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Quality Assurance Contracts in a Multi-Level Supply Chain

Abstract

Firms are often challenged in controlling quality when their supply chains become longer because of outsourcing. Should a firm change its quality control approach to adapt to the longer supply chain? This paper aims to address the question by studying a brand owner's optimal choice between two commonly used quality control approaches: inspection-based quality control and external failure-based quality control, in two supply chains: a dyadic supply chain and a multi-level supply chain where the brand owner outsources manufacturing to a contract manufacturer. Our study finds that the brand owner's optimal choice between the two quality control approaches could be opposite in the two supply chains. Specifically, we show that if agency cost exists between the contract manufacturer and the brand owner, it is possible that the brand owner should switch to inspection-based quality control in the multi-level supply chain from external failure-based quality control that is more profitable for the brand owner in the dyadic supply chain. Unlike an external failure-based approach that only takes action after an external failure occurs, inspections add extra value to supply chains directly by preventing defective components and finished products from becoming external failures. In the dyadic supply chain, this extra value created by inspections is internal to the brand owner, who performs both manufacturing and inspections, and therefore, will not affect agency costs. However, in the multi-level supply chain, where the contract manufacturer performs manufacturing and component inspection, part of the extra value created by inspections is not internal to the brand owner anymore and would affect how payments are made and profits are allocated with agency cost implications along the supply chain. In fact, inspections can serve as effective levers for the brand owner to limit the manufacturer's profit by excluding defective finished products and components, which in turn reduce agency costs. Hence, the efficiency of an inspection-based approach relative to an external failure-based approach can be higher in the multi-level supply chain than in the dyadic one. Our findings suggest that it can be potentially harmful to assume that a quality control approach, which had success in a dyadic supply chain, would continue to achieve the same success in a longer supply chain with outsourced manufacturing. Firms must pay close attention to changes in supply chain structures and re-evaluate the efficiencies of different quality control approaches accordingly. Failing to do so could lead firms with established reputation in quality (e.g., Mattel) to stumble badly on product quality.

Key words: quality control, inspection, external failure, supply chain, outsourcing, moral hazard, accounting and operations interface

JEL Classifications: D81, D82, D86, L14, L15, L24.

1. Introduction

Quality inspection of products and components adds value to firms by preventing defects from reaching markets causing external failures. However, costly quality inspection has been increasingly replaced by quality control mechanisms that only respond to external failures (Balachandran and Radhakrishnan 2005). Meanwhile, globalization in recent decades has stretched supply chains longer with more layers as a result of outsourcing and offshoring. A longer supply chain leads to reduced supply chain visibility and effectiveness of performance measures, and therefore brings new challenges to established quality programs. Recent high profile blunders in product quality and recalls in different industries have highlighted these challenges and called for cohesive and coordinated efforts to address these challenges (Chao, et al. 2009; Thirumalai and Sinha 2011).

Mattel Inc., a leading toy maker in the world with the best quality reputation in the industry, was caught selling toys with high levels of lead in their paint in 2007. Mattel had to recall a large number of toys, and suffered a substantial loss in market value as well as reputation. The paint with a high level of lead was supplied by Dongxing New Energy Co. to one of Mattel's main outsourced manufacturers, Lee Der Industrial Company, who had manufactured toys for Mattel since 1993. A critical component of Mattel's contracts with its vendors is vendor compliance with quality standards for materials such as paint. Mattel also conducted audits of certified paint suppliers and vendors to ensure that Mattel's requirements were being followed (Tang 2008; Bapuji and Beamish 2008a, and b). Vendor certification allows pre-qualified suppliers' components to bypass costly and time consuming inspections and be directly used in final product manufacturing. Suppliers are only penalized once external failures occur. When the quality failure happened and Lee Der and its paint supplier were found responsible by follow-up audits, Mattel penalized the culprits and all shipments from Lee Der were cancelled (Bapuji and Beamish 2008a). Mattel's extensive base of certified suppliers had grown to 37 in China by 2007, which was believed to result in better operational performance (Ittner et al. 1999; Anderson, et al. 1999). However, industry experts argued that as its supply chain became longer due to outsourcing, Mattel had started to lose control of its supply chain (Tang 2008).

The quality failure of Mattel naturally leads to an important question: *Should a firm change its quality control approach as its supply chain becomes longer due to outsourcing?* More specifically, given the increasing use of quality control approaches based on external

failures, could these high profile quality failures suggest that alternative quality control approaches, such as the old fashion quality inspection may perform better in a longer supply chain? This research, following the moral hazard framework used in existing research (Hwang, et al. 2006; Balachandran and Radhakrishnan 2005; Baiman et al. 2000, 2001), attempts to shed light on the performances of quality control approaches in multi-level supply chains with outsourced manufacturing. The findings contribute to the existing literature by providing better understandings in how the existence and distribution of agency costs along a supply chain could affect firms' optimal choice of quality control approaches in multi-level supply chains.

Quality management literature has provided significant insight as to why a buyer may prefer a quality program based on external failures despite the higher effectiveness of inspection—it is often because of a lower agency cost associated with such a program. In particular, Balachandran and Radhakrishnan (2005) examine warranty contracts based on information from the inspection of incoming products and external failures. Their quality control schemes are similar to this research but they are examined and compared in a dyadic supply chain. Their important findings indicate that first best quality may or may not be achieved depending on whether the warranty contract is designed based on external failures or incoming inspection, and whether the buyer's quality is observable (single moral hazard) or unobservable (double moral hazard). Hwang, et al. (2006) compare an inspection inspired quality appraisal regime and vendor certification, and conclude that certification may outperform appraisal due to a lower agency cost induced by certification. Vendor certification can be associated with a warranty contract that allows the vendor to be penalized in case of external failures attributed to the vendor, much like that of Mattel's. Mann and Wissink (1990) investigate incentives for product quality by comparing money-back warranties and replacement warranties under a single moral hazard setting. Baiman et al. (2000) use a double moral hazard setting to study penalties based on incoming inspection information with unobservable quality improvement efforts. Other studies (e.g. Cooper and Ross 1985, and Reyniers and Tapiero 1995a and b) of quality control issues also involve moral hazard in a dyadic relationship. In particular, Lee and Li (2011) consider a dyadic supply chain in which a buyer sources a component from a supplier. They study whether the buyer should improve the quality of the component by using inspection or by collaborating with the supplier and exerting quality effort together with the supplier. However,

they do not consider how the buyer's preference over the two quality control methods changes as the supply chain becomes longer with outsourcing.

The moral hazard issues in quality control becomes more complicated when the supply chain becomes longer with more suppliers and subcontractors involved as a result of outsourcing and delegating key decisions. Delegation has been found to be a valuable driver in similar contexts with asymmetric information (Zhang 1997; Kulp 2002; Rajan and Reichelstein 2004; Zhu et al. 2007). In addition, Melumad and Reichelstein (1987) examine delegation vs. centralization in the context of control and information. Bushman et al. (2000) use a linear contract to develop conditions under which delegation may or may not have value. Rajan and Reichelstein (2004) study a generalized resource allocation problem when resource productivity information and agent's (division's) effort are not observable due to delegation or decentralization. Saouma (2008) studies an outsourcing situation with moral hazard where a manufacturer outsources an assembly in a dyadic supply chain and finds that the manufacturer prefers more testing under outsourcing. In addition, Schmitz (2005) examines structural issues in the control of sequential tasks with moral hazard, and shows that separating control of tasks can be more efficient than integrating control of the tasks. Based on the literature, the challenge of efficient quality control in an extended and decentralized supply chain has not been studied in existing literature to our best knowledge.

To examine the impact of added levels in a supply chain on the performances of quality control approaches, this research considers two simple supply chain structures: a dyadic supply chain that resembles those used in previous studies, where a brand owner manufactures a product and controls its quality using a component directly sourced from a component supplier; and a multi-level supply chain, where the brand owner outsources product manufacturing to a contract manufacturer who will source the component from the same component supplier. We study two types of commonly adopted quality control approaches: Inspection-based quality control, which manages quality completely based on inspection information on both incoming components and finished products, and external failure-based quality control, which manages quality completely based on information from realized external failures. Under inspection-based quality control, in the dyadic supply chain, the brand owner performs finished product manufacturing, component inspection and finished product inspection, whereas in the multi-level supply chain, the brand

owner only performs finished product inspection and the contract manufacturer performs finished product manufacturing and component inspection.

