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Quality control in food supply chain management: An analytical model and case study of the adulterated milk incident in China

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ABSTRACT

Managing the food supply chain quality and risk has received significant attention in recent years especially in global emerging markets such as India and China. In this paper, we present a mutually supporting analytical model and exploratory case to study the managerial and policy issues related to quality control in food supply chain management with a focus on the Chinese dairy industry. Based on a general supply-chain model with acceptance sampling tests under uncertain product quality, we show that, depending on the sampling technology, the decentralized supply-chain structure may lead to a distortion in product quality. We also explore the effects of different pricing and regulatory options of vertical control on product quality and the distribution of the total supply-chain profit. In addition, we use an exploratory case study of the 2008 adulterated milk incident in China to investigate practical issues in ensuring product quality/safety in food supply chain management. Our analytical results and two comparative cases show that, instead of the common "poor quality" misperception of food products from global emerging markets, it is actually the poor vertical control strategy for managing the food supply chain quality and risk that caused the adulterated milk incident. A number of other important managerial and policy insights and implications regarding supply chain design, informational visibility, corporate social responsibility, and regulatory action in managing the global food supply chain quality and risk are also discussed.

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1. Introduction

Managing the food supply chain quality and risk has received significant attention in recent years especially in global emerging markets. For example, India has encountered a number of food safety problems in its spice exports including high pesticide residues, aflatoxin contamination, and the use of prohibited food colorants (Umali-Deininger and Sur, 2007). In 2007, Menu Foods, a Canadian pet food manufacturer and retailer, massively recalled its popular brands of pet foods which were said to cause sickness and death of pet animals. According to the company, high levels of melamine found in its pet foods, which originated in wheat gluten and rice protein concentrate imported from Chinese suppliers, were the cause of the incident, though such a claim was disputed by Chinese officials. Rightly or wrongly, these recent events have led to suppliers in global emerging markets being held mostly responsible

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for the quality and safety problems of food products distributed by multinational firms (Farah, 2007). For example, when salmonella was found in black pepper made by Daniele International in 2010, the company's two Vietnamese suppliers were quickly blamed by the Rhode Island Food Safety Authorities (FoodNavigator-USA, 2010). In the 2008 adulterated milk incident, the original response by Sanlu Group, the company whose dairy products were first detected with a high level of melamine, and Fonterra, Sanlu's New Zealand partner, was to blame the milk farmers and dealers who allegedly sold contaminated milk to Sanlu (Financial Times, 2008a). However, given the fact that most multinational enterprises today have well-established quality management systems with aids of advanced technologies for quality control, it is hard to imagine how those hazardous food products could have passed all the quality inspections along their supply chains to reach the marketplace in such a massive scale. Additionally, the pressing requirements for fast delivery and low costs imposed by multinational firms can also severely challenge a supplier's bottom line, which results in quality alteration or deterioration.

In this paper, we present a mutually supporting analytical model and case study to shed new light on the theoretical and practical aspects of managing the food supply chain quality and

risk in global emerging markets with a focus on the Chinese dairy industry. We will first develop a general theoretical model to establish key analytical results regarding quality control in food supply chain management under different market and regulatory settings, and then use a case study of the 2008 adulterated milk incident in China with two comparative cases of the centralized and decentralized approaches for supply chain quality control and risk management to further explore practical issues in order to derive important managerial and policy insights in terms of vertical control strategy, informational visibility, and regulatory action in managing the food supply chain quality and risk.

While there has been a growing number of empirical work on the quality issue in supply chain management (refer to Li and Warfield (2011) for a good characterization), there have been surprisingly fewer analytical papers on quality modeling in food supply chain management. Wang and Li (2012) use a pricing approach based on dynamically identified food shelf life with the objectives to reduce food spoilage waste and to maximize food retailer's profit. Wang et al. (2012) develop a new risk assessment approach to perform structured analysis of aggregative food safety risk in the food supply chain by using the concepts of fuzzy set theory and analytical hierarchy process. In the more general area of supply chain quality management, Yao and Zhang (2009) develop a two-stage leader-follower game theoretic model to analyze the decisions made by the buyer and supplier with a quality cost-sharing contract in a supply chain. Wu et al. (2011) study a two-tier supply chain consisting of a buyer and two competing suppliers with uncertain product qualities. Xiao et al. (2011) explores coordination of a two-tier supply chain with a revenue-sharing contract between a manufacturer and supplier. Xie et al. (2011) study quality improvement in a market segment shared by two supplier–manufacturer supply chains which offer a given product at the same price but compete on quality. Ma et al. (2013) investigate the equilibrium behaviors of a manufacturer–retailer supply chain under three supply chain structures, namely, manufacturer Stackelberg, retailer Stackelberg, and vertical Nash, and show how the retailer's profit and marketing effort and manufacturer's profit and quality-improvement effort are affected by marketing and quality costs under different settings. Liu et al. (2013) and Liu and Xie (2013) study quality supervision and coordination issues for the logistics service supply chain under multi-period conditions and a service quality guarantee.

In terms of relevant empirical or case-based studies, Roth et al. (2008) develop a conceptual framework to identify six key elements—traceability, transparency, testability, time, trust and training—which are critical to the preservation of public welfare through a safe food supply using food products originating in China as examples. The 2008 adulterated milk incident in China has been separately reported in various industry reports and articles with such focuses as business ethics (e.g., DeLaurentis, 2009; Song, 2009), agriculture economics (e.g., Hu, 2009; Gale and Hu, 2009), and actional legitimacy (Petrun and Sellnow, 2010). Lu et al. (2009) present a more comprehensive teaching case regarding corporate crisis management based on the incident. With two comparative cases of the decentralized and centralized approaches, our case study differs from those presented in the above reports and articles with a focus on food supply chain quality control and risk management. To the authors' knowledge, our paper makes significant contributions in two major aspects. First, we develop a theoretical model with general cost and valuation structures to explore the generic effects of operational, strategic, and policy issues regarding vertical control, quality testing, price-based control, and regulatory action in food supply chain quality control with uncertain product quality captured by a general distribution function (as opposed to a specific distribution function assumed in most existing models). While the effects of the wholesale and retail prices and quality-

improvement costs on product quality in supply chain management have been explored in the existing literature (e.g., Xie et al., 2011; Ma et al., 2013), our paper presents the first analytical model that identifies the effects of quality distortion due to sampling testing technology and different supply chain structures. In addition, we use comparative cases of two companies with different supply-chain structures in the 2008 adulterated milk incident in China, which was one of the largest global food safety events in recent years, to investigate key issues in food supply chain quality management as well as to extract useful managerial and policy insights which can be applied to today's global emerging markets. The remainder of the paper is organized as follows. In Section 2, we develop the analytical model. In Section 3, we present the within case analyses of the two Chinese dairy companies. The cross case analysis and managerial and policy insights are discussed in Section 4, and conclusion is in Section 5.

2. Analytical model

We now develop an analytical model that considers the centralized and decentralized food supply-chain structures similar to that in Tirole (1988) with additional components to capture the efforts of quality control by multiple players in a supply chain. While the model is intended to analyze the strategic and policy issues related to food quality control in supply chain management in today's global emerging markets, the examples used to describe the model specifications as well as to discuss the analytical results will be primarily based on the 2008 adulterated milk incident in China with more detailed information to be presented in the case study later in the paper. Fig. 1 illustrates the structures of the centralized and decentralized supply chains of the analytical model with the names and roles of players drawn from the case study. For the centralized supply chain, we consider an enterprise analogous to the Sanyuan Group in the case study which operated a highly integrated supply chain. For the decentralized supply chain, we consider an enterprise analogous to the Sanlu Group in the case study whose supply chain consisted of decentralized small-scale farms as the major sources of raw milk supply and third-party collection agents as the middlemen, as shown in Fig. 1. The above definitions of the centralized and decentralized supply

