From IC(M) in (35),

$$\begin{aligned} & wp_H q_H + w_M \{(1-a)(1-q_H)(1-\theta_M) + h(1-p_H)q_H\} - M_H \\ & \geq wp_L q_H + w_M \{(1-a)(1-q_H)(1-\theta_M) + h(1-p_L)q_H\} - M_L \end{aligned}$$

$$\text{or } w - w_M h \geq \Delta M / (q_H \Delta p) = M_H / (q_H \Delta p). \quad (41)$$

Then (35) and (37) together imply IR(M) in (36) is automatically satisfied (not binding). Then according to the objective function, the optimal solution for the manufacturer's side is

$$\{w^c = \{M_H / (q_H \Delta p), w_M^c = 0\}.$$

From ICs in (38), we have

$$\begin{aligned} c_1 - (c_1 - c_0)(1 - q_H)\theta_M - S_H + w_S[a(1 - q_H)(1 - \theta_M) + (1 - h)(1 - p_H)q_H] \\ \geq c_1 - (c_1 - c_0)(1 - q_L)\theta_M - S_L + w_S[a(1 - q_L)(1 - \theta_M) + (1 - h)(1 - p_H)q_L] \\ c_1 \geq \theta_M \Delta S / \Delta q + c_0 + w_S[a(1 - \theta_M) - (1 - h)(1 - p_H)]. \end{aligned} \quad (42)$$

We assume (as a sufficient condition) that the brand owner's investigative technology is characterized with $a(1 - \theta_M) > (1 - h)(1 - p_H)$ [combined with component inspection, the chance of the supplier being correctly assigned for its own component-caused external failure is higher than the chance of being **incorrectly** assigned for the manufacturer-caused external failure].

Thus given the objective function could be maximized by minimizing $\{c_1, c_0, w_S\}$ subject to (42) and (40), the optimal solution is $\{c_1^c = \theta_M \Delta S / \Delta q, c_0^c = 0, w_S^c = 0\}$, leading to the following profits for supply chain parties:

$$\pi_S^{c^-} = S_H \{[1 - (1 - q_H)\theta_M] \theta_M / \Delta q - 1\} = \pi_S^{d^-} = \pi_S^{d^*}, \quad (43)$$

$$\pi_M^{c^-} = M_H [p_H / \Delta p - 1] > \pi_M^{d^-} > \pi_M^{d^*}, \quad (44)$$

$$\begin{aligned} \pi_B^{c^-} &= rp_H q_H - l[1 - p_H q_H - (1 - q_H)\theta_M] - p_H M_H / \Delta p - [1 - (1 - q_H)\theta_M] \theta_M S_H / \Delta q \\ &= \pi_B^{d^-} - [1 - (1 - q_H)\theta_M] \theta_M S_H / \Delta q < \pi_B^{d^-} < \pi_B^{d^*}. \end{aligned} \quad (45)$$

Centralization in a Relation-Based Supply Chain

Again, here there are no limited liability constraints, i.e., B(c) is solved without (37) and (40).

Hence, first best solution (details are omitted here due to similarities to above) is achieved, with

$$\pi_B^{c^+} = rp_H q_H - l[1 - p_H q_H - (1 - q_H)\theta_M] - [S_H + M_H] = \pi_B^{d^+}, \quad (46)$$

$$\pi_S^{c+} = \pi_M^{c+} = \pi_S^{d+} = \pi_M^{d+} = 0. \quad (47)$$

$$\begin{aligned} \pi_S^{c-} + \pi_M^{c-} + \pi_B^{c-} &= \pi_S^{c+} + \pi_M^{c+} + \pi_B^{c+} = \pi_S^{d*} + \pi_M^{d*} + \pi_B^{d*} = \pi_S^{d-} + \pi_M^{d-} + \pi_B^{d-} = \pi_S^{d+} + \pi_M^{d+} + \pi_B^{d+} \\ &= rp_H q_H - l[1 - p_H q_H - (1 - q_H)\theta_M] - M_H - S_H. \end{aligned} \quad (48)$$

These results allow us to conduct some detailed analysis of the effects of supply chain quality contracting structures on the performance of supply chain parties. Details are presented in the following section.

ANALYSIS AND DISCUSSIONS

Summarizing the above results, we identify the following findings that provide important theoretical and managerial implications.

Proposition 1: *Supplier under either decentralization or centralization scheme receives the same compensation contracts and earns the same expected profit:*

$$\pi_S^{c-} = \pi_S^{d-} = \pi_S^{d*} = S_H \{ [1 - (1 - q_H)\theta_M] \theta_M / \Delta q - 1 \} > 0 \text{ and } \pi_S^{c+} = \pi_S^{d+} = 0.$$

This proposition indicates that the supplier is indifferent regardless of supply chain quality control scheme. Whether the manufacturer or the brand owner contracts with the supplier to assure high quality component supply, it requires the same amount of compensations to the supplier. The supplier with a transaction relationship with the contracting party could still earn a positive return because the downstream parties are limited by the scope of payments that can be implemented. However, the supplier in a long-term relation-based contract could be fully penalized for the non-conforming components and external failures identified as the supplier's faults. This tradeoff balances supplier contracts and profits between centralization and decentralization.