Our study finds that the brand owner's optimal choice of quality control approach could indeed change when its supply chain becomes longer with outsourced manufacturing. We show that how agency costs are distributed along the multi-level supply chain plays a critical role in determining the brand owner's choice of quality control approach. Specifically, if agency costs exist between the contract manufacturer and the brand owner, it is possible that the brand owner should switch to inspection-based quality control in the multi-level supply chain from external failure-based quality control that is more profitable for the brand owner in the dyadic supply chain. In addition to inducing quality efforts, as compared to an external failure-based approach which is only activated after an external failure occurs, inspections directly add extra value to supply chains by preventing defective components and finished products from becoming external failures while receiving full prices. In the dyadic supply chain, part of this extra value created by inspections is internal to the brand owner who performs both manufacturing and inspections, and therefore, will not affect agency costs. However, in the multi-level supply chain where the contract manufacturer performs manufacturing and component inspection, the extra value created by inspections is not internal to the brand owner anymore. This would affect how payments are made, profits are allocated, and agency costs are incurred in the supply chain. Actually, inspections can serve as effective levers for the brand owner to limit the manufacturer's profit by excluding defective finished products and components, which in turn reduces agency costs. As a result, the efficiency of the inspection-based approach relative to the external failure-based approach is higher in the multi-level supply chain than in the dyadic supply chain.

Our results indicate that it can be unwise and potentially harmful to assume that a quality control approach, which had success in a dyadic supply chain, would continue to achieve the same success in a longer supply chain with outsourced manufacturing. When the structure of a supply chain changes such as becoming longer due to outsourced manufacturing, how quality control activities interact with other value-added activities such as manufacturing and influence agency costs can be very different for different quality control approaches. Hence, firms must pay close attention to changes in supply chain structures and re-evaluate the efficiencies of different quality control approaches accordingly in order to determine the right quality control

approach. Otherwise, a firm with established reputation in quality (e.g., Mattel) could stumble badly on product quality.

The rest of the paper is organized as follows. Section 2 studies inspection-based quality control and external failure-based quality control in a dyadic supply chain. Section 3 extends the model to a multi-level supply chain with outsourced manufacturing. Section 4 discusses several extensions of the models. Section 5 concludes the study.

2. The Base Model: A Dyadic Supply Chain

In the base model, we consider a dyadic supply chain, as shown in Figure 1(a), in which a risk neutral brand owner (e.g., Mattel) designs, manufactures, and markets a product (e.g., a toy) using a component (e.g., paint) supplied by a risk neutral component supplier. Each finished product needs y units of the component. The brand owner plans to produce x units of the product; in turn the brand owner contracts with the supplier for xy units of the component. Without loss of generality, we set $x = 1$ and $y = 1$. Selling the product in the market, the brand owner receives a revenue r for a product with good quality, but receives a penalty of l for a product with bad quality (e.g., in the form of product return and disposal costs and lost customer lifetime value).

[Insert Figure 1 about here]

For a finished product to be in good quality, both the manufacturing process and the component must be in good quality. In other words, the quality of the finished product is jointly determined by the quality of the component supplied by the supplier and the quality of the brand owner's manufacturing process (e.g., Tagaras and Lee 1996; Ittner 1999). The brand owner and the supplier can exert efforts to improve the quality of the manufacturing process and the quality of the component, respectively. The quality efforts of both parties are private actions and are not verifiable, nor contractible. 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 $S(q)$. We consider binary quality effort levels where high (H) and low (L) quality efforts are the equivalent of making effort and no effort respectively, i.e., $q \in \{q_H, q_L\}$ with $\Delta q = q_H - q_L > 0$ and corresponding quality cost $\{S_H, S_L\}$ with $S_L = 0$ and $\Delta S = S_H - S_L > 0$. Similarly, the brand owner's quality effort in the manufacturing process, $p \in \{p_H, p_L\}$ ($\Delta p = p_H - p_L > 0$ and $p \in (0,1)$), is the probability that the manufacturing process performs the desired functions. The

corresponding quality effort costs are $\{M_H, M_L\}$ respectively, with $M_L = 0$ and $\Delta M = M_H - M_L > 0$. We assume that the quality of the manufacturing process and the quality of the component are independent. Similar settings have been used in existing literature to study quality issues in supply chains (e.g., Balachandran and Radhakrishnan 2005; Hwang et al. 2006).

Because both the manufacturing process and the component must be in good quality, i.e., perform their desired functions, to have a good quality finished product, the probability that a finished product is in good quality is given by pq . To ensure the quality of the finished product, the brand owner can implement quality control programs to monitor and incentivize the quality of the component supplied by the supplier as well as the quality of its manufacturing process. In this paper, we consider two widely adopted quality control approaches: inspection-based quality control and external failure-based quality control. Both quality control approaches can be viewed as specific forms of warranty contracts (see Balachandran and Radhakrishnan 2005).

2.1. Inspection-based Quality Control

Under inspection-based quality control, all quality related activities in the supply chain (e.g., those involved in component quality and manufacturing process and finished product quality) are controlled and contracted completely based on the outcomes of inspections. In the dyadic supply chain, the brand owner inspects the incoming component and contracts with the component supplier based on the information of the component inspection. The brand owner inspects the incoming components using an inspection technology and incurs an inspection cost of $I \geq 0$. The inspection technology is not perfect in detecting quality problems: it does not reject a good unit, nor does it identify all defective units. Specifically, the probability of the inspection technology identifying a defective component is θ , leading to the expected component rejection rate as $(1 - q_i)\theta$ for $i = H, L$. Therefore, the amount of finished product produced with “good manufacturing but bad components” by the brand owner is $(1 - q_i)(1 - \theta)p_j$ for $i, j = H, L$, while the amount of finished product produced with “bad manufacturing” by the brand owner is $[q_i + (1 - q_i)(1 - \theta)](1 - p_j)$. This leads to the total amount of defective finished product before the final product inspection as $f(q_i, p_j, \theta) = [1 - p_j q_i - (1 - q_i)\theta]$, for $i = H, L$.

The brand owner then inspects the finished product using a finished product inspection technology with an inspection cost of $I_F \geq 0$.¹ The inspection technology also does not reject a good unit, nor does it identify all defective units. Specifically, the probability of the inspection technology identifying a defective finished product is δ , leading to the finished product rejection rate as $f(q_i, p_j, \theta)\delta$ which we call internal failure rate. As a result, along with $p_j q_i$ good finished products, $f(q_i, p_j, \theta)(1 - \delta)$ defective finished products will be sold to the market and lead to external failure.

Under quality control based on inspection, the brand owner (denoted with a subscript BM as brand owner-manufacturer) will contract to compensate the component supplier (denoted with a subscript S) with $\{c_1, c_0\} \geq 0$ per unit for “accepted” components, and “rejected” components after the inspection, respectively. The sequence of events is as follows:

- (1) The brand owner and the supplier agree on the component prices $\{c_1, c_0\}$.
- (2) The supplier chooses quality enhancement effort q and supplies the component to the brand owner.
- (3) The brand owner inspects the component. If the component is identified as good, the brand owner pays c_1 to the supplier and accepts the component for manufacturing. If the component is identified as defective, the brand owner pays c_0 to the supplier and rejects the component.
- (4) The brand owner then makes the quality effort p in its manufacturing process, and inspects the finished product. If the finished product passes the inspection, the brand owner will sell it in the market for r . Otherwise, the brand owner will not sell the finished product in the market and incurs an internal failure cost of m . If the finished product is sold in the market after passing the finished product inspection but fails in the market, the brand owner incurs an external failure cost of $l (> m)$.

The supplier's profit function under quality control based on inspection is,

$$\pi_S(c_1, c_0 | q_i, p_j, \theta) = c_1 [1 - (1 - q_i)\theta] + c_0 (1 - q_i)\theta - S_i. \quad (1)$$

¹ We thank an anonymous reviewer for the suggestion of finished product inspection.

The first two terms in the supplier profit function are the expected compensation the supplier would receive from the brand owner based on the component inspection outcome and the last term is the cost of quality effort. Thus, the brand owner's profit function is,

$$\begin{aligned} \pi_{BM}(c_1, c_0 | q_i, p_j, \theta, \delta) = & rp_j q_i - lf(q_i, p_j, \theta)(1 - \delta) - mf(q_i, p_j, \theta)\delta \\ & - [c_1 [1 - (1 - q_i)\theta] + c_0(1 - q_i)\theta] - M_j - I - I_F. \end{aligned} \quad (2)$$

The first term is the revenue from selling products with good quality. The second and the third term are the expected external failure cost and the expected internal failure cost, respectively. The fourth term is the compensation to the supplier for the component, and the remaining terms are the costs of manufacturing quality effort and inspections. The brand owner solves the following program under quality control based on inspection (BM-I),

Program BM-I (brand owner-supplier-under-inspection):

$$\max_{\{c_1, c_0\} \geq 0} \pi_{BM}(c_1, c_0 | q_i, p_j, \theta, \delta)$$

Subject to

$$IC_S^I: \quad \pi_S(c_1, c_0 | q_H, p_H, \theta) \geq \pi_S(c_1, c_0 | q_L, p_H, \theta),$$

$$IR_S^I: \quad \pi_S(c_1, c_0 | q_H, p_H, \theta) \geq 0.$$

The first constraint is incentive compatibility constraint (IC), which requires supplier effort in producing high quality product and the second is the individual rationality constraint (IR). Note that the IC constraint is based on the brand owner commitment of high effort.²

Solving program BM-I leads to a binding IC_S^I , which along with $\{c_1, c_0\} \geq 0$ implies IR_S^I is satisfied. So the optimal solution is given by $c_0^* = 0$, and $c_1^* = S_H / (\theta \Delta q)$. The component supplier's profit is

$$\pi_S^* = \frac{S_H}{\Delta q} \left(q_L + \frac{1}{\theta} - 1 \right) > 0,$$

which implies that only the second-best solution is possible. The brand owner's profit is

$$\pi_{BM}^* = rp_H q_H - [l(1 - \delta) + m\delta][1 - p_H q_H - (1 - q_H)\theta] - (\pi_S^* + S_H + M_H + I + I_F). \quad (3)$$

² Without the high effort commitment, the constraint becomes $\pi_S(c_1, c_0 | q_H, p_j, \theta) \geq \pi_S(c_1, c_0 | q_L, p_j, \theta)$, which does not lead to qualitative changes in the results.