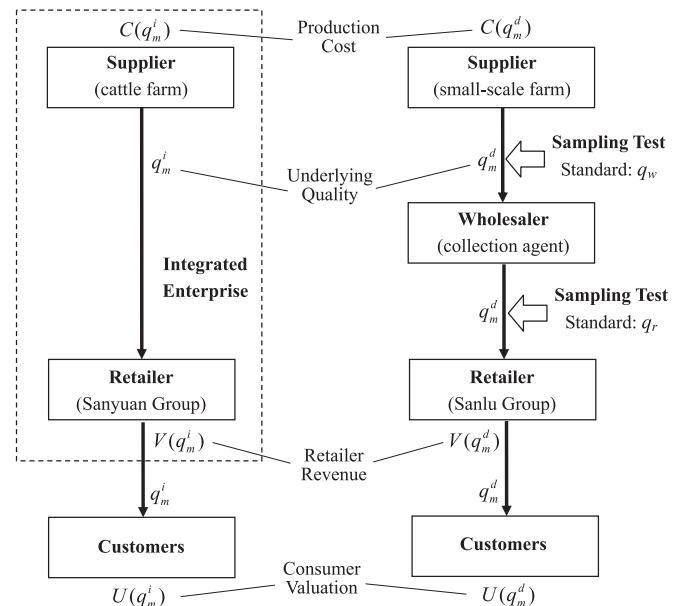


Fig. 1. Centralized supply chain (Sanyuan) vs. decentralized supply chain (Sanlu).

chains are based on the existing literature of supply chain contracts. Specifically, centralization refers to the situation where decisions in a supply chain are made by a single decision maker who has all information at hand. Respectively, decentralization refers to the situation where a supply chain consists of multiple decision makers having different information and incentives (Tirole, 1988; Anupindi and Bassok, 1999; Corbett and Tang, 1999; Corbett et al. 2004). It is noted, however, that the terms “centralization” and “decentralization” may have different meanings based on different organizational theories in economics, strategic management, and operations research such as bounded rationality (Chandler, 1966), relational capitals (Dyer and Singh, 1998), and the vertical boundary of a firm (Besanko et al., 2009).

Food quality embraces both sensory attributes, such as size, weight, texture, and flavor, which are readily perceived by the human senses as well as hidden attributes, such as safety and nutrition, which require sophisticated instrumentation to measure (Jha, 2010). In general, food quality measurement can be based on either attributes (go or no-go information) or variables (measurement on a continuous scale). Our analytical model can be applied to both the attribute-based and variable-based food quality measurements. For ease of exposition, however, we will use only the attribute-based quality measurement to demonstrate the basic model structure, but will also discuss how to convert the model for the variable-based measurement. In the analytical model, we will first study a two-tier food supply chain, and then extend the analytical results and insights to three or more tiers. Suppose that a supplier first produces a lot of a particular food product for a retailer who then sells the product to consumers. The number of items in a lot is assumed to be a large number specified in a contract, and the quality specification of the product is also specified in the contract. Some of the items may not meet the quality specification due to the variability in production technology or input quality. Let q_m denote the proportion of items which conform to the quality specification. For example, q_m can be the proportion bottle milk or sports drink beverage in a lot which meets the quality specification, e.g., with an acceptable level of melamine or plasticizer required by the retailer. Consumers value the product at $U(q_m)$ where $U'(q_m) \geq 0$ and $U''(q_m) \leq 0$, which indicate that, while consumers prefer a higher quality level, their marginal valuation decreases as the product quality approaches perfection (i.e., 100% conforming). Notice that the major analytical results and insights presented in the paper will not change if we assume a simpler linear valuation function (i.e., $U'(q_m) \geq 0$, $U''(q_m) = 0$) as in most standard models in product design (Moorthy and Png, 1992; Chen, 2001).

To improve product quality, the supplier can put in effort to increase the proportion of conforming items with cost $c(q_m)$, where $c'(q_m) \geq 0$ and $c''(q_m) \geq 0$, which indicates that the production cost will increase significantly as the product quality approaches perfection—a common phenomenon in quality management (Juran and Godfrey, 1998). To focus on the relationship between the supplier and retailer, we assume that the retailer's revenue function, denoted by $V(q_m)$, has the same general functional properties as the consumer valuation $U(q_m)$, i.e., $V'(q_m) \geq 0$ and $V''(q_m) \leq 0$, which implies that the retailer's revenue is directly influenced by consumer valuation. In particular, the revenue of the retailer will increase as the quality of the product improves ($V'(q_m) \geq 0$), but the marginal rate of revenue increase tends to slow down as the quality approaches perfection ($V''(q_m) \leq 0$). Again, all the major analytical results and insights presented in the paper will not change if we assume a simpler linear revenue function (i.e., $V'(q_m) \geq 0$ and $V''(q_m) = 0$), i.e., the revenue of the retailer increases linearly as the quality of the product increases.

It should be noted that, for the purpose of theory building, we try to keep our model general without restrictive assumptions. The only two assumptions required are the convex increasing cost function ($c'(q_m) \geq 0$ and $c''(q_m) \geq 0$) for the supplier and the concave increasing revenue function ($V'(q_m) \geq 0$ and $V''(q_m) \leq 0$) for the retailer. Our model can also be modified with additional assumptions based on different practical considerations and arrangements in food supply chain management, such as the downward sloping or reduced-form demand function, competitive pricing, and costs for quality supervision and improvement (e.g., Xie et al., 2011; Ma et al., 2013; Liu and Xie, 2013). As long as the assumptions of convex increasing cost function and concave (or linear) increasing revenue functions hold (with everything else being equal), the major analytical results and insights derived from our model will not change.

Since it is usually not possible for the retailer to inspect the underlying quality of every item (with 100% inspection) due to such considerations as avoiding destructive testing and handling damage, high production volume, and high inspection costs, the retailer will run an acceptance sampling test after the whole lot of items are received from the supplier (see, e.g., Schilling, 1982; Stephens, 2001; Hubbard, 1996). Let q_r be the required quality by the retailer in the sampling test, i.e., the retailer will accept the entire lot if q_r portion of the inspected items are conforming to the quality specification with the non-conforming items been replaced or amended (Juran and Godfrey, 1998). Let W_1 and W_0 denote the payments received by the suppliers for passing and failing the sampling test, respectively, where $\Delta W = W_1 - W_0 > 0$. Notice that the base payment, W_0 , is not necessarily positive (i.e., a penalty for failing the sampling test may be applied), and the additional costs for remanufacturing and other corrective actions may also be deducted. The retailer's sampling technology is denoted by $s_r(q_m, q_r)$, which is the probability for the entire lot to pass the sampling test. Assume that the sampling technology is common knowledge and that $\partial s_r(q_m, q_r) / \partial q_m \geq 0$ and $\partial s_r(q_m, q_r) / \partial q_r \leq 0$, which indicate that the probability to pass the test is increasing in q_m , the product's underlying quality, but decreasing in q_r , the required quality by the retailer. For example, suppose that n items are randomly selected and inspected in a sample. If more than nq_r items are conforming, the entire lot passes the sampling test. Based on binomial distribution, the probability of passing the test is $s_r(q_m, q_r) = \sum_{i=[nq_r]}^n C(n, i) q_m^i (1 - q_m)^{n-i}$. Notice that the simple testing procedure assumed in the model reflects the fact that some rather basic testing methods for quality control are still used in many emerging markets where the applications of more advanced testing technologies, such as continuous sampling and Taguchi methods, are still limited due to a lack of physical and human resources. For example, before the 2008 adulterated milk incident, major Chinese dairy processors procured raw milk largely from small-scale dairy farms and individual household farmers using a simple standard that graded tested fresh liquid milk by its protein content. Failing to meet the standard would lead to a lower purchase price which might not be sufficient to cover the production cost (Zhu, 2008).

