The Mechanism of Food Fraud and Governance: Theory and Evidence

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Article

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The Mechanism of Food Fraud and Governance: Theory and Evidence *

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Abstract This study constructs and expands the food fraud governance framework, including the risk formation mechanism and fraud regulation system. The risk formation mechanism issues that quantity-quality substitutability is a fundamental condition for food fraud and separates the effects of resource input constraints from information asymmetry. Furthermore, this study considers the roles of penalties and rewards for the quality risk regulation institution. The results show that penalty-based quality regulation design is doomed to be inefficient because it can only mitigate the effects of information asymmetry. Simultaneously, a reward can further alleviate the impact of resource input constraints. Higher food quality is not always better, especially when the resource input is constrained. Further, we conclude that the food-safety risk governance system designed by policymakers should consider the quantity and quality of food simultaneously.

Keywords: Risk formation mechanism, Regulation institution, Information asymmetry, Input capacity constraints, Quantity-quality substitute

\textit{JEL} Classification Q18; L15

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Abstract
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INTRODUCTION
Since the first recorded food-safety incident, lead-contaminated sugar, in ancient Rome, food-safety risk management has become a vital livelihood issue concerned by all social groups (Keith, 2002). Major food-safety incidents often accompany strengthening food-safety legal systems and supervision. For example, the New York swill milk incident led to the birth
of the 1906 Food and Drug Act (Egan, 2005), and the Sanlu melamine incident brought about the China Food-Safety Law (Geng, Xu, and Beachy, 2015). Although supervision and penalties are continuously strengthened, food-safety incidents worldwide still occur frequently. Notice that quality and safety are two different features of food, and quality has multiple dimensions. Here, we should specify the concept of food-safety risk and its relationship with the quality. Quality is not equal to safety, but it has a critical impact on safety. Therefore, we define quality in this study as the property of food that highly correlates to safety. In other words, quality in this study is equal to safety.

Food fraud was a typical symptom of food-safety risk in the USA in the 1850s, Japan in the 1950s, China in the 21st century, and many other developing countries. However, little is known about why food fraud occurs. Mostly, we attribute food fraud to information asymmetry. However, confusion exists about why food fraud does not occur in the early days of processed food but after it develops to a particular scale, although information asymmetry has not changed. For example, oranges are used to produce orange juice when supply exceeds demand. The juice is safe because we have enough primary oranges. However, the quality of juice will decline as orange juice demand increases and juice fraud occurs because of the orange limitation. Thus, 100 oranges for 100 cups of orange juice is safe if the demand is for 100 cups. However, fraud will occur if the orange juice demand increases to 120 cups or more. That means information asymmetry is not the only cause of food fraud. Therefore, a more in-depth study is needed on the formation mechanism of food-safety risks. Falsification and fraud do not only occur in the food industry. Evidence shows that rapidly expanding producers are prone to be involved in quality safety issues. The recent Tesla new energy
vehicle accident in China is a typical example outside the food sector. Tesla’s new energy vehicles are expanding faster in China, and limited capabilities have led to many defective parts being used without consumers’ knowledge, resulting in frequent accidents (https://peoplesdaily.pdnews.cn/business/tesla-s-china-orders-halve-in-may-as-consumers-worry-about-safety-214402.html).

Sperling (2010) and Fagotto (2014) studied food-safety regulation from an ethical and legal perspective based on the information asymmetry assumption. Based on the prevalence of food fraud and adulteration, most studies attribute food-safety incidents to the moral hazard of producers under information asymmetry (Zhou, Jin and Liang, 2022; Delmastro and Zollo, 2021). However, information asymmetry is insufficient for food-safety incidents, and quality regulation based on penalty is not generally efficient (Chen, Huang, Mishra, et al., 2018). Just as Liu, Kerr & Hobbs (2012) claimed, increasing government regulation does not guarantee an improved food-safety system. Li and Shi (2011) illustrated that under input constraints, quality investment in food processing and manufacturing enterprises is insufficient in the rapid expansion of market demand. Li and Shi (2011) declared that producers dump low prices to occupy the market because consumers usually use market sales as a signal of quality. Thus, strengthening supervision cannot fundamentally change the result of insufficient quality investment.

Studies show that input capacity constraints and quantity-quality substitutes critically impact the quality decision. On the one hand, Esó, Nocke & White (2010) and Chen, Nie & Wang (2015) introduced input resource constraints into the producers’ objective function and obtained different results from those without constraints. Chen, Huang, Mishra, et al. (2018)
and Chen, He and Paudel (2018) further showed that firms facing constraints tend to reduce product quality to ensure output quantity. On the other hand, the substitutability between quantity and quality inhabits the producer’s quality innovation willingness because the increase in output quantity reduces the marginal effect of quality on price (The, 2022; Gaudin, 2022; Spence, 1975; Sheshinski, 1976). Considering the trade-off between quality and quantity, McCannon (2008) showed that the stronger the relationship between quality and quantity is, the more sales are shifted from the high-quality producer to the low-quality one.