All derivations and proofs are provided in the Technical Appendix. The supplier's profit represents the agency cost for the brand owner. Note that π_s^* decreases in θ but increases in $S_H / \Delta q$, the cost effectiveness of quality effort at the supplier, which is also considered as the strength of the incentives necessary to induce the effort. A higher ratio $S_H / \Delta q$ means the supplier needs to incur higher cost to achieve the same quality improvement, and thus requires higher compensation from the brand owner for the effort. π_{BM}^* increases in both θ and the finished product inspection accuracy δ . It is intuitive that the higher the component inspection accuracy, the lower the supplier agency cost and the higher the brand owner's profit. The second term in the brand owner's profit π_{BM}^* , $[l(1-\delta) + m\delta][1 - p_H q_H - (1 - q_H)\theta]$ is the expected external failure and internal failure costs.

2.2. External Failure-based Quality Control

Alternatively, the quality related activities in the supply chain can be controlled and contracted completely based on potential external failures. Under this approach, the brand owner does not conduct component inspection or finished product inspection before a finished product is manufactured and sold in the market. The brand owner would unconditionally accept the component provided by the supplier. The brand owner now relies on identifying the responsibility of an external failure once it occurs through quality audit to incentivize quality effort from the component supplier.

If an external failure occurs after a finished product is sold in the market, the brand owner then applies a quality audit technology, at a cost of $A \geq 0$, to investigate the external failure and identifies the cause and responsibility of the external failure (see Balachandran and Radhakrishnan, 2005). In Mattel's case, such quality audit is an integral component of internal investigation in case of external failure (Bapuji and Beamish 2008a). The outcome of quality audit can be shared in the supply chain (Kulp et al. 2004), as the basis of penalties for the responsible parties. The quality audit technology is imperfect too: there is a probability, a , that the supplier is correctly held responsible for the external failure due to unqualified component, and a probability, h , that the brand owner is correctly held responsible for quality problems in its manufacturing process despite good components. The proportions of external failures that the audit technology identifies as the supplier's and brand owner's faults are respectively

$$e_s(q_i, p_j) = a(1 - q_i) + (1 - h)(1 - p_j)q_i, \quad (4)$$

and

$$e_M(q_i, p_j) = (1 - a)(1 - q_i) + h(1 - p_j)q_i, \quad (5)$$

where $a \in (0, 1]$ and $h \in [0, 1]$. The parameters $\{a, h\}$ define the accuracy of the quality audit technology, with higher a and higher h indicating higher accuracy. Therefore, the external failure rate which is essentially $e_s(q_i, p_j) + e_M(q_i, p_j)$ can be written as

$$e(q_i, p_j) = 1 - p_j q_i, \text{ for } i, j = H, L.$$

It is worth noting that the external failure rate is independent of the precisions of the quality audit technology (i.e., a and h) after quality efforts are chosen. While the quality audit could influence the choices of quality efforts, as an activity only occurs after external failures, it cannot reduce the external failure rate directly.

Under external failure-based quality control, the brand owner will contract to compensate the component supplier with $\{c_1, c_0\} \geq 0$ per unit conditional on whether the supplier is responsible for an external failure or not. The sequence of events is as follows:

- (1) The brand owner and the supplier agree on the component prices $\{c_1, c_0\}$.
- (2) The supplier chooses quality enhancement effort q and supplies the component to the brand owner.
- (3) The brand owner unconditionally accepts the component for manufacturing.
- (4) The brand owner then makes the quality effort p in its manufacturing process and sells the finished product in the market for r . If the finished product fails in the market, the brand owner incurs an external failure cost of l and will conduct the quality audit to identify who is responsible for the failure. If it is the supplier's responsibility due to faulty component, the brand owner will pay the supplier c_0 . Otherwise, the brand owner pays the supplier c_1 .

The supplier's and the brand owner's profit functions can be stated as follows respectively,

$$\pi_S(c_1, c_0 | q_i, p_j, a, h) = c_1(1 - e_s) + c_0 e_s - S_i, \quad (6)$$

$$\pi_{BM}(c_1, c_0 | q_i, p_j, a, h) = r p_j q_i - l e(q_i, p_j) - [c_1(1 - e_s) + c_0 e_s] - M_j - A. \quad (7)$$

The first two terms in the supplier profit function are the expected compensation the supplier would receive from the brand owner based on the external failure identified as the supplier's responsibility and the last term is the cost of quality effort. In the brand owner profit function, the first term is the revenue from selling the product of good quality. The second term is the expected external failure cost. The third and fourth terms are the expected supplier compensation for the component, and the remaining terms are costs of manufacturing quality effort and quality audit. The brand owner solves the following program under external failure-based product warranty (BM-E),

Program BM-E (brand owner-supplier-under-external failure):

$$\max_{\{c_1, c_0\} \geq 0} \pi_{BM}(c_1, c_0 \mid q_i, p_H, a, h)$$

Subject to

$$IC_S^E: \pi_S(c_1, c_0 \mid q_H, p_H, a, h) \geq \pi_S(c_1, c_0 \mid q_L, p_H, a, h),$$

$$IR_S^E: \pi_S(c_1, c_0 \mid q_H, p_H, a, h) \geq 0.$$

Solving the program leading to a binding IC_S^E , which, along with $\{c_1, c_0\} \geq 0$, implies that IR_S^E is satisfied. So the optimal solution is given by $c_0^{*'} = 0$ and

$c_1^{*'} = S_H / \Delta q / [a - (1-h)(1-p_H)]$. The component supplier's profit is

$$\pi_S^{*'} = \frac{S_H}{\Delta q} \left\{ q_L + \frac{1-a}{a - (1-h)(1-p_H)} \right\},$$

and the brand owner's profit is

$$\pi_{BM}^{*'} = rp_H q_H - l(1 - p_H q_H) - (\pi_S^{*'} + S_H + M_H + A). \quad (8)$$

The supplier profit $\pi_S^{*'}$, as the agency costs in inducing component quality effort, increases in $S_H / \Delta q$, but decreases in the audit accuracy, a and h . A greater accuracy of audit would allow the brand owner to better discern the supplier's quality effort. Better information connecting quality effort to its outcome reduces agency costs and inefficiencies associated with them. The second term in the brand owner's profit, $l(1 - p_H q_H)$ is the expected external failure cost.

Comparing the brand owner's profits under inspection-based quality control π_{BM}^* in (3) and under external failure-based quality control $\pi_{BM}^{*'}$ in (8) reveals a crucial difference between

the two quality control approaches. The brand owner's expected external and internal failure costs in equation (3), $[l(1-\delta)+m\delta][1-p_Hq_H-(1-q_H)\theta]$ is a function of the accuracy of the inspections, θ and δ . This reflects the fact that in addition to incentivizing quality efforts, inspections directly add extra value to the brand owner by preventing some defects from becoming external failures in the market, thereby reducing external and internal failure costs. In contrast, the brand owner's expected external failure cost (note that there is no internal failure cost in this case) in equation (8), $l(1-p_Hq_H)$ is independent of the accuracy of the quality audit, a and h . It indicates that other than incentivizing quality efforts, there is no activity under external failure-based quality control that can directly prevent or reduce external failure. Nevertheless, the basic idea of external failure-based quality control is to only take action (e.g., quality audit and payment adjustment) after an external failure happens. We will see that this crucial difference between the two quality control approaches will play a central role on influencing the brand owner's preference over the two approaches in different supply chains.

2.3. The Optimal Quality Control in the Dyadic Supply Chain

We now characterize the brand owner's choice between inspection-based quality control and external failure-based quality control in the dyadic supply chain.

PROPOSITION 1: *In the dyadic supply chain, the brand-owner prefers external failure-based quality control to inspection-based quality control, if*

$$\left\{ \frac{1}{\theta} - \frac{[1-(1-h)(1-p_H)]}{[a-(1-h)(1-p_H)]} \right\} \frac{S_H}{\Delta q} > (l-m)\delta[1-p_Hq_H-(1-q_H)\theta] + l(1-q_H)\theta - (I+I_F-A).$$

This result is derived from a traditional relative cost-benefit analysis. The right hand side of the condition in Proposition 1 is the net direct benefit of inspection-based quality control relative to external failure-based quality control excluding incentive related factors. As we discussed above, inspections can directly add value to the brand owner by preventing some defects from becoming external failures in the market, thereby reducing external failure. The first two terms of the right hand side of the condition, $(l-m)\delta[1-p_Hq_H-(1-q_H)\theta] + l(1-q_H)\theta$ which is the difference between failure costs under the two quality control approaches, represents this extra added value of inspection relative to an external failure-based approach. The third term $I+I_F-A$ is the direct cost differential between conducting inspections and quality audit.