It is noted that the conceptualization of food quality with q_m and q_r in this paper is based on the concept of “relative risk” associated with the consumption of different types of food products commonly used by government agencies around the world (e.g., Food and Drug Administration, 2003). To exert precaution in quality control for some products such as milk, prepared food, ready consumable food items, the required quality can be set at 1% or 100% (i.e., $q_r = 1$), and our model can be converted into a 0/1 based decision system in which any non-conforming item detected during the quality test will result in the entire lot being rejected by the retailer. According to the guidelines

published by the American National Standards Institute/American Society of Quality Control (ANSI/ISO/ASQC A3534, 1993), it is also important to distinguish between “defect” (i.e., a product which is not fit for consumption with potential health and safety effects) and “non-conformity” (i.e., a product which does not meet the quality specification) in sampling tests. Accepting a lot of food products based on a sample which contains one or more non-conforming items (i.e., $q_r < 1$) does not necessarily compromise the public health and safety for several reasons. First, the quality specification used in the sampling test and the actual quality of the non-conforming item may still be higher than the health/safety standard established by the government. Therefore, a “non-conforming” item is not necessarily a “defective” item. For example, after the 2008 adulterated milk incident in China, the dairy producers are now required to use the quality specification of 1 ppm to test melamine, which is much stricter than the legally acceptable level (2.5 ppm) established by the Chinese government and by the World Health Organization (Wall Street Journal, 2008).³ In addition, the exact legally acceptable level of a particular food quality, such as the safe limit of ractopamine (Paylean) in meat products, may be controversial or still under study.⁴ For example, before and during the adulterated milk incident in China, no specific standard was established by the Chinese government regarding the legally acceptable level of melamine in dairy products due to lack of scientific knowledge. As a result, dairy companies had to set their own quality specifications for sampling tests with no specific information about the resulting extent of health/safety effects (International Risk Governance Council, 2008). (The issue related to the health/safety standards of melamine before, during, and after the adulterated milk incident will be discussed in more details in our case study.)

As mentioned previously, the food quality measurement used in our model can also be based on a continuously distributed variable (i.e., variable-based quality measurement), such as the protein content in raw milk and the amount of pesticide residues in an item. The model can then be modified with a slightly different interpretation of the sampling technology as follows. The retailer will first randomly select and inspect a certain number of items and compute the average quality level. The entire lot will pass the sampling test if the average quality level is higher than q_r , and vice versa. For example, if the underlying quality is normally distributed with q_m and σ as the mean and standard deviation, respectively, and n items are randomly selected and inspected in a sample, then the sample quality is also normally distributed with q_m and σ/\sqrt{n} as mean and standard deviation, respectively. It can then be shown that $s_r(q_m, q_r) = 1 - F(q_r)$, where $F(\cdot)$ denotes the probability distribution function of the sample quality. As discussed in Schilling (1982) and Juran and Godfrey (1998), variable-based sampling plans can generally provide the same degree of consumer protection as attribute-based sampling plans while using considerably smaller samples.

2.1. Centralization case

We will first analyze the centralization case within an integrated food supply chain as the benchmark. Since information

³ It can be assumed that, if there is any item in a sample that does not meet a legally acceptable quality standard, the entire lot will be rejected (even though the proportion of non-conforming items is lower than q_r). This will affect $s_r(q_m, q_r)$, the probability for the lot to pass the sampling test. Given the general model structure, however, all the major analytical results and insights derived from the current model would remain largely unchanged.

⁴ The acceptable levels of ractopamine in meat products established by the governments of the United States, Canada, New Zealand, and European Union are 30 ppb, 40 ppb, 10 ppb, and 0 ppb, respectively.

about the supplier’s underlying product quality is common knowledge in a centralized supply chain, no sampling test is necessary, and the objective of the two firms is to maximize the joint profit. It should be noted that, while vertical integration is a direct way to realize the centralization case, it is also possible for legally independent firms to achieve the state of centralization through strong vertical control within other arrangements such as joint venture, contracting, and supply-chain integration (see, e.g., Roth et al., 2008; Besanko et al., 2009), as will be shown in the case study presented later in the paper. To maximize the joint profit of the integrated supply chain, the objective function is

$$\text{Maximize}_{q_m} V(q_m) - c(q_m) \quad (1)$$

Since the objective function is concave, the first-order condition, $V'(q_m) = c'(q_m)$, will lead to the optimal solution. We will use q_m^i to denote the optimal underlying quality for the centralized case.

2.2. Decentralization case

In the decentralization case, the supplier and retailer act independently to maximize their own profits (Tirole, 1988), which is analogous to the situation in many global emerging markets where individual small-scale suppliers and household workers form the major sources of supply of raw materials and semi-processed food products. For example, before the 2008 adulterated milk incident, the “dispersed sourcing model” was commonly used by major Chinese milk processors to enter into formal or informal contractual agreements with small-scale dairy farms and “backyard” farmers for raw milk procurement (Hu, 2009). The decision-making process of the two players in the decentralized supply chain is as follows. In the first stage, the retailer announces its quality requirement q_r in the sampling test to the supplier. In the second stage, the supplier chooses q_m given q_r and ΔW , the additional payment for passing the sampling test. We will first assume that ΔW is exogenous (e.g., the additional payment is specified in a long-term contract or government regulation). The assumption will later be relaxed to analyze the situation where the retailer or government determines the additional payment. Consistent with the standard process for solving multi-stage games (see, e.g., Mitra and Webster, 2008; Yao and Zhang, 2009), we now use backward induction to analyze the problem. Starting from the second stage, given the quality requirement q_r by the retailer, the supplier’s problem is to maximize its expected revenue minus the production cost, i.e.,

$$\text{Maximize}_{q_m} (W_0 + \Delta W)s_r(q_m, q_r) + W_0[1 - s_r(q_m, q_r)] - c(q_m) \quad (2)$$

The first-order condition is

$$\Delta W \partial s_r(q_m, q_r) / \partial q_m - c'(q_m) = 0 \quad (3)$$

The optimal solution, if exists, will satisfy the following second-order condition:

$$\Delta W \partial^2 s_r(q_m, q_r) / \partial q_m^2 - c''(q_m) \leq 0 \quad (4)$$

Since we use general forms of the revenue and cost functions, we will focus on the cases where the second-order condition is satisfied (i.e., with interior solutions) for the remainder of the paper. We can then solve for the optimal quality level based on the first-order condition as a function of q_r . Let $q_m(q_r)$ denote the optimal underlying quality chosen by the supplier. In the first stage, anticipating the supplier’s response, the retailer’s problem is

$$\begin{aligned} & \text{Maximize}_{q_r} V(q_m(q_r)) - (W_0 + \Delta W)s_r(q_m(q_r), q_r) - W_0[1 - s_r(q_m(q_r), q_r)] \\ & = V(q_m(q_r)) - \Delta W s_r(q_m(q_r), q_r) - W_0, \end{aligned} \quad (5)$$

which is equivalent to the retailer choosing both q_r and q_m subject to the first-order condition in (3), i.e.,

$$\text{Maximize } V(q_m) - \Delta W s_r(q_m, q_r) - W_0, \text{ subject to (3)} \quad (6)$$

The Lagrange function based on (6) is

$$L = V(q_m) - \Delta W s_r(q_m, q_r) - W_0 + \lambda [\Delta W \partial s_r(q_m, q_r) / \partial q_m - c'(q_m)], \quad (7)$$

which leads to the following condition that establishes the relationship between q_m and q_r under decentralization

$$V'(q_m) - c'(q_m) = \left[\Delta W \frac{\partial^2 s_r(q_m, q_r)}{\partial q_m^2} - c''(q_m) \right] \frac{\partial s_r(q_m, q_r) / \partial q_r}{\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r} \quad (8)$$

Using (3) and (8), we can solve for q_r and q_m . Let q_m^d denote the optimal underlying quality under decentralization. The comparison of the optimal underlying qualities under the centralized and decentralized cases leads to the following proposition. (See the Appendix for proof.)