The primary purpose of this study is to design a new food fraud governance system, which expands the theoretical quality regulation study and improves the efficiency of food quality risk regulation in practice. This study comprehensively considers the impacts of information asymmetry, quantity-quality substitution, and resource input constraints on food quality safety risks for the food fraud formation mechanism. Information asymmetry is necessary, and quantity-quality substitutability is sufficient, while input capacity constraints are the root cause of food adulteration and fraud. This study combines penalty and reward for the regulation system design. A penalty can only resist the impact of information asymmetry, while rewards can eliminate the negative effects of resource investment constraints.

The remainder of this paper is organized as follows. Section two constructs a theoretical framework to reveal the food-safety risk formation mechanism. Section three presents three case studies. It employs the milk industry’s typical food-safety incidents to prove the theoretical framework’s scientificity and rationality. Finally, this study designs an improved, reasonable quality regulation system based on the above analyses.

THEORETICAL FRAMEWORK STRUCTURE
**Quantity-quality interaction**

The relationship between product quality and quantity is a vertical issue in producer quality decisions but has not obtained enough concerns. Spence (1975) and Sheshinski (1976) offered the original quantity-quality interaction model. The two studies stimulated a series of follow-up theoretical and empirical studies (The, 2022; Scott, Sesmero, 2022; Gaudin, 2022). They obtained the relationships between quality and quantity from the social welfare perspective. However, quality and quantity are dependent on producer behaviors. Therefore, different from those prior studies, we capture quantity-quality interaction from the primary objective function of a profit maximization firm under monopoly conditions. The conclusions can be expanded to other market structures by employing competition except in perfectly competitive markets because firms in the market are priced receivers. Suppose a producer in a sub-food industry maximizes its profits by choosing the optimal output quantity and quality and obeys the following objective function.

$$\max_{x,q} \pi = p(x,q)x - c(x,q).$$  \hspace{1cm} (1)

$x$ and $q$ represent the two endogenous variables, quantity and quality, respectively. $p(x,q)$ and $c(x,q)$ are the price and cost of the producer. This is a typical profit function in classical microeconomics theory. Following the first-order optimal condition, we obtain the following equation.

$$\frac{\partial \pi(x,q)}{\partial x} = p_x(x,q)x + p(x,q) - c_x(x,q) = 0, \hspace{1cm} (2a)$$

$$\frac{\partial \pi(x,q)}{\partial q} = p_q(x,q)x - c_q(x,q) = 0. \hspace{1cm} (2b)$$

Then, we have:
\begin{align}
    p_x(x, q) &= \frac{1}{x} [c_x(x, q) - p(x, q)], \quad (3a) \\
    p_q(x, q) &= \frac{1}{x} c_q(x, q) = AC_q(x, q). \quad (3b)
\end{align}

Derivate (3a) with \( q \) and combine with (3b), we get the final expression of \( P_{sq} \), the cross-derivative of quantity and quality to price, which can be used to capture the interactions between output quantity and quality.

\[
p_{sq}(x, q) = \frac{1}{x} [MC_q(x, q) - AC_q(x, q)].
\]

\( MC_q(x, q) \) and \( AC_q(x, q) \) indicate the impacts of quality on marginal cost and average cost. Equation (4) shows that \( p_{sq} \) depends on the influence of quality on marginal cost and average cost, and then we have the following proposition.

**Proposition 1** \( p_{sq} \geq 0 \) if \( MC_q(x, q) \geq AC_q(x, q) \), while \( p_{sq} < 0 \) if \( MC_q(x, q) < AC_q(x, q) \).

**Remarks** Proposition 1 gives the threshold and conditions for the interaction between output quantity and quality from the producer’s perspective. We can also obtain the corresponding condition from the demand perspective. For example, if a constant elasticity of substitution utility function. \( p_{sq} < 0 \) denotes the substitute relationship between quantity and quality and \( p_{sq} > 0 \) indicates complementarity. Complementary relationship indicates that with the increase in output quantity, the impact of output quality on marginal cost is more significant than on average cost. Substitution means that with the increase in output quantity, the impact of output quality on marginal cost is smaller than on average cost. This study focuses on the substitute case because it is a sufficient condition for food fraud. Evidence has
shown that as the service scale increases, low-quality restaurants are likely to lower their quantity and easily get involved in food-safety incidents under capacity constraints (Chen, He, and Paudel, 2018). Additionally, proposition 1 implies that optimal quality can be obtained only when there is no interaction between quantity and quality in equilibrium. Thus, the interaction between quantity and quality is the foundation of foodborne incident analysis. If there is no relationship between quantity and quality, the producer cannot increase output quantity by reducing quality.