The left hand side of the condition in Proposition 1, representing incentive related factors, is the agency cost differential between the two quality control approaches or $\pi_s^* - \pi_s^{*'}$. It is straightforward that the agency cost differential is decreasing in accuracy of inspection, θ , increasing in audit accuracy a or h , and proportional to the cost effectiveness of quality effort at the supplier $S_H / \Delta q$. Due to the limited liability of the supplier, the brand owner is constrained by its ability to penalize the supplier even if inferior component quality outcome is observed. This constraint is a main source of agency costs under both quality control approaches.

This result shows that inspection-based quality control may or may not be the preferred quality control approach relative to external failure-based quality control in a dyadic supply chain depending on whether the net direct benefit of inspections can be enough to offset the agency cost difference between the two quality control approaches. Similar arguments have also been made in previous studies (e.g., Balachandran and Radhakrishnan 2005; Hwang, et al. 2006).

3. A Multi-Level Supply Chain with Outsourced Manufacturing

In this section, we consider that the brand owner outsources the manufacturing process to an independent contract manufacturer who will take the responsibility in procuring the component from a component supplier, exerting quality effort in the manufacturing process and producing the finished product for the brand owner. By outsourcing manufacturing, the brand owner now is mainly responsible for designing and marketing the final product. In this multi-level supply chain with outsourced manufacturing, quality control is conducted and contracted sequentially—the manufacturer contracts on component quality with the component supplier, while the brand owner contracts on finished product quality with the manufacturer. Similar to Mattel who depends on contract manufacturers such as Lee Der Industrial for product assembling and quality control (Bapuji and Beamish 2008a), brand owners such as Apple, Dell, and Sony rely on Foxconn, a major player in the electronic manufacturing services (EMS) industry, to build and maintain supplier networks to source for quality components (Gupta and Chan 2012; Eccles, Serafeim, and Cheng 2012).

We define two segments of quality control in this multi-level supply chain, as shown in Figure 2. The first segment is the component quality control between the manufacturer and the supplier, i.e. segment M-S; and the second is the finished product control between the brand owner and the manufacturer, i.e. segment B-M. Compared to the dyadic supply chain in Figure 1,

the multi-level supply chain in Figure 2 is longer with one more supply chain member, the contract manufacturer, because of the outsourcing of manufacturing.

[Insert Figure 2 about here]

3.1. Inspection-based Quality Control

Under inspection-based quality control, the qualities in the supply chain will be managed and contracted completely based on outcomes from the inspections, which is similar to the dyadic supply chain. In the multi-level supply chain with outsourced manufacturing, the contract manufacturer conducts component inspection on the quality of the component provided by the component supplier, and contracts with the supplier (segment M-S) based on the inspection result. As observed in Tang (2008), when companies outsource manufacturing to contract manufacturers, it is also common for them to outsource quality inspection and shipping to the contract manufacturers. Hence, the quality control task of the contract manufacturer in the supply chain is consistent with its role in the supply chain — it inspects components received and directly compensates the supplier for the quality confirmed by the inspection result.

The difference from the dyadic supply chain in the base model is that now the brand owner in the multi-level supply chain only inspects the finished product, while the manufacturer performs inspection on the component from the supplier. The brand owner contracts with the manufacturer (segment B-M) based on the inspection results of the finished product. The brand owner would pay the manufacturer w_1 per unit if the finished product is found a good product or w_0 per unit if the finished product is a defect. In addition, because the component inspection is conducted by the manufacturer, the brand owner agrees that such compensation for the manufacturer should at least cover the component inspection cost, I , regardless of the outcome of the finished product inspection, or $\{w_1, w_0\} \geq I$.³

The brand owner contracts with the manufacturer in the following sequence of events:

- (1) The brand owner and the manufacturer agree on the prices of the product $\{w_1, w_0\}$.
- (2) The manufacturer chooses quality effort p and contracts with the supplier. Then, the manufacturer produces and ships the finished product to the brand owner.

³ This condition requires that the brand owner bears the inspection cost as it does in a dyadic supply chain, and therefore eliminates the possibility that the differences in quality programs between the dyadic and the multi-level supply chains may come from a simple cost shift from the brand owner to the manufacturer. We thank for the associated editor for this assumption.

(3) The brand owner receives the finished product from the manufacturer and inspects the finished product. If the finished product passes the inspection, the brand owner will sell it in the market for r and pay the manufacturer w_1 . If the finished product fails to pass the inspection, the brand owner will not sell the product and will incur an internal failure cost of m and pay the manufacturer w_0 . If the finished product is sold in the market after passing the inspection but fails in the market, the brand owner incurs a penalty cost of l .

The contract manufacturer will contract with the supplier in the similar sequence as the brand owner does in the dyadic supply chain specified in Section 2.1, except that it is the manufacturer, rather than the brand owner, that offers the contract. The contract manufacturer pays the supplier $c_1 \geq 0$ per unit for “accepted” components and $c_0 \geq 0$ per unit for “rejected” components based on the inspection outcomes. The expected profits for the supplier (S), the manufacturer (M) and the brand owner (B) are as follows,

$$\pi_S(c_1, c_0 | q_i, p_j, \theta) = c_1 - (c_1 - c_0)(1 - q_i)\theta - S_i, \quad (9)$$

$$\begin{aligned} \pi_M(c_1, c_0, w_1, w_0 | q_i, p_j, \theta, \delta) = & w_1 [p_j q_i + f(q_i, p_j, \theta)(1 - \delta)] + w_0 f(q_i, p_j, \theta) \delta \\ & - c_1 + (c_1 - c_0)(1 - q_i)\theta - M_j - I, \end{aligned} \quad (10)$$

and

$$\begin{aligned} \pi_B(w_1, w_0 | q_i, p_j, \theta, \delta) = & r p_j q_i - l f(q_i, p_j, \theta)(1 - \delta) - m f(q_i, p_j, \theta) \delta \\ & - w_1 [p_j q_i + f(q_i, p_j, \theta)(1 - \delta)] - w_0 f(q_i, p_j, \theta) \delta - I_F. \end{aligned} \quad (11)$$

The supplier’s profit function is the same as that in the dyadic supply chain, as its role does not change. In the manufacturer’s profit function, the first two terms represent the expected compensation from brand owner based on finished product quality; the next two terms indicate how much the manufacturer pays the supplier for the component based on component inspection; the last two terms are the manufacturer’s quality effort cost and inspection cost. In the brand owner profit function, the first term is the revenue from selling products with good quality; the second and third terms are the expected external failure cost and the expected internal failure cost, respectively; the fourth and the fifth terms are the compensations to the manufacturer depending on the finished product quality; and the last term is the finished product inspection cost. The manufacturer commits p_H to the supplier, unknown to the brand owner (see Balachandran and Radhakrishnan 2005). The brand owner solves the following program,

Program B-M-I (brand owner-manufacturer-based-on-inspection):

$$\max_{\{w_1, w_0\} \geq I} \pi_B(w_1, w_0 | q_i, p, \theta, \delta)$$

Subject to

$$IC_M^I: \pi_M(c_1^*, c_0^*, w_1, w_0 | q_H, p_H, \theta, \delta) \geq \pi_M(c_1^*, c_0^*, w_1, w_0 | q_H, p_L, \theta, \delta), \quad (12)$$

$$IR_M^I: \pi_M(c_1^*, c_0^*, w_1, w_0 | q_H, p_H, \theta, \delta) \geq 0, \quad (13)$$

$$(c_1^*, c_0^*) = \arg \max_{\{c_1, c_0\} \geq 0} [\pi_M(c_1, c_0, w_1, w_0 | q_H, p_H, \theta, \delta) : IC_S^I, IR_S^I]. \quad (14)$$

IC_M^I and IR_M^I denote the manufacturer's incentive compatibility and individual rationality constraints, respectively. The last constraint indicates that the brand owner solves the problem as a grand mechanism given the optimal manufacturer-supplier contract as sub-game perfect. The program B-M-I is a moral hazard problem just like that of the brand owner in Program BM-I.