Proposition 1. *The underlying quality under the decentralization case is lower than that under the centralization case (i.e., $q_m^d \leq q_m^i$) if and only if $\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r > 0$.*

The proposition indicates that the effects of different supply-chain structures on product quality depend on the properties of the sampling technology, i.e., the probability for a lot of items to pass the sampling test. Specifically, when $\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r > 0$, decentralization would lead to a “quality distortion” with a lower underlying quality than centralization. To see this, let’s again assume that the underlying quality is normally distributed with q_m and σ as the mean and standard deviation, respectively, and n items are taken and inspected in a sample. It can then be verified that the condition $\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r = n f(q_r)(q_r - q_m) / \sigma^2 > 0$ holds if and only if $q_m < q_r$ where $f(\cdot)$ is the probability density function of the sample quality. In other words, quality distortion under decentralization occurs when the profit-maximizing supplier is able to take advantage of the probability distribution of passing the sampling test to supply an average underlying quality that is lower than the required quality by the retailer under the cost and revenue structures. The intuition is that while the retailer may demand a higher level of required quality under the decentralization case, the supplier’s ability to improve product quality is also constrained by the increasing production cost. If the sampling technology allows the supplier to have a relatively “easy ride” to pass the sampling test (i.e., $\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r > 0$ or $q_m < q_r$) under the condition of poor informational visibility, the supplier would choose to “take its chance” with the sampling technology as opposed to exerting sufficient effort in quality improvement. This phenomenon is analogous to the concept of supermodularity in economics where, if one player (retailer) chooses to reduce $s_r(q_m, q_r)$ (i.e., with higher q_r), the other player (supplier) will have an incentive to reduce $s_r(q_m, q_r)$ (i.e., with lower q_m). For example, in the 2008 adulterated milk incident in China, as some dairy companies demanded higher protein content (the required quality) in raw milk, the suppliers’ response was not to increase the actual protein content, but to add melamine to boost the apparent protein content (i.e., to focus on the sampling technology for passing the test). The centralization option with stricter vertical quality control would thus be a better choice to ensure food product quality/safety under such a situation. For other commonly used probability distribution functions for product quality, such as binomial and gamma distributions, the conditions under which $\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r > 0$ holds are less straightforward. For example, under the assumption of binomial distribution, the probability of passing the sampling test is $s_r(q_m, q_r) = \sum_{i=[nq_r]}^n C(n, i) q_m^i (1 - q_m)^{n-i}$. Suppose that 10 items are randomly selected ($n = 10$) and inspected in a sample. If more than nq_r items are conforming, the entire lot

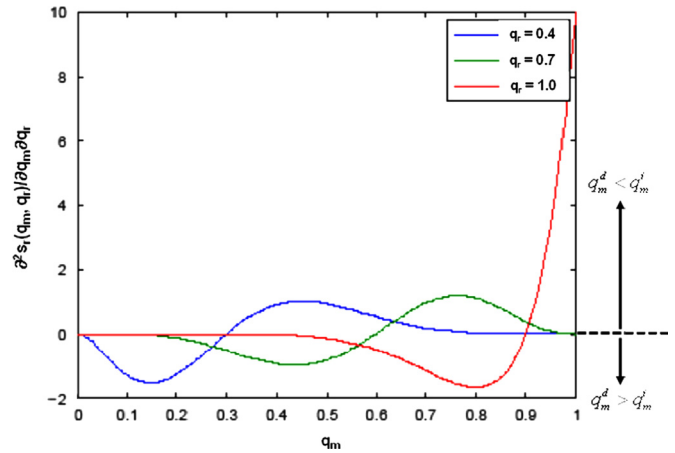


Fig. 2. Vertical control choices under binomial distribution.

passes the sampling test. Fig. 2 shows how $\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r$ (which determines whether the centralized or decentralized strategy would lead to a higher quality level, i.e., $q_m^d \leq q_m^i$) will change given different values of q_m and q_r . As can be observed from the figure, if the required quality is at least the same as the underlying quality, the centralized approach is a better choice for vertical control (i.e., $q_m^d \leq q_m^i$) to ensure food product quality and safety, though the advantage would diminish as q_m approaches 100%.

2.3. Effects of pricing and regulatory options

We now analyze a variation of the model where the retailer determines ΔW , the difference between the prices for passing and failing the sampling test, which is analogous to the situation before the 2008 adulterated milk incident in the Chinese dairy industry where the dispersed small-scale farms and household farmers had no bargaining power or ability and knowledge for price negotiation, and thus were obliged to receive the prices offered by major dairy processors (Hu, 2009). By adding ΔW as a decision variable and replacing $q_m(q_r)$ with $q_m(q_r, \Delta W)$ in (5), we can use a modified Lagrange function to obtain the following proposition regarding the effect of the retailer’s pricing decision on the underlying quality. (See the Appendix for proof.)

Proposition 2. *If ΔW is determined by the retailer, the underlying quality under decentralization is always lower than or equal to that under centralization (i.e., $q_m^d \leq q_m^i$).*

The proposition indicates that the situation of quality distortion under decentralization would actually worsen as the retailer gains more bargaining power. This seemingly surprising result is largely due to the profit maximization scheme used by the retailer. Similar to the double marginalization situation (Tirole, 1988), the price difference ΔW is used by the retailer as a mechanism to extract additional economic surplus from the supplier. As its profit is being squeezed, the supplier would choose to take its chance with the sampling technology as opposed to exerting more effort in quality improvement which would incur a higher cost given the convex increasing production cost function. In other words, the supplier and retailer are “locked into” a contractual arrangement that leads to a lower underlying quality under decentralization due to their self interests. The profit-maximization scheme used by the retailer thus eliminates the possibility that decentralization would lead to a higher underlying quality than centralization presented in Proposition 1.

We now consider a three-tier supply chain in which a supplier sells to a wholesaler who in turn sells to a retailer. Such an

arrangement is commonly seen in global emergent markets for large-scale enterprises to organize their supply chains. For example, milk collection agents (wholesalers) are commonly used by major Chinese dairy companies as the middlemen to procure raw milk from the geographically dispersed small-scale farms and household farmers. Let \bar{q}_m^d denote the underlying quality under the three-tier supply chain. Also let q_w and q_r denote the required qualities by the wholesaler and retailer, respectively, in the sampling tests. Based on a much lengthier proof given in the Technical Appendix (posted as an online resource), we have the following result.

Proposition 3. *In the three-tier supply chain where the price difference between passing and failing the sampling test between each pair of tiers is determined by the player downstream, the underlying quality is lower than those under the two-tier supply chain and the centralized supply chain, i.e., $\bar{q}_m^d \leq q_m^d \leq q_m^i$.*

The proposition indicates that the result of quality distortion presented previously can be extended to a food supply chain with three or more tiers, i.e., the more tiers or middlemen, the lower the underlying quality. The reasoning is that more tiers in the vertical chain would further squeeze the supplier’s profit, which leads to the supplier’s exerting even less effort in quality improvement. As a relevant example, the use of collection agents by major dairy companies was cited as one of the main causes of the 2008 adulterated milk incident in China (Xinhua News Agency, 2008). Some farmers reportedly chose to engage in the adulteration practice since their earnings were squeezed by the collection agents who were also under pressure to maintain cash flows from milk procurement (Li et al., 2008; DeLaurentis, 2009).

One implication of the above propositions is that the market mechanism itself sometimes may not be enough to correct the quality distortion under decentralization, and government intervention would then be necessary. We now assume that the prices for passing and failing the sampling test are determined by the government under decentralization, which is similar to the situation in some regional dairy markets in China where the government now sets both a maximum price cap and a minimum protection price for raw milk (Xinhua News Agency, 2009). For example, Heilongjiang Province already has reference prices for raw milk set by local commissions based on production costs and local market conditions. The National Development and Reform Commission (NDRC) of China has also been considering adopting a similar mechanism for setting raw milk prices (Gale and Hu, 2009). Suppose that, before the retailer and suppliers sequentially determine q_r and q_m , the government first sets ΔW and W_0 with the objectives to correct the quality distortion under decentralization as well as to achieve a desired distribution of the supply-chain profit. The next proposition concerns how the price control scheme can be implemented. (See the Appendix for proof.)

Proposition 4. *The government can induce the improvement of the underlying quality from q_m^d to q_m^i by setting*

$$\Delta W = \frac{c''(q_m)}{\partial^2 s_r(q_m, q_r) / \partial q_m^2}$$

where q_r satisfies

$$\frac{\partial s_r(q_m, q_r) / \partial q_m}{\partial^2 s_r(q_m, q_r) / \partial q_m^2} = \frac{c'(q_m)}{c''(q_m)} \tag{9}$$

Then adjust W_0 or W_1 to achieve the desired distribution of the total supply-chain profit.