Proposition 2: (a) *For transactional supply chains, the manufacturer earns more expected profit while the brand owner earns less profit under centralization than under decentralization*

$$(\pi_M^{c-} > \pi_M^{d-} > \pi_M^{d*}, \text{ and } \pi_B^{c-} < \pi_B^{d-} < \pi_B^{d*}).$$

(b) *For relational supply chains, the manufacturer earns zero profit while the brand owner earns the same maximum profit under centralization or decentralization*

$$(\pi_M^{c+} = \pi_M^{d+} = 0, \pi_B^{c+} = \pi_B^{d+} = rp_H q_H - l[1 - p_H q_H - (1 - q_H)\theta_M] - [S_H + M_H]).$$

Thus from the brand owner standpoint, centralization and decentralization in supply chain quality management are equivalent for a relational supply chain. However, for a transaction-based supply chain, the brand owner would prefer decentralization since ceding the control of component quality to the manufacturer allows it to concentrate on guiding the manufacturer to achieve both high processing quality and component quality, without having to compensate the supplier for inducing high component quality in centralization.

Proposition 3: *In a transactional supply chain, if*

$\{[1 - (1 - q_H)\theta_M]\theta_M S_H / \Delta q + M_H\} / p_H \geq M_H / \Delta p$, *then in decentralization contracts the brand owner profit is the same as first best; otherwise, the brand owner profit is second best.*

The cost to attract the manufacturer to participate includes the manufacturer's own quality enhancement cost plus manufacturer's incentives to attract the supplier to exert quality effort in delivering components. Therefore it could be substantial if the supplier's cost of quality effort is very high. On the other hand, the finished product price differential used by brand owner to attract manufacturer's best quality effort is increasing in the manufacturer's quality cost, but decreasing in the manufacturer's high quality level. This proposition indicates that in a transaction-based supply chain, if it costs more for the brand owner to attract the manufacturer to participate in the quality contract than to exert quality effort, the brand owner achieves the same

profit as first best. Otherwise, inducing the best quality effort from the manufacturer is a dominating force, reducing the brand owner's profit to a second best level.

Proposition 4: *The supply chain earns the same total profit regardless of centralization or decentralization, relation-based or transaction-based contracts.*

$$\pi_S^{c-} + \pi_M^{c-} + \pi_B^{c-} = \pi_S^{c+} + \pi_M^{c+} + \pi_B^{c+} = \pi_S^{d*} + \pi_M^{d*} + \pi_B^{d*} = \pi_S^{d-} + \pi_M^{d-} + \pi_B^{d-} = \pi_S^{d+} + \pi_M^{d+} + \pi_B^{d+}$$

Interestingly, regardless of the time nature or structure of the supply quality contracts, the supply chain as a whole earns the same total profit as the product prices and component prices required to attract the manufacturer and supplier to exert the best effort only affects the relative profit of each supply chain party. With the best average quality achieved at the component and finished product level, the profit potential for the whole supply chain is realized.

Proposition 5: *When $a(1-\theta_M) > (1-h)(1-p_H)$, each supply chain party's profit under either centralization or decentralization is not affected by "a" or "h".*

This proposition points to a very interesting result in that as long as the brand owner's investigative technology has reasonable accuracy in terms of correctly vs. incorrectly identifying the responsible party for the product failure, the actual magnitude or small variation of the investigative technology has no impact on the profit achieved. In a transaction-based supply chain relationship, this is mainly caused by the fact that the most the brand owner can penalize the manufacturer or supplier for faults in external failures is to make no payment for defective product or component delivery. Thus the manufacturer or supplier only makes profits when the products or components delivered are truly good, which is independent of the investigative technology used by the brand owner. Under a long term relation-based contracts, the supplier's and manufacturer's profits are completely extracted by the brand owner, using strong penalties when the manufacturing process or components are assigned as the causes of external failures. In

both cases, the manufacturer's or supplier's profits are not related to the brand owner's failure investigative technology.

CONCLUSION

In this paper, we develop quality contracting models in a three-stage supply chain. The objective is to better understand whether and how different supply chain quality contracts affect supply chain performance. Four types of contracting schemes are implemented under a centralized and a decentralized supply chain structure, with a relation-based and a transaction-based supply chain relationship. These contracting alternatives are motivated by a growing trend of outsourcing and increasing complexity of supply chain relationships.

Our results show that first, contrary to the conventional wisdom with regard to supply chain centralization vs. decentralization, and relational vs. transactional supply chain relationships, the supply chain as a whole can be equally efficient in delivering quality products under these alternative schemes. This indicates that when the quality inducing incentive contracts are designed appropriately, a decentralized supply chain, such as those under outsourcing, for example, should not necessarily expect a lower level of performance than a centralized supply chain, as long as supply chain parties involved are by and large risk neutral. By the same token, a supply chain featuring a short-term, transaction-based supply chain relationship does not necessarily perform worse than a supply chain with a long-term and close relationship. Second, however, the indifference in overall supply chain performance does not always translate to equal performance for all supply chain members. In fact, when the supply chain operates under short-term transactions, the manufacturer can benefit from centralization of the supply chain while the brand owner prefers decentralization. Third, beyond a reasonable level of investigative accuracy, quality inspection has no immediate effect on supply chain performance. This indicates that

while quality inspection is a crucial component of supply chain quality control, supply chain efficiency may not fully respond to higher inspection effectiveness once a throughput level of inspection accuracy is reached. These results indicate that even when the supply chain members are all risk neutral, quality contracting schemes in supply chains (transaction-based vs. relational) and supply chain governance structures (centralized vs. decentralized) can have various impact on supply chain members' performances.

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