Solving the program leads to the following solution: $c_0^* = 0$, $c_1^* = S_H / (\theta \Delta q)$, $w_0^* = I$, and $w_1^* = M_H / (\delta q_H \Delta p) + I$ if agency cost exists between the brand owner and the manufacturer. The supplier's, the manufacturer's and the brand owner's profits are respectively

$$\pi_S^* = \frac{S_H}{\Delta q} \left(q_L + \frac{1}{\theta} - 1 \right),$$

$$\pi_M^* = [p_H q_H + (1 - p_H q_H - (1 - q_H) \theta)(1 - \delta)] \frac{M_H}{\delta q_H \Delta p} + I [1 - (1 - q_H) \theta] - \pi_S^* - (S_H + M_H + I), \quad (15)$$

and

$$\pi_B^* = r p_H q_H - [l(1 - \delta) + m \delta] [1 - p_H q_H - (1 - q_H) \theta] - [\pi_M^* + \pi_S^* + I_F]. \quad (16)$$

The supplier's profit π_S^* , which is the agency cost between the supplier and the contract manufacturer, is the same as the one in the dyadic supply chain as the supplier's role does not change. The manufacturer's profit π_M^* is the agency cost between the brand owner and the manufacturer in the B-M segment. The added B-M segment of the supply chain may introduce additional agency cost leading to a positive profit to the manufacturer (i.e., $\pi_M^* > 0$). The total agency cost for the brand owner under inspection-based quality control in the multi-level supply chain can be written as:

$$\pi_S^* + \pi_M^* = [p_H q_H + (1 - p_H q_H - (1 - q_H)\theta)(1 - \delta)] \frac{M_H}{\delta q_H \Delta p} - I(1 - q_H)\theta - [S_H + M_H].$$

We can see that the total agency cost for the brand owner is composed of three parts, which can help to understand how the multi-level supply chain is different from the dyadic one. The first part, $[p_H q_H + (1 - p_H q_H - (1 - q_H)\theta)(1 - \delta)] M_H / (\delta q_H \Delta p)$, which is a mix of terms associated with finished product manufacturing (e.g., p_H , Δp and M_H) and terms associated with component inspection (θ) and finished product inspection (δ), is unique to the multi-level supply chain with outsourcing. It represents the agency cost that resulted directly from the interaction between finished product manufacturing and component inspections, both of which are performed by the manufacturer, and finished product inspection, which is performed by the brand owner. In the first term, $[p_H q_H + (1 - p_H q_H - (1 - q_H)\theta)(1 - \delta)]$ is the amount of finished product that will be identified as “good” and sold in the market after passing both component and finished product inspections, and $M_H / (\delta q_H \Delta p)$ is the brand owner’s payment differential between a “good” finished product and a “bad” one as incentives to induce the manufacturer’s quality effort. Note that this interaction between finished product manufacturing and inspections does **not** exist in the agency cost for the brand owner in the dyadic supply chain (see π_S^* in Section 2.1) where both finished product manufacturing and the inspections are performed by the brand owner itself, so therefore, the interaction is internal to the brand owner.

The second part, $I(1 - q_H)\theta$, which is also unique to the multi-level supply chain, is the payment that would have been made to the manufacturer on defective finished product due to defective components, had there been no component inspection. Recall that the manufacturer would receive a payment $w_0^* = I$ for a defective finished product. Some of this payment on a defective finished product as a result of a defective component can be avoided because component inspection prevents $(1 - q_H)\theta$ amount of defective components going into finished product manufacturing. Clearly, this payment saving created by the component inspection is also internal to the brand owner in the dyadic supply chain.

Interestingly, the first two parts of the agency cost for the brand owner ($[p_H q_H + (1 - p_H q_H - (1 - q_H)\theta)(1 - \delta)] M_H / (\delta q_H \Delta p) - I(1 - q_H)\theta$) are decreasing in θ and δ . It implies that due to their nature in directly adding value by reducing external failure, inspections,

whether performed by the brand owner (finished product inspection) or the manufacturer (component inspection), can serve as effective levers for the brand owner to control the agency cost in the multi-level supply chain. Finally, the third part $S_H + M_H$ is the direct cost of quality efforts. This part helps control the agency cost for the brand owner (because the sign in front of this part is negative).

3.2. External Failure-based Quality Control

As in the dyadic supply chain, under external failure-based quality control, no inspections will be conducted and the qualities in the supply chain will be controlled and contracted completely based on potential external failure. The brand owner first contracts with the contract manufacturer in the sequence of events as follows:

- (1) The brand owner and the contract manufacturer agree on the unit prices of the product $\{w_1, w_0\}$.
- (2) The contract manufacturer chooses quality effort p and contracts with the component supplier for the component.
- (3) The brand owner receives the finished product from the manufacturer and sells it in the market for r per unit. If the finished product fails in the market, the brand owner incurs an external failure cost l and pays the manufacturer w_0 . Otherwise, the brand owner pays the manufacturer w_1 .

The brand owner pays the manufacturer $\{w_1, w_0\} \geq A$ to at least cover the manufacturer's quality audit cost, solely depending on whether the finished product fails in the market or not. In case of an external failure, the brand owner will pay the contract manufacturer w_0 , regardless of who, the manufacturer, the component supplier, or both, is responsible to the external failure, because the brand owner is surely not responsible for the failure after outsourcing the manufacturing process. In some sense, we consider an external failure-based quality control setting that strongly favors the brand owner.

The contract manufacturer then contracts with the component supplier in a similar sequence of events (1)~(4) under external failure-based quality control in the dyadic supply chain as described in Section 2.2, except that it is the contract manufacturer, rather than the brand owner, that offers the contract and conduct potential quality audit in the case of external failure.

Now, the manufacturer accepts the component without inspection. Therefore, the number of failed finished products will be $e(q_i, p_j) = 1 - p_j q_i$ while the number of good products will be $p_j q_i$, given the quality effort levels of q_i and p_j respectively. When an external failure occurs, the manufacturer will be penalized by the brand owner by receiving w_0 that is lower than w_1 . Then, the manufacturer will perform a quality audit to identify between the manufacturer and the component supplier who is actually responsible to the failure and pays the supplier $\{c_1, c_0\} \geq 0$ according to the outcome of the quality audit.

Under quality control based on external failure, profit functions of the supply chain members can be stated as follows:

$$\pi_S(c_1, c_0 | q_i, p_j, a, h) = c_1(1 - e_s) + c_0 e_s - S_i, \quad (17)$$

$$\pi_M(c_1, c_0, w_1, w_0 | q_i, p_j, a, h) = w_1 p_j q_i + w_0 e(q_i, p_j) - [c_1(1 - e_s) + c_0 e_s] - M_j - A, \quad (18)$$

and

$$\pi_B(w_1, w_0 | q_i, p_j, a, h) = r p_j q_i - l e(q_i, p_j) - [w_1 p_j q_i + w_0 e(q_i, p_j)]. \quad (19)$$

The supplier's profit function is the same as that in the dyadic supply chain, as its role does not change. In the manufacturer's profit function, the first two terms represent the expected compensation from brand owner based on external failure; the next two terms indicate how much the manufacturer pays the supplier for the component based on the amount of external failure that is identified as the supplier's fault; the last two terms are the manufacturer's quality effort cost and quality audit cost. In the brand owner profit function, the first term is the revenue from selling the product a good quality; the second term is the expected external failure cost; the third and fourth terms are the compensations to the manufacturer depending on the external failure. Similar to supplier inspection (B-M-I), the manufacturer commits p_H to the supplier, which is unknown to the brand owner. The brand owner solves the following program.

Program B-M-E (brand owner-manufacturer-under-external failure):

$$\max_{\{w_1, w_0\} \geq A} \pi_B(w_1, w_0 | q_i, p_j, a, h)$$

Subject to

$$IC_M^E: \pi_M(c_1^*, c_0^*, w_1, w_0 | q_H, p_H, a, h) \geq \pi_M(c_1^*, c_0^*, w_1, w_0 | q_H, p_L, a, h),$$

$$IR_M^E: \pi_M(c_1^{*'}, c_0^{*'}, w_1, w_0 | q_H, p_H, a, h) \geq 0,$$

$$(c_1^{*'}, c_0^{*'}) = \arg \max_{\{c_1, c_0\} \geq 0} [\pi_M(c_1, c_0, w_1, w_0 | q_H, p_H, a, h): IC_S^E, IR_S^E].$$

IC_M^E and IR_M^E are the brand owner's incentive compatibility and individual rationality constraints respectively under the external failure-based quality control. The third constraint refers to the manufacturer's equilibrium solution of its own contract with the supplier that is sub-game perfect. This program's optimal solution is: $c_0^{*'} = 0$, $c_1^{*'} = S_H / \Delta q / [a - (1-h)(1-p_H)]$, $w_0^{*'} = A$, and $w_1^{*'} = M_H / (q_H \Delta p) + A$ if agency costs exist between the brand owner and the manufacturer. The supplier's, the manufacturer's and the brand owner's profits are respectively,

$$\begin{aligned} \pi_S^{*'} &= \frac{S_H}{\Delta q} \left\{ q_L + \frac{1-a}{a - (1-h)(1-p_H)} \right\}, \\ \pi_M^{*'} &= M_H \frac{p_H}{\Delta p} - (\pi_S^{*'} + S_H + M_H), \end{aligned} \quad (20)$$

and

$$\pi_B^{*'} = r p_H q_H - l [1 - p_H q_H] - M_H \frac{p_H}{\Delta p} - A. \quad (21)$$