According to the proposition, the government can use the price floor (W_0) and the price difference (ΔW) as control mechanisms (which is equivalent to setting both the price floor and price cap) not only to correct quality distortion but also to influence income

distribution under decentralization. As a simple numerical example, under the assumption of normal distribution with $\sigma=1$ and $n=50$, assume $v(q_m) = q_m$ and $c(q_m) = q_m^2$. Then we have

$$s_r(q_m, q_r) = \text{prob}\{\bar{x} \geq q_r\} = 1 - F(q_r) = \int_{q_r}^{+\infty} \frac{1}{(\sigma/\sqrt{n})\sqrt{2\pi}} \exp[-((x - q_m)^2 / (2\sigma^2/n))] dx, \tag{10}$$

$$\frac{\partial s_r(q_m, q_r)}{\partial q_m} = \int_{q_r}^{+\infty} \frac{1}{(\sigma/\sqrt{n})\sqrt{2\pi}} \exp\left[-\frac{(x - q_m)^2}{2\sigma^2/n}\right] \frac{(x - q_m)}{\sigma^2/n} dx, \tag{11}$$

and

$$\frac{\partial^2 s_r(q_m, q_r)}{\partial q_m^2} = \int_{q_r}^{+\infty} \frac{1}{(\sigma/\sqrt{n})\sqrt{2\pi}} \exp\left[-\frac{(x - q_m)^2}{2\sigma^2/n}\right] \left\{ \left[\frac{(x - q_m)}{\sigma^2/n}\right]^2 - \frac{1}{\sigma^2/n} \right\} dx \tag{12}$$

Based on (9), we obtain $q_r=0.54$, which can then be used to solve for the critical price difference $\Delta W=0.369$ to induce the supplier to set the underlying quality at $q_m^i = q_m^d = 0.5$.

It should be noted that two typical purposes of setting the price floor are to protect suppliers’ interest and to ensure product quality, as in the current Chinese dairy industry, which is consistent with the objectives of our analysis. The purpose of setting the price cap, however, is usually to curb inflation, which is beyond the scope of the paper. Nevertheless, the proposition does show a “side benefit” of setting the price cap which can be used to ensure both product quality and social justice under decentralization. Another implication of the proposition is that a socially responsible food company whose objective is not to maximize its own profit but to improve the quality/safety of the product can design a contract menu based on (9) to induce the supplier to voluntarily correct the quality distortion or to comply with a health/safety standard under decentralization in a regulation-free environment, and then reallocate the total supply-chain profit similar to the two-part tariff case (Tirole, 1988). Such a practice to control q_m by adjusting ΔW and q_r , however, may not be effective if q_r is constrained (e.g., $q_r=1$ with an attribute-based quality specification). It should also be noted that the price-based control strategy is valid under the specific model formulation of the paper, and the analytical results may vary given different model assumptions and specifications such as supplier competition and different market structures.

Another extension of the model is to consider the cost of fraud imposed by the government through the enforcement of a food safety regulation. Specifically, a benchmark or standard can be set at q_m^i , the underlying quality for the centralized case, with an additional cost of quality distortion (i.e., cost of fraud) for any underlying quality level that is lower than the benchmark or standard. (The analysis can be extended to the situation where the benchmark or standard is set at a different level.) If the underlying q_m is higher than q_m^i , there is no fraud cost. However, if $q_m^i - q_m > 0$, there is a probability such that the fraud will be caught. Let this probability be $p(\Delta q_m)$ as an increasing function in Δq_m where $\Delta q_m = q_m^i - q_m$, i.e., lower underlying quality means higher probability to be caught. When the fraud is discovered, a penalty cost, denoted by $g(\Delta q_m)$, is imposed by the government. Assume that $g'(\Delta q_m) \geq 0$ and $g''(\Delta q_m) \geq 0$, which implies that the bigger the quality distortion, the higher the fraud cost and the marginal fraud cost. (For severe punishments such as death sentence and life imprisonment as in the 2008 adulterated milk incident in China, the cost of fraud can be assumed to be extremely high as Δq_m increases.) Then the expected cost of fraud, denoted by $c_f(q_m) = p(\Delta q_m)g(\Delta q_m)$, is a convex decreasing function in q_m , i.e., $c_f'(q_m) \leq 0$ and $c_f''(q_m) \leq 0$ for $q_m \leq q_m^i$. It can then be shown that

the conditions of quality distortion under decentralization established in Propositions 1 and 2 are still valid. Similar results can also be derived if the cost of fraud is shared between the supplier and retailer. (See the technical appendix for the proof.) In the sections that follow, we will present a case study which covers a number of important practical managerial and policy issues regarding quality control in food supply chain management.

3. Case study: the adulterated milk incident in China

We now present an exploratory case study of the adulterated milk incident in China to further explore practical issues related to managing food supply chain quality and risk in the previous section. According to the classic book in case research design and methods by Yin (2009), there are six most commonly used sources of evidence in doing case studies: documentation, archival records, interviews, direct observations, participation-observation, and physical artifacts. Since the adulterated milk incident has been under criminal investigation in China with most people with direct knowledge sentenced to death or prison, the formal structured interview case approach is not possible. Therefore, our case study utilizes archival records in a number of published or unpublished reports supplemented with interviews with managers in the Chinese dairy industry. Our purpose is to present an exploratory case study in which comparative cases are investigated to extract useful managerial and policy insights through within and cross case analyses. In particular, we investigate and compare the operations and supply-chain management practices of Sanlu Group, which was at the center of the incident, and Sanyuan Group, a company with a very different business model and supply-chain control strategy which not only survived the incident but is now positioning itself as a dominant player in the market. A number of key insights concerning quality control in food supply chain management derived from the analytical model will also be explored.

3.1. Background

As China has grown wealthier over the past three decades, the domestic dairy industry has taken off with a total market value around ¥20 billion. The per capita consumption of dairy products in China increased from about 3 kg in 1985 to 28.6 kg in 2007 (Business Week, 2008; Maynard, 2009). As shown in Fig. 3, the total output of dairy products in China increased from around 3 million tonnes in 1985 to more than 35 million tonnes in 2007. Dairy exports also reached 12,000 t per month in mid-2008. In China's eleventh 5-year plan, the government has set ambitious targets for milk production of over 57 million tonnes in 2020 (Gale and Hu, 2009). In response to the surging domestic and international demands of dairy products

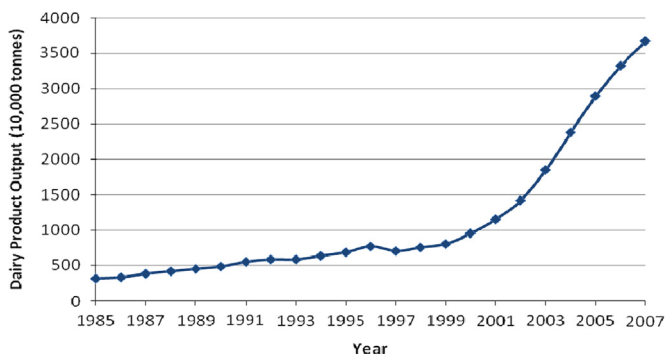


Fig. 3. Total dairy product output in China (1985–2007).
Source: National Bureau of Statistics of China.

Table 1

Number of dairy farms, number of cows owned, and output in China (2006).
Source: Hu (2009).

| Herd size | Number of farms | Number of cows | Milk output (tonnes) |
|-----------|--------------------|--------------------|----------------------|
| 1–5 | 1,271,729 (81.00%) | 4,034,876 (44.10%) | 5,356,552 (35.31%) |
| 5–20 | 263,715 (16.80%) | 2,714,241 (29.67%) | 4,135,290 (27.26%) |
| 21–100 | 30,780 (1.96%) | 1,257,814 (13.75%) | 2,827,367 (18.64%) |
| 101–200 | 2294 (0.15%) | 335,503 (3.67%) | 713,905 (4.71%) |
| 201–500 | 950 (0.06%) | 336,148 (3.67%) | 741,448 (4.89%) |
| 501–1000 | 336 (0.02%) | 235,228 (2.57%) | 707,555 (4.66%) |
| > 1000 | 162 (0.01%) | 234,816 (2.57%) | 688,867 (4.54%) |
| Total | 1,569,966 (100%) | 9,148,626 (100%) | 15,170,984 (100%) |

and government supports, most major milk processing enterprises, including Yili, Mengniu, Sanlu, and Bright as the top four firms in the Chinese dairy industry, started aggressive marketing campaigns and capacity expansion plans in the early 2000s, and the four-firm concentration ratio reached nearly 50% in 2006. However, as a result of the industry's "blind expansion," as noted by the National Development and Reform Commission (2008) of China, in the 2008 adulterated milk incident, problems in operations and supply chain management led to a breakdown of quality assurance in the Chinese dairy industry. The incident severely damaged the industry, and the World Health Organization (WHO) called the incident the "largest food safety event it had had to deal with in recent years." In the subsections that follow, we will present the within case analyses of the distinct operations and supply-chain management practices used by Sanlu Group and Sanyuan Group, which led to the two companies' very different fates in the adulterated milk incident.

3.2. Within case analysis: Sanlu group

Beginning as a cooperative of 18 farm households with 30 cattle and 170 sheep, the Sanlu Group became China's largest milk power processing company in 2004 with total assets of \$324 million (Hu, 2009). After entering into a joint venture agreement with New Zealand dairy cooperative Fonterra which took a 43% equity stake, Sanlu sales reached ¥10 billion as its market share reached 18% in 2007. Like most of the other leading milk processing enterprises in China, Sanlu adopted the growth strategy of "establishing the market first and then establishing the factory" (Niu, 2003). To implement such a strategy, the company tried to project itself as a provider of excellent nutritional value to consumers with an aggressive advertising campaign to boost its image, which included a special edition of the CCTV (China's national TV station) program "quality reports weekly" focusing on the company's products (CCTV In-Depth Report, 2007).

In terms of operations and supply chain management, Sanlu, as well as many other major milk processors in China, adopted the highly decentralized "dispersed sourcing model" which heavily depended on independent small-scale farms and household "backyard" farmers as raw milk suppliers in order to reduce operational costs and maintain flexibility. In fact, Sanlu was the first dairy company in China that devised the small-farm procurement strategy in Hebei Province in the 1990s. According to Hu (2009), in addition to signing formal contracts with small-scale farms with specified sale prices of raw milk, Sanlu also came up with a number of innovative ways to enter into agreements with independent household farmers, including (1) leasing dairy cows to household farmers, (2) selling dairy cows to household farmers at a 30% discount price, and (3) being a loan guarantor for household farmers borrowing half the buying price of a cow from a bank. Various grades of raw milk were paid different prices by Sanlu based on a simple sampling test of its protein content, and a certain percentage of earning received by a household farmer from

milk sales was used to repay the company (Xinhua News Agency, 2008). These practices were soon copied by other major milk processing enterprises in the Chinese dairy industry. As shown in Table 1, adapted from Hu (2009), there were about 1.57 million dairy farms in China in 2006 of which 1.27 million (81%) owned only 1–5 cows, and farms with fewer than 100 cows supplied more than 80% of the country's milk output. To better connect and control the exceedingly large number of geographically dispersed small-scale farms and household farmers within its supply chain network, Sanlu, like many other Chinese milk processors, also utilized independent collection agents or collection stations as the middlemen in the sourcing and procurement processes. As a result, the decentralized dispersed sourcing model allowed Sanlu to quickly build up its supply chain network with small-scale individual suppliers to support the company's fast expansion strategy into the vast Chinese dairy market.

Sanlu's advantages in operational costs and flexibility accomplished with its decentralized dispersed sourcing model, however, came at the expense of less effective quality supervision in supply chain management. Due to the significant differences among small-scale raw milk suppliers in terms of technical and management skills, sanitary conditions, and quality/safety awareness, quality problems in raw milk production evolved into a major concern. For example, according to Zhang (2008), only 20% of small-scale "backyard" farmers used disinfectant prior to milking, compared with over 90% of large-scale farms. In addition, Sanlu's relatively quick expansion also led to a shortage of milk sources and the collection of raw milk without close supervision of quality. As a consequence, some of Sanlu's suppliers and collection agents started to gradually use melamine, a chemical which can appear to heighten the protein levels of milk so that the milk is erroneously identified as a higher grade. The price caps imposed by the government and feed price hikes also pressured some farmers and collection agents to add cheaper chemical substitutes, such as melamine, to raw milk. Although there have been reports that Sanlu knew of the abnormal side effects of its formula, including kidney stones and urinary tract problems, as early as March 2008 (SinoCast China Business Daily News, 2008), melamine was "officially" discovered in Sanlu's formula in August 2008. While the dairy products of 21 other companies also were tested positive for melamine to a lesser degree, all of the publicly reported deaths and most of the controversy in the incident were linked to Sanlu.

The initial response of Sanlu to the incident was to pass the blame to dairy suppliers for knowingly adding melamine to disguise sales of adulterated raw milk (Financial Times, 2008a). However, sequential investigations and analyses revealed that Sanlu's weak supply chain control, especially the lack of training and monitoring of business partners, allowed the adulterated milk to pass through the quality control and inspection points in the company's supply chain and eventually reached its customers. As Sanlu's increasing demand tightened supply, some milk farmers and milk collection agents were recruited without basic quality control training or even a background check. Since the milk collection process at Sanlu's collection stations was not well regulated and organized according to sources with proper documentation, raw milk from different farmers often mixed in the same container, which prevented the identification of a problem's source and reduced the ability to hold perpetrators accountable for quality assurance breaches (DeLaurentis, 2009). In addition, the experience of Fonterra, Sanlu's foreign partner and major stakeholder, did not appear to be helpful in stopping the quality/safety problems. While Fonterra advised Sanlu on quality testing, the New Zealand company said that it never independently checked any of its partner's product, and was not aware of the practice of adulteration until one month before the incident erupted (Financial Times, 2008b). Furthermore, although the Administration of Quality, Supervision, Inspection, and Quarantine (AQSIQ) System

was established by the Chinese government in 2007, a number of Sanlu's products were exempted from government inspection for having passed government quality checks three times in succession. Additionally, when a substance is novel or is not a designated food additive—as was the case with melamine—there are many unknowns, and knowledge of this kind is often incomplete or not adequately sought out. When melamine was first discovered in milk in China, there was a rush to find toxicological information about the chemical, but little was found. The few pre-existing laboratory analyses of melamine had determined that it has a low toxicity in animals, and is rapidly eliminated from the body in urine (International Risk Governance Council, 2008). As a result, product quality/safety was compromised due to a lack of managerial and regulatory control and supervision along Sanlu's entire supply chain.

The Chinese dairy industry was severely damaged by the incident. As of January 2009, the adulterated milk had sickened nearly 300,000 infants and caused the death of at least six children. Sanlu went into bankruptcy while its chairwoman, Tian Wenhua, was sentenced to life imprisonment and two other third-party milk suppliers were sentenced to death in January 2009. At least 11 countries stopped importing Chinese dairy products, while others, including U.S. and many EU member states, imposed tighter quality and safety checks (Business Week, 2008). According to a report from China's General Administration of Customs, exports of dairy products in 2008 dropped from an average of 12,000 t per month to just over 1000 t (Maynard, 2009). In the domestic market, sales fell by 30–40% on a comparative basis as consumer confidence faltered after the incident erupted. Yili and Mengniu, two other leading milk processors, recalled melamine related products worth ¥6.4 billion (Xinhua News Agency, 2008), and the total financial effect for the entire industry was estimated to be around ¥20 billion according to the Chinese Dairy Association (Nanfeng Daily, 2008).

3.3. Within case analysis: Sanyuan Group

One notable company whose entire product lines successfully passed all the subsequent tests performed by AQSIQ was Sanyuan Group. Sanyuan Group, which operates a highly integrated supply chain for its dairy products, is a relatively old food company with more than 45 years of experience in the dairy business. In fact, the company not only survived the adulterated milk incident, but has also seized the opportunity to grow amid the current turmoil in the industry.

Contrary to the strategy of "establishing the market first" adopted by Sanlu and other major milk processing enterprises in China, Sanyuan closely followed the old industry wisdom that "secure milk sources win the battle" with a nearly self-sufficient supply chain, which was considered as the company's core competency (Economic Weekly China, 2009a). In terms of sourcing and procurement, unlike Sanlu and most other major players in the Chinese dairy industry which had few company-owned dairy farms, Sanyuan's Luhe Dairy Cattle Center owned a total of 27 dairy farms with 35,000 heads of cattle, producing 9500 kg of fresh milk per cow per year, which was the highest in China. The total estimated output of fresh milk from Luhe Dairy Center was 332,500 t per year, which accounted for almost half of the total production of large-scale farms with more than 1000 heads of cattle in China according to Table 1. In fact, 80% of the Sanyuan's raw milk came from dairy farms that the company either owned or had a stake in (Maynard, 2009). For those independently owned dairy farms which supplied the balance (20%) of raw milk, Sanyuan also utilized centralized purchasing and control strategies to provide animal feed, breeding cattle, veterinary care, and technical training through a well-established support and monitoring system. Since 2001, Sanyuan had contracted only with

cattle farms for its raw milk supply because of the belief that a farm of scale could afford quality control. In addition, unlike Sanlu which relied heavily on third-party milk collection agents, most of the milk collection stations of Sanyuan were company-owned, and the company is currently in the process of phasing out all the collection stations to have raw milk delivered directly to its processing facilities (Economic Weekly China, 2009b).