Similarly, the supplier's profit is the same as the one in the dyadic supply chain as the supplier's role does not change. The manufacturer's profit $\pi_M^{*'}$ is the agency cost between the brand owner and the manufacturer. The added B-M segment of the supply chain may introduce additional agency cost leading to a positive profit to the manufacturer (i.e., $\pi_M^{*' > 0$). The total agency cost for the brand owner is

$$\pi_S^{*'} + \pi_M^{*'} = \frac{M_H p_H}{\Delta p} - (S_H + M_H).$$

The above agency cost contains two parts. While the second part is the cost of quality efforts $S_H + M_H$, the first part, $M_H p_H / \Delta p$ is the agency cost necessary to induce quality efforts due to outsourcing. One interesting and crucial observation on the above total agency cost is that it is independent of the accuracy of quality audit (i.e., a and h). This unique property is caused by two reasons: First, recall that in the multi-level supply chain, quality audit after an external failure would only matter for the contract manufacturer and the component supplier, not for the

brand owner. This is why the agency cost, under external failure-based quality control in the dyadic supply chain (i.e., π_s^{*f} in Section 2.2), is dependent on the accuracy of quality audit but the one in the multi-level supply chain is not. Second, and more importantly, as we discussed at the end of Section 2, quality audit will only be conducted after finished product manufacturing in case of an external failure and does not directly add value to the supply chain by reducing external failure. All components will make it to the finished product manufacturing and all finished products will be sold. Therefore, a similar interaction to the one between finished product manufacturing and inspections under inspection-based quality control does not exist between finished product manufacturing and quality audit under external failure-based quality control. This observation indicates that when a supply chain is stretched longer with outsourced manufacturing, how quality control activities will interact with manufacturing and influence agency costs could be very different for different quality control approaches. Consequently, as we will demonstrate later, the relative efficiency between different quality control approaches could change when a supply chain becomes longer with outsourcing.

There are two interesting commonalities between the agency costs under the two quality control approaches in the multi-level supply chain. First, according to (15) and (20), the agency costs between the manufacturer and the supplier (i.e., the supplier profits π_s^* and π_s^{*f}) are substitutable to the agency costs between the brand owner and the manufacturer (i.e., the manufacturer profits π_M^* and π_M^{*f}). This is because when the supplier profit is sufficiently large, the individual rationality constraint for the manufacturer becomes binding. The manufacturer therefore participates with zero profit saving the brand owner extra agency cost to induce the manufacturer's quality effort. By the same token, a sufficiently small supplier profit leaves a positive profit for the manufacturer that is protected by its limited liability. Second, the total agency costs under both approaches in the multi-level supply chain (i.e., $\pi_s^* + \pi_M^*$ and $\pi_s^{*f} + \pi_M^{*f}$) are no less than their counterparts in the dyadic supply chain because the supplier profits are the same in the two supply chains. In other words, without considering potential manufacturing cost savings (which we will discuss in Section 4), both quality control approaches will become less efficient to the brand owner in the multi-level supply chain due to decentralization.⁴

⁴ We thank the Associate Editor and an anonymous reviewer for this point.

3.3. The Optimal Quality Control in the Multi-level Supply Chain

We now demonstrate the impact of supply chain structure (with or without outsourcing) and the distribution of agency costs (where in the supply chain agency costs are incurred) on the brand owner's choice of optimal quality control approach. In the dyadic supply chain, the presence of agency costs can only occur in between the brand owner and the component supplier. However, agency costs can occur between the brand owner and the contract manufacturer, between the contract manufacturer and the component supplier, or both in the multi-level supply chain.

PROPOSITION 2: *In the multi-level supply chain with outsourced manufacturing, if agency costs do not exist between the brand owner and the contract manufacturer, the brand-owner's preference between external failure-based quality control and inspection-based quality control stays unchanged from the one in the dyadic supply chain.*

This result indicates that if no agency costs exist between the brand owner and the contract manufacturer (i.e., the B-M segment) in the multi-level supply chain, the brand owner's optimal choice between inspection-based quality control and external failure-based quality control stays the same as its optimal choice in the dyadic supply chain. This implies that the brand owner does **not** necessarily need to change its quality control approach just because its supply chain becomes longer with outsourced manufacturing. If no agency costs exist between the manufacturer and the brand owner, i.e., when the manufacturer's profits are zero, the total agency costs for the brand owner would be the supplier's profits which stay the same as the ones in the dyadic supply chain as we discussed before. Therefore, the total agency costs for the brand owners under the two quality control approaches in the multi-level supply chain stay the same as their counterparts in the dyadic supply chain. As a result, the brand owner's preferences between the two quality control approaches in the two supply chains are the same as well.

A closer look at the manufacturer's profits π_M^* and π_M^{**} (in Sections 3.1 and 3.2) shows that π_M^* and π_M^{**} or the agency costs between the manufacturer and the brand owner are more likely to be zero when the supplier profits π_S^* and π_S^{**} , quality improvement costs S_H and M_H , and the component inspection cost I are high (making the terms $\pi_S^* + S_H + M_H + I$ and $\pi_S^{**} + S_H + M_H$ high), as they essentially remove all manufacturer profit at high manufacturing quality effort in quality control based on either inspection or external failure. It implies that if the

quality efforts are expensive and the supplier plays a significant role, thereby retaining a high profit in a supply chain, outsourcing finished product manufacturing would less likely lead to a need to change the quality control approach in the supply chain.

However, if the scenarios are opposite, that is, if the quality efforts are not expensive (e.g., in toy manufacturing) and the supplier plays a lesser role, thereby retaining a small profit (e.g., supplying paint), agency costs between the manufacturer and the brand owner in the B-M segment can well exist. Specifically, the contract manufacturer may not be able to accept liability. This limited liability could induce agency costs in the B-M segment when agency costs and other costs in the M-S segment are sufficiently small such that the manufacturer is willing to participate with nonnegative profit before its limited liability becomes engaged. This interesting agency cost effect between the two segments of the supply chain is possible only when the supply chain is longer than two levels. Our main result, presented in the following proposition, shows how the existence and the distribution of agency costs along the supply chain could change the brand owner's optimal choice between the quality control approaches.

PROPOSITION 3: *Consider that the brand owner prefers external failure-based quality control to inspection-based quality control in the dyadic supply chain. In the multi-level supply chain, if there exist agency costs between the brand owner and the contract manufacturer, the brand-owner would choose inspection-based quality control if*

$$[1 - (1 - q_H)\theta](1 - \delta) \frac{M_H}{\delta q_H \Delta p} - I(1 - q_H)\theta < (l - m)\delta[1 - p_H q_H - (1 - q_H)\theta] + l(1 - q_H)\theta - (I + I_F - A).$$

When the supply chain becomes longer due to outsourcing, Proposition 3 shows that if agency costs exist between the brand owner and the contract manufacturer, the brand owner may indeed need to change its quality control approach. Specifically, if the condition in Proposition 3 holds, the brand owner should switch from external failure-based quality control that is optimal in the dyadic supply chain to inspection-based quality control. The right hand side of the above condition is the net direct benefit of inspection-based quality control relative to external failure-based quality control, which is exactly the same as the right hand side of the condition in Proposition 1. The left hand side of the condition is the agency cost differential between the two quality control approaches in the multi-level supply chain, that is $(\pi_S^* + \pi_M^*) - (\pi_S^{*'} + \pi_M^{*'})$.

How is it possible that the agency cost differential between the two approaches can be less than the net direct benefit of inspection (i.e., condition in Proposition 3 holds) so that

inspection-based quality control would be preferred in the multi-level supply chain, while the agency cost differential is greater than the net direct benefit of inspection (i.e., condition in Proposition 1 holds) so that external failure-based quality control is preferred in the dyadic supply chain? A useful technical observation is that the agency cost differential between the two quality control approaches in the multi-level supply chain is very different from the one in the dyadic supply chain (see the difference between the left hand sides of the conditions in Propositions 1 and 3). This difference makes it possible for the two inequalities in the two conditions with the same right hand side to be opposite, implying opposite preferences between the two quality control approaches for the brand owner in the two supply chains. We next provide detailed explanations for this interesting possibility.

When the external failure-based quality control is preferred in the dyadic supply chain, it implies that the agency cost for the brand owner is higher under the inspection-based quality control, i.e., $\pi_s^* > \pi_s^{*f}$. As the supply chain is stretched longer to the multi-level supply chain, if agency costs exist between the brand owner and the manufacturer, the total agency costs for the brand owner under both quality control approaches would become higher than those in the dyadic supply chain (see discussions at the end of Section 3.2). Proposition 3 indicates that the increase in agency cost under an external failure-based approach could be much higher than the increase under an inspection-based approach so that it becomes a less efficient approach than the inspection-based approach. In other words, while reducing the efficiencies of both approaches, a longer supply chain could reduce the efficiency of an external failure-based approach more than that of an inspection-based approach. This can be attributed to the following two factors.