Downstream in its supply chain, Sanyuan's production and distribution operations were also highly centralized. The production and quality control processes were highly standardized with ISO 9001 and ISO 9002 certifications, and the company operated its own transportation fleet with 375 vehicles to ensure the delivery times and the proper temperatures inside milk containers during delivery. ERP systems were used to digitally link the sourcing, production, quality control, and delivery operations to achieve speedy information exchange and supply chain integration (Hisen Technology, 2009). In fact, Sanyuan's centralized approach goes beyond the standardized processes embedded in its operations and information systems. The company also actively promoted ethical conduct as a corporate culture through directly involving employees in the establishment of its quality-management system. By linking product quality, consumer safety, and profit in employees' minds, Sanyuan was able to encourage workers to identify quality as a company hallmark. As a notable example, Sanyuan's workers test-drinked every batch of milk before it left its production facilities (DeLaurentis, 2009). In addition, Sanyuan operated the largest research center for developing new technologies and procedures for dairy cattle embryo production and cattle breeding with the largest dairy cow gene pool in China. With the strong ownership of all the sourcing, production, quality management, and distribution operations as well as the effective implementation of information technologies, Sanyuan was able to create a supply-chain system with a focus on visibility, traceability, accountability, and empowerment, which enabled the company to ensure product quality and, as a result, to survive the adulterated milk incident.

The implementation of the centralized model for quality control in supply chain management by Sanyuan, however, was not without its own shortcomings and disadvantages. First of all, not recruiting small-scale farms and household farmers greatly limited the company's capability to expand in the fast growing Chinese dairy market. In addition, the unit production costs of large-scale farms were about 20% higher than those of small-scale farms and household "backyard" farmers (with lower costs of feed and labor) according to a survey done by the National Development and Reform Commission of China. Furthermore, establishing large-scale farms and a vertically integrated supply chain incurred additional fixed costs to acquire and consolidate collectively-owned land and build new collection, storage, and processing facilities (Gale and Hu, 2009). All these disadvantages led to Sanyuan's losing ground to those aggressive new comers such as Yili, Mengniu, and Sanlu in the marketplace. As a matter of fact, Sanyuan's market share in the Beijing area, the company's home base, dropped from 80% a decade ago to below 40% in 2007 (Xinhua News Agency, 2008).

The competitive dynamics in the Chinese dairy industry eventually changed to Sanyuan's favor in the wake of the 2008 adulterated milk incident as the company was one of the few established milk processors whose entire product lines were cleared in the nationwide tests performed by AQSIQ. It turned out that, in addition to Sanlu, many leading domestic brands, including Yili, Mengniu, and Bright, were tarnished in the incident as their products were also tested positive for melamine, though to a lesser degree. Soon after the incident erupted, Sanyuan's sales tripled in the Beijing area as the company's share price jumped by 52% in 5 days, while panic buying was also reported in other cities

and provinces. Sanyuan's employees had to work 18–20 h per day in order to meet the surging demand (Maynard, 2009). In March 2009, Sanyuan paid about \$7.2 million for a 95% stake of Sanlu, buying up its facilities, patents, and the brand name for significantly less than what they were worth. The new Sanyuan Group, which was recently renamed Capital Agribusiness Group, is now positioning itself as one of the most dominant players in the Chinese dairy industry.

3.4. Lessons learned

Today the Chinese dairy industry has been gradually getting back on its feet. Foreign investors are back with Sequoia and Fonterra (which has written off its investment in Sanlu) leading the way to establish new partnerships with Chinese dairy companies (Mergers & Acquisitions Report, 2009). The industry also appears to have learned a valuable lesson about the importance of quality control in supply chain management. Sanyuan's centralized approach is now copied by major players in the market. The nation's two biggest dairy companies, Mengniu and Yili, both with products tested positive for melamine, have announced that they had either stopped buying from middlemen or had taken control of the milk collection stations in their supply chains. In particular, Mengniu, which currently owns only seven dairy farms, is reported to be planning the establishment of 20 new company-owned dairy farms, each with more than 10,000 cows, in the next few years (Maynard, 2009). Before the adulterated milk incident, companies invested much more in sales, distribution, and branding—how the brand looks and feels to consumers—but somehow quality became more of an afterthought. Now major Chinese dairy companies have a new focus in their messages to consumers: product safety in supply chain management. Mengniu sent out over 500 million Chinese New Year messages to mobile phone users explaining its supply chain to assure them of the safety of Mengniu milk in 2009, while Yili has launched a host of advertisements under the slogan "Milk You Can Trust." American Dairy (which is actually a Chinese company selling under the brand name of Feihe) also spent about \$3 million in one month on advertising with CCTV alone to regain consumer confidence (Gillet, 2009).

The Chinese government is also taking an active role in safety inspection and quality assurance. On October 9, 2008, the Ministry of Health and five other government agencies issued a joint statement which set the legally acceptable level of melamine content in dairy products (including milk) at 2.5 ppm, the same safe limit established by WHO in 2010 (World Health Organization, 2010). The Chinese Centre for Disease Control and Prevention further required that any amount exceeding 1 ppm during quality tests would give reason to suspect the presence of melamine was intentional (Wall Street Journal, 2008). Stricter recall rules and food safety standards are now specified in the new Food Safety Law, which took effect on June 1, 2009. In the 6 months following the incident, 1644 groups of quality check experts were assigned to factories across the country to help ensure dairy food safety. Regulatory authorities inspected every one of the country's 20,393 milk collection stations, and closed down those without high enough sanitary or quality testing procedures (Xinhua News Agency, 2008). The guaranteed minimum purchasing (protection) prices of raw milk are now established in a number of provinces/regions where major milk sources are located in order to protect dairy farmers' interest and to avoid quality being compromised as a result of vicious price competition (Xinhua News Agency, 2009; Gale and Hu, 2009).

Among all the current players in the Chinese dairy industry, the new Sanyuan Group (i.e., Capital Agribusiness Group) appears to be in the best position to fill the market void created by Sanlu's

demise with the integration of Sanyuan's well-managed supply chain and Sanlu's well-established distribution network covering almost all the major regions in China. While other milk processors in China are scrambling to rebuild their supply chain networks and to regain consumer confidence in product quality and safety, Sanyuan has apparently found a new focus: corporate social responsibility. The company recently introduced a new series of "low-carbon milk" with significant efforts spent in the sourcing, production, and distribution stages to reduce the carbon footprint of its dairy products. Since 2009, Sanyuan has started a series of "warm-marketing campaigns" emphasizing the company's social responsibility to customers in terms of trust and quality assurance (China Net News, 2009). However, it also appears that Sanyuan has learned from Sanlu's mistakes of "blind expansion." In an interview with China News, Mr. Zhang Fuping, Sanyuan's CEO and chairman of the board, stressed the importance of taking a slow and steady expansion strategy in order to ensure product quality (China News, 2009). The distinct experiences and fates of Sanlu and Sanyuan in the adulterated milk incident show the crucial importance of having the right food supply chain for quality control in place to support a company's sustainable growth in a vast emerging market such as China.

4. Managerial and policy insights

In this section, we perform the cross case analysis to derive important insights into managing food supply chain quality and risk in global emerging markets as well as to link the case study findings with those derived from the analytical model and those in the existing literature.