First, according to (15) and (20), the manufacturer's profits or the agency costs between the manufacturer and the brand owner are offset by the supplier profits (see discussions at the end of Section 3.2). Also, recall that the supplier profits (π_s^* and π_s^{*f}) do not change as the supply chain is stretched from dyadic to multi-level under both quality control approaches. Thus, everything else being equal, a higher supplier profit implies a smaller manufacturer profit, or agency cost between the manufacturer and the brand owner, thereby a smaller increase in the total agency cost for the brand owner. If the supplier profit or the agency cost for the brand owner is higher under the inspection-based approach than under the external failure-based approach in the dyadic supply chain, the manufacturer profit or the increase in agency cost for

the brand owner under the inspection-based approach is more likely to be smaller in the multi-level supply chain.

Second and more fundamentally, as a supply chain is stretched longer because of outsourcing, how quality control interacts with manufacturing and influences agency cost could change differently for different quality control approaches. Under inspection-based quality control, inspections directly add value to the supply chain by removing the defective components and finished products, thereby reducing potential external failure. In the dyadic supply chain, the brand owner performs the two inspections and finished product manufacturing. The interactions between the inspections and finished product manufacturing will be internal to the brand owner and do not affect agency cost or the supplier's profit. Instead, only the interaction between component inspection and component manufacturing would influence agency cost or the supplier's profit. In the multi-level supply chain, the manufacturer performs component inspection and manufacturing. As we discussed in Section 3.1, the interaction between the two inspections and finished product manufacturing will affect the manufacturer's profit, thereby the agency cost for the brand owner directly. Furthermore, the interaction between the inspections and finished product manufacturing actually helps to limit the manufacturer's profit, thereby reducing the agency cost for the brand owner.

The picture is drastically different for external failure-based quality control in which quality audit does not directly add value to the supply chain by reducing external failure directly and would only occur after manufacturing in case of an external failure. In the dyadic supply chain, the brand owner conducts potential quality audit, which in turn affects the agency cost between itself and the supplier. In the multi-level supply chain, potential quality audit is conducted by the manufacturer and its outcome is internal between the manufacturer and the supplier and the brand owner is fully spared from the outcomes of audit. Therefore, it would not affect the agency cost to the brand owner directly. Those key differences lead to the difference in agency cost differentials between the two quality control approaches in the two supply chain as reflected by the left hand sides of the conditions in Propositions 1 and 3.

When the above two factors are strong enough, together they can shift the brand owner's optimal choice of quality control approach from external failure-based approach in the dyadic supply chain to inspection-based approach in the multi-level supply chain. It is worth pointing out that although the cost of component inspection, I and the quality audit cost, A , are incurred to

the manufacturer in the multi-level supply chain, the brand owner will fully compensate the manufacturer for the costs ensured by the limited liability constraints, $\{w_1, w_0\} \geq I$ and $\{w_1, w_0\} \geq A$. Thus, the change in the brand owner preference is not caused by simply shifting I and A to the manufacturer, but by the changes in agency costs.⁵ In fact, we could set both I and A to zero and our key results and insight would still hold.

The conditions in Propositions 1 and 3 also suggest that the higher the ratio $S_H/\Delta q$ or the lower the ratio $M_H/\Delta p$, the more likely the brand owner will have different quality program choices when moving from a two- to three-level supply chain. As measures of incentive strengths to induce quality efforts at the supplier and the manufacturer respectively, a higher $S_H/\Delta q$ implies a larger supplier agency cost, while a lower $M_H/\Delta p$ implies a smaller manufacturer agency cost. The former increases the chance that external failure-based quality control is the brand owner's choice in the dyadic supply chain, and the latter increases the chance that inspection-based quality control is the choice in the multi-level supply chain.

Our results not only have theoretical significances, but also offer important practical insight. We demonstrate that it can be potentially detrimental to assume that a quality control approach, which had success in a dyadic supply chain, would continue to achieve the same success in a longer supply chain with outsourced manufacturing. As the structure of a supply chain changes, firms must re-evaluate the efficiencies of different quality control approaches in the new supply chain to determine the right quality control approach. External failure-based quality control approaches such as supplier certification and quality audit have become more popular than old fashion inspection-based quality control approaches in practice. Our study shows that external failure-based approaches may not necessarily dominate inspection-based approaches in a longer supply chain with outsourced manufacturing. Especially when agency costs exist at various levels of supply chains, which is often a result from poor visibility and limited ability to accept liability in longer supply chains (Terlaak and King 2006; Saouma 2008), inspection-based quality control can be a more efficient approach due to the fact that inspections can directly reduce potential external failure. This is consistent with reports of increasing effort to improve inspection in outsourced manufacturing to prevent quality failures, as Mattel has done in the aftermath of its massive recall: "Mattel also pledged to significantly increase the frequency

⁵ We thank the associate editor for this point.

of its paint inspections, testing every batch delivered to every vendor, in order to prevent lead paint from being used in its toys” (Casey and Zamiska 2007).

4. Discussions and Extensions

This section considers several extensions of the model and discusses the implications of those extensions on our main results and insight.

4.1. Cost Saving in Outsourced Manufacturing

One of the most common reasons for outsourcing is the possible saving in production costs. As we have pointed out before, without considering potential manufacturing cost saving, the multi-level supply chain would lead to lower profit for the brand owner than the dyadic supply chain. We can extend our models by adding a production cost, v to the brand owner in the dyadic supply chain, while the contract manufacturer’s production cost in the multi-level supply chain remains to be zero to allow a production cost advantage from outsourcing. Alternatively, v can be considered a cost saving from outsourced manufacturing.

PROPOSITION 4: (a) *Under inspection-based (external failure-based) quality control, the brand owner prefers multi-level supply chain with outsourced manufacturing to dyadic supply chain, if $v[1 - (1 - q_i)\theta] > \pi_M^*$ ($v > \pi_M^{*'}$).* (b) *The brand owner prefers multi-level supply chain when using inspection-based quality control, but dyadic supply chain when using external failure-based quality control, if $\pi_M^{*'} > v > \pi_M^* / (1 - (1 - q_i)\theta)$.*

The decision on whether to outsourcing should carefully balance between potential production cost saving provided by outsourcing and the added agency costs between the contract manufacturer and the brand owner due to outsourcing. Part (a) of Proposition 4 indicates when the potential production cost saving, which is v adjusted for the actual amount of finished product made $1 - (1 - q_i)\theta$ under inspection-based quality control ($(1 - q_i)\theta$ are defective and excluded by inspection) and v under external failure-based quality control, is greater than the manufacturer agency cost π_M^* (or $\pi_M^{*'}$), the multi-level supply chain yields a higher profit for the brand owner than the dyadic supply chain, therefore justifying outsourcing. This implies that a firm’s choice of supply chain structure (i.e., outsourcing or not) and choice of quality control approach (which would influence agency costs) are related. As shown by part (b) of Proposition 4, when the production cost saving v falls between the agency cost in the B-M segment under external failure-based quality control and the one under inspection-based quality control after

being adjusted for the actual amount of finished product made, the brand owner will prefer outsourced manufacturing when using inspection-based quality control, but will prefer a dyadic supply chain when using external failure-based control.

While the brand owner's optimal choice of quality control is the same with and without the cost saving v in a multi-level supply chain, such a choice would need to be adjusted in a dyadic supply chain because of this cost saving. The key drivers in the brand owner's quality control choice remain to be the agency costs along the supply chain and the relative benefits offered by a quality program, because this cost saving does not directly interact with the source of agency costs in the supply chains.

4.2. Quality Audit in External Failure-based Quality Control

Conducting quality audit is costly. One natural question is why would the brand owner and/or the manufacturer choose to include quality audit as a part of quality control? Next, we further explore the role of quality audit in quality control based on external failure and examine whether our main results would change without quality audit.

There are two immediate scenarios where audit is not necessary: the contract stops at the manufacturer and the supplier is not responsible for any external failures because there is no information that ties the supplier to the problem; in this case, an incentive compatible contract to induce supplier quality is not implementable, for there is no external failure-based outcome on which to be contracted. Alternatively, the manufacturer has all the bargaining power such that it can push the responsibility of external failure entirely to the supplier. This is the case as if it was the supplier who issued the warranty, and an incentive contract can be implemented.⁶ These are the two extreme cases with the external failure risk and responsibility solely held by the manufacturer in the first case and by the supplier in the second.

The auditing technology can be used to determine the extent to which external failure risks are shared between the manufacturer and the supplier. Particularly, the more accurate the auditing technology, the more likely the supplier is correctly held responsible for external failure and the more risks the supplier shares from external failure. As a result, the supplier contract has higher power, leading to a smaller supplier agency cost. It is interesting to note that if the auditing technology is (or is close to) perfect, the supplier is almost always held responsible for

⁶ In Saouma (2008), such a case is possible when the component cannot be specified *ex ante* or decoupled from the final product for quality purposes.

its contribution to external failures, and this would lead to an outcome that is equivalent to a supplier warranty that attributes all the external failure responsibilities to the supplier. Importantly, regardless of the auditing technology under product warranty, our main result regarding the brand owner's preference of quality control in the dyadic and the multi-level supply chains remain the same. This is because in the dyadic supply chain, the only relevant agency cost is that of the supplier's, which is decreasing with a and h . In the multi-level supply chain, the auditing technology affects the distribution of agency costs along the supply chain, but not the total agency cost. Based on Proposition 3, one could conclude that the total agency cost differential between inspection-based and external failure-based quality controls remains the same regardless of the auditing technology. All these suggest our qualitative results remain robust regardless of auditing technology considered.