From the perspective of supply chain design, our analytical model and case study show that establishing the right supply chain is the key to ensure food product quality in today's global emerging markets. Many of the global emerging markets, such as China and India, are huge in terms of both the number of potential customers and the vast geographical distribution of regional markets. One danger for companies intending to capture these mass markets within a short period of time is the outgrowth of the supply chain or the building of a supply chain with inexperienced or untrustworthy local suppliers, as in the case of Sanlu. As shown in our analytical model and case study, the centralized approach allows a company to better control its food product quality in supply chain management than the decentralized approach, especially when advanced quality control methods cannot be applied due to limited physical/human resources as well as when the testing technologies and procedures can be systematically influenced or altered. However, organizing a more centralized food supply chain is likely to require more time and financial resources, and not all companies will be able to build a company-owned supply chain like Sanyuan. For these companies, there are a number of other viable options for establishing strong partnerships as well as for exerting vertical control among legally independent firms in a supply chain, such as developing the so-called "supplier code of conduct," utilizing supplier certification programs, and enforcing high quality standards with a strict monitoring and control system (see, e.g., Wycherley, 1999; Roth et al., 2008; Besanko et al., 2009).

The centralized approach for quality control should also go beyond the sourcing stage to include other stages in food supply chain management, such as production, material management, transportation, distribution, and system integration, as shown in Sanyuan's experience. Besides the elimination of middlemen during the procurement stage, a company can develop standardized processes certified by international organizations as a means to prevent quality problems during the production stage.

In addition, special attention should be paid to potential quality problems which may occur during distribution and transportation as opposed to simply relying on third-party logistics providers to do the job, especially for perishable food products. Furthermore, effective information technologies for supply chain integration, such as ERP, can be used to systematically monitor and control the material and information flows within a food supply chain to improve transparency and traceability. Creating a culture which encourages employees to actively participate in the establishment and implementation of the quality management system, as shown in Sanyuan's experience, is also an important component in building an integrated food supply-chain system for quality control.

From the perspective of managing supply-chain partnership, our comparative case study shows the importance of informational visibility and verification in global supply chain management. Trust building is often emphasized as a critical task in developing strong partnerships in supply chain management in many developed countries (see, e.g., Johnston et al., 2004; Fawcett et al., 2008). However, in an emerging market where the applications of advanced quality control methods and technologies are limited, as exemplified by Sanlu's simple testing procedure for raw milk procurement considered in our analytical model, verification between partners through audits and oversights is a key element for building a long-term relationship upon which trust can be gradually developed (Roth et al., 2008). Fonterra's failure to independently check any of Sanlu's products was a classic example of some multinational enterprises' misunderstanding that taking concerted efforts to avoid making their Chinese partners "lose face" is a way of showing trust. In contrast, Sanyuan's requiring its employees to taste every batch of milk leaving its factory not only is a good practice for quality control but also contributes to the long-term processes of improving informational visibility and building trust among all the internal and external stakeholders in the company's supply chain.

From the perspective of regulatory control, our analytical model and case study show that the government may utilize effective control mechanisms, including quality inspection and price control, to ensure product quality/safety in food supply chain management. The government plays a key role in ensuring product quality/safety and social welfare as the watchdog for supply chain operations. In an emerging market where the regulatory structure is underdeveloped, the government can perform independent tests and inspections to monitor and control quality at various stages of a food supply chain, as done by the Chinese government after the adulterated milk incident. Additionally, in a market where price control mechanisms are in place for various economic and social purposes, the government may utilize different price control schemes for ensuring food product quality/safety in supply chain management. Rightly or wrongly, many multinational firms come to China and other developing countries to look for low-cost suppliers. As a supplier's profit is squeezed, product quality is often compromised as a result. By setting the right levels of price cap and price floor, the government cannot only correct quality distortion under decentralization but also achieve the desired distribution of the total supply chain profit to protect suppliers, as shown in our analytical model and case study.

5. Conclusion

In this paper, we use a mutually supporting analytical model and case study to investigate the managerial and policy issues related to quality control in food supply chain management. Our analytical results show that, depending on the sampling technology, the

decentralized supply-chain structure may lead to a distortion in product quality under certain conditions. We also explore the effects of different pricing and regulatory options of vertical control on product quality and the distribution of the total supply-chain profit. In addition, we use a case study of the 2008 adulterated milk incident in China to explore key issues in managing food supply chain quality and risk as well as to derive a number of important managerial and policy insights. We also show that, instead of the common “poor quality” misperception of food products from global emerging markets, it is actually the poor vertical control strategy for managing supply chain quality and risk that caused the adulterated milk incident. In conclusion, our analyses show an important truth about food quality control in today’s global emerging markets. Managing food supply chain quality and risk requires the integrated strategy which addresses issues in supply chain design, quality testing and verification, informational visibility, regulatory environment, and perhaps most importantly, corporate social responsibility.

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Appendix A. Proof of Proposition 1

Based on the Lagrange function in (7), the first-order conditions are $V'(q_m) - \Delta W \partial s_r(q_m, q_r) / \partial p_m + \lambda [\Delta W \partial^2 s_r(q_m, q_r) / \partial q_m^2 - c''(q_m)] = 0$, (A.1)

$$\Delta W \partial s_r(q_m, q_r) / \partial q_r + \lambda \Delta W \partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r = 0, \tag{A.2}$$

and

$$\Delta W \partial s_r(q_m, q_r) / \partial q_m - c'(q_m) = 0 \tag{A.3}$$

Solving (A.1)–(A.3) leads to the condition in (8). Given (4) and the assumption $\partial s_r(q_m, q_r) / \partial q_r \leq 0$, if $\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r > 0$, then $V'(p_m) - c'(p_m) \geq 0$ according to (8). We thus have

$$[V'(q_m) - c'(q_m)]|_{q_m = q_m^i} \geq [V'(q_m) - c'(q_m)]|_{q_m = q_m^d} = 0 \tag{A.4}$$

Since $c'(q_m) \geq 0$, $c''(q_m) \geq 0$, $V'(q_m) \geq 0$, and $V''(q_m) \leq 0$, the inequality in (A.4) suggests that $q_m^i \geq q_m^d$. Similarly, we can show that $q_m^i \leq q_m^d$ if $\partial^2 s_r(q_m, q_r) / \partial q_m \partial q_r < 0$. □

Appendix B. Proof of Proposition 2

For the supplier’s decision, the first-order and second-order conditions in (3) and (4) lead to

$$c'(q_m) \partial^2 s_r(q_m, q_r) / \partial q_r^2 - \partial s_r(q_m, q_r) / \partial q_m c''(q_m) < 0 \tag{B.1}$$

Given the Lagrange function in (7) with ΔW as the additional decision variable, the additional first-order condition is

$$-s_r(q_m, q_r) + \lambda \partial s_r(q_m, q_r) / \partial q_m = 0 \tag{B.2}$$

By using (A.1)–(A.3), and (B.2), we have

$$V'(q_m) - c'(q_m) = \frac{[c''(q_m) \partial s_r(q_m, q_r) / \partial q_m - c'(q_m) \partial^2 s_r(q_m, q_r) / \partial q_r^2] s_r(q_m, q_r)}{[\partial s_r(q_m, q_r) / \partial q_m]^2} \geq 0 \tag{B.3}$$

The above inequality follows (B.1). Since $c'(q_m) \geq 0$, $c''(q_m) \geq 0$, $V'(q_m) \geq 0$, and $V''(q_m) \leq 0$, the inequality $[V'(q_m) - c'(q_m)]|_{q_m = q_m^i} \geq [V'(q_m) - c'(q_m)]|_{q_m = q_m^d} = 0$ suggests that $q_m^i \geq q_m^d$. □

Appendix C. Proof of Proposition 4

First notice that $V'(q_m) - c'(q_m) = 0$ at q_m^i according to (1). Based on the condition in (8) that establishes the relationship between the supplier’s and retailer’s quality decisions under decentralization, $V'(q_m) - c'(q_m) = 0$ if and only if

$$\Delta W \partial^2 s_r(q_m, q_r) / \partial q_m^2 - c''(q_m) = 0 \tag{C.1}$$

Given $q_m = q_m^i$, ΔW and q_r can be obtained by solving (C.1) and the first-order condition in (3), as shown in the first part of the proposition. For the second part, since increasing W_0 will increase the supplier’s profit while decreasing the retailer’s profit by the same amount according to the profit functions in (2) and (8), the government can thus adjust W_0 (or W_1) to achieve any (feasible) desired distribution of the total supply chain profit. □

Appendix D. Supplementary materials

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.ijpe.2013.12.016>.

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