4.3. Alternative Quality Control Approaches

While quality control programs based on inspection and external failure have their individual strengths and weaknesses, it seems plausible to combine the two to potentially take advantage of their strengths. Specifically, we consider a mixed quality control mechanism involving supplier inspection in the M-S segment and external failure-based warranty in the B-M segment of the supply chain⁷. To keep modeling details to a minimum, we retain the component inspection cost I , but not finished product cost I_F or audit cost A . As shown earlier, dropping them would not change the main effects of the models.

Comparing the mixed mechanism with quality control based on inspection and external failure, we can show that mixing the two control mechanisms may not always provide better solutions for the brand owner. For example, an obvious benefit of the mixed approach is cost savings in finished product inspection and quality audit. However, the benefits associated with agency cost under finished product inspection are no longer available to the brand owner. When the differences in agency costs accumulate, the direct cost savings with the mixed model are reduced and may be eliminated. Similarly, the comparison between the mixed and the external failure based models shows that their key difference originates from whether the defective components are screened in inspection (mixed model) or identified in audit after external failure. Thus their trade-off depends on the total agency cost differential associated with the value added

⁷ Other mixed models, such as that in Balachandran and Radhakrishnan (2005), are also possible, but are unlikely to lead to different results.

component inspection and quality audit $I(1 - q_H)\theta$, the savings of external failure cost $l(1 - q_H)\theta$ due to preventing defective components from being built into the finished product, and the direct cost differential between inspection and quality audit $I - A$. Component inspection adds value by eliminating defective components, while quality audit distributes risks and responsibilities of external failure between the manufacturer and the distributor without changing the total agency cost. Thus, when the savings in agency cost and external failure cost associated with component inspection in mixed model are less than the direct cost differential with quality audit, the mixed model leads to a lower brand owner profit. It is important to note, however, that the key tradeoffs identified and discussed earlier regarding the two quality control mechanisms remain valid for the mixed model.

Another possible alternative is to centralize quality control at the brand owner in the multi-level supply chain to maintain control when manufacturing is outsourced. In such case, the relative efficiency of the inspection-based quality control in the multi-level supply chain can be weaker. This is because the interaction between inspections (conducted by the brand owner now) and finished product manufacturing (still carried out by the manufacturer) as we discussed in Section 3.1 is weakened. However, the interaction between inspections and manufacturing and its benefit in controlling the agency costs for the brand owner still exist. Therefore, our main results and insight would still qualitatively hold.

5. Conclusion

Motivated by recent challenges in quality control faced by outsourcing firms, we examined and compared two quality control approaches, one based on inspection and the other based on external failure, in a classic dyadic and a multi-level supply chain. Inspection-based quality control prevents defective components and finished products from reaching the market and causing damage in long-term customer value. External failure-based quality control allocates external failure risks to supply chain members to induce quality control effort. As external failure-based quality control has gained popularity, recent quality failures have cast a shadow on this trend as the supply chain becomes longer with outsourcing.

This research studies an important question: when involved in outsourcing, should firms change their quality control approach? In particular, should they change from an external failure-based approach to the old fashion inspection-based approach? We follow a moral hazard

framework to investigate the performances of the two quality control approaches in the dyadic and the multi-level supply chains. Our results indicate that the existence of agency costs in the supply chain is critical in driving the firm's optimal choice of quality control approach. This is because inspection adds value by eliminating defective components and products to prevent external failures while external failure-based control shares external failure risks to induce effort, both directly affecting agency costs among the supply chain members.

When agency costs exist in the dyadic supply chain, the brand owner would prefer external failure-based to inspection-based quality control, if the higher agency costs of inspection-based quality control is greater than the direct benefit added by inspection from eliminating faulty components and products. When the supply chain becomes longer with outsourced manufacturing, the brand owner's choice remains unchanged if agency costs only exist between the outsourced manufacturer and the supplier. However, as the supply chain is stretched, visibility and ability to accept liability are limited, leading to more likely moral hazard problems and the existence of agency costs. In this case, the brand owner may be better off to switch to inspection-based quality control. This is because in the dyadic supply chain, the value of inspection from preventing defective components and products is internalized by the brand owner and therefore has no direct impact on agency cost. As the manufacturer joins the supply chain, it takes over quality control and component inspection, activities compensated by the brand owner and related to agency costs. The extra value brought by inspection includes savings from reduced payments associated with the identified defects, while such savings directly contribute to reduction of agency costs, leading to a higher brand owner profit under inspection. This suggests that as supply chains become longer, firms need to reevaluate their choice of quality control program, particularly when agency costs are common along the outsourced supply chain.

This research can be extended by allowing both the manufacturer and the supplier to have moral hazard issues in their respective quality contracts. These are not treated as double moral hazard problems (Balachandran and Radhakrishnan 2005; Plambeck and Taylor 2006) in the current model. It should be an interesting extension to consider double moral hazard in examining governance structures and quality control approaches in supply chains. This research could also be extended by studying the "centralized" quality control such that the brand owner is directly involved in contracting for supply in higher tier suppliers as observed in today's

complex supply chain (Choi and Linton 2011). This would present some more moral hazard challenges than the decentralized control in the current paper.

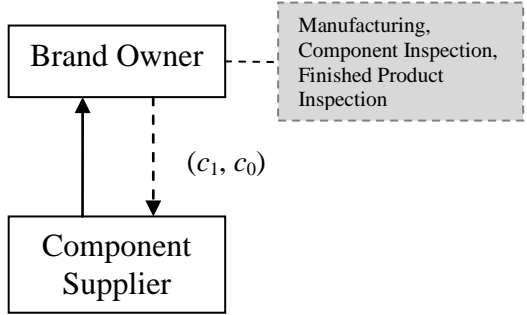
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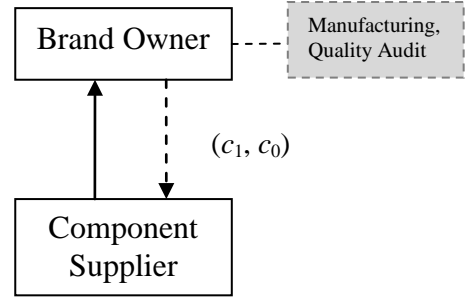
Figure 1. The Dyadic Supply Chain

Inspection-Based Quality Control



(a)

External Failure-Based Quality Control



(b)

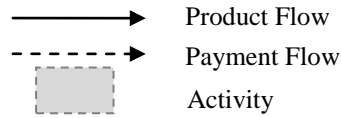
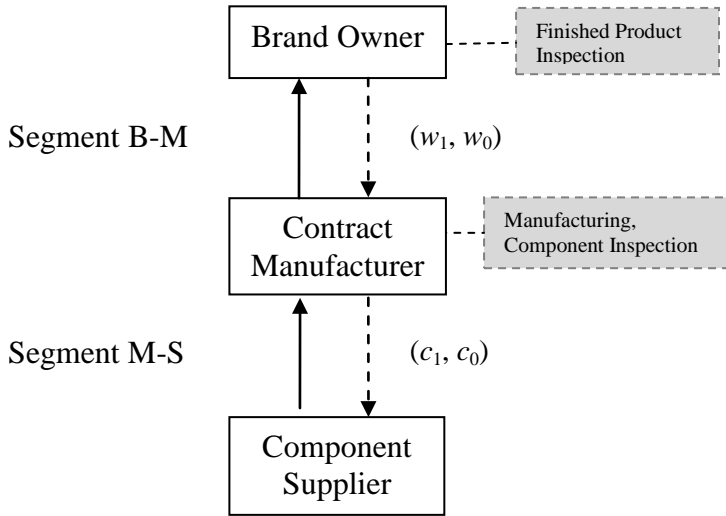


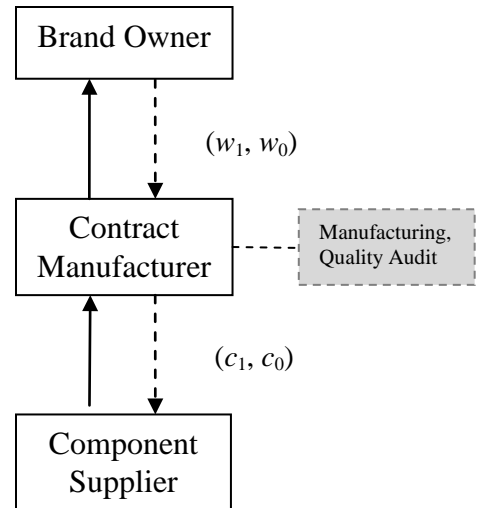
Figure 2. The Multi-level Supply Chain

Inspection-Based Quality Control



(a)

External Failure-Based Quality Control



(b)