Furthermore, according to the production theory of microeconomics, we learn that the marginal rate of technical substitution between quantity and quality is increase. Thus, as output quantity increases, the decrease in quality accelerates. This feature is reasonable and can be used to illustrate that fast-growing firms are at higher risks of food quality incidents than their counterparts. The substitute relationship between quantity and quality is outlined in Figure 1.

\[ \mathcal{S}(x,q) \] Figure 1 represents the production possibility function of output quantity and quality. Figure 1 shows the substitute relationship between output quantity and quality, which is the foundation of the following analysis. On the one hand, considering the substitute of quantity and quality and input capacity constraints, food quality is not “the higher, the better.” Because too high quality means small food quantity, which would raise food-safety risks in another mechanism. On the other hand, food quality has the attribute of quasi-public goods.
Therefore, it needs government regulation. Suppose $q$ in Figure 1 is the minimum quality requirement specified by government regulation. Then the curve under $q = q$ will become a dotted line. Thus, the producer cannot make output decisions here under quality regulation. However, under information asymmetry, this line will disappear. And to simplify our analyses, we will ignore the value of lowest quality, which has no fundamental impact on the conclusions. However, all the analyses are developed under the quality regulation rule.

**Information asymmetry**

The influence of information asymmetry on quality decision-making is widely accepted in food-safety risk governance. However, concern for quality is meaningless without quantity. Unfortunately, prior studies have not considered the effect of quantity by employing the quantity-quality interaction. In this study, we rethink the impact of information asymmetry on producer quality decisions by considering the interaction between quantity and quality.

Assume producer profits $\pi(x, q, \delta)$ are the function of output quantity $x$, quality $q$, and information condition $\delta$. Larger $\delta$ means higher symmetric quality information. In other words, the effect of quality on price increases for larger $\delta$. More assumptions about profit function are $\frac{\partial \pi}{\partial x} > 0$, $\frac{\partial \pi}{\partial q} > 0$, $\frac{\partial \pi}{\partial \delta} > 0$, $\frac{\partial^2 \pi}{\partial x^2} < 0$, $\frac{\partial^2 \pi}{\partial q^2} < 0$, $\frac{\partial^2 \pi}{\partial \delta^2} > 0$, $\frac{\partial^2 q}{\partial \delta^2} > 0$.

These assumptions guarantee that the function is concave in quality and quantity but convex in information. A specific profit function for the producer that satisfies the conditions is constructed as follows.

$$\pi = (\alpha + \delta q - x)x - \frac{1}{2}x^2 - \frac{c}{2}q^2.$$  

(5)
Market size is denoted $\alpha$ and $c$ is the cost parameter $\alpha \geq c$ and $c > 1$. $\alpha \geq c$ means the market size is large enough while $c > 1$ shows that quality improvement is difficult than quantity increase. More importantly, the profit function is concave in output quantity and quality. The implicit equilibrium solution of this function is:

$$(x, q) = \left(\frac{\alpha}{3c - \delta^2}, \frac{\delta \alpha}{3c - \delta^2}\right).$$

Equation (6) indicates that output quality (quantity) increases (decreases) with information symmetry. Based on the production possibility bound theory, the impacts of information on quantity and quality decisions are shown in Figure 2. Figure 2 shows the maximum total quality and quality, which depend on the available resource inputs. Given the total resource input, output quantity and quality are substitutes.

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Insert Figure 2 about here

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**Proposition 2** Information asymmetry lower quality.

**Remarks** Proposition 2 reveals the influence of information asymmetry on the foodborne illness incident. Given the production possibility boundary decided by the total available resource inputs, the producer will increase its output quantity but lower the quality under asymmetric information. Thus, information asymmetry reduces product quality and increases food-safety risks. That is why a rapidly expanding producer is prone to be involved in a food-safety incident.

**Input capacity constraints**

Here, we focus on input capacity constraints. The constraints here are more severe than those
mentioned in the information asymmetry section. The firm cannot make output decisions following the profit maximization first-order optimal condition under the input capacity constraints.

Suppose that the total input a firm can obtain is $R$ less than the optimal quantity a firm needs under no constraints. These input constraints impact both quantity and quality, while the restriction is $x + \theta q = R$. $\theta > 1$ is the quality consumption parameter, and the quantity conversion parameter is standard to 1. Thus, quality improvement consumes more resource consumption than quantity increase. Larger $\theta$ indicates a lower technique level. Furthermore, it has $\frac{\partial q}{\partial R} > 0$, $\frac{\partial q}{\partial \theta} < 0$, which implies an increase in input resource, thus enhancing output quality, while the rise in resource consumption parameter inhibits quality. $c > 1$ is a quality-related cost parameter. Thus, the producer maximizes the following objective function.

$$
\pi = (\alpha + \delta q - x)x - \frac{1}{2}x^2 - \frac{c}{2}q^2
$$

(7)

The following equilibrium solutions are obtained from equation (7) following the constraints optimization principle.

$$ (x^\ast, q^\ast) = \left( \frac{cR + \delta \theta R + \theta^2 \alpha}{c + 2\delta \theta + 3\theta^2}, \frac{\delta R + \delta \theta R + \theta^2 \alpha}{c + 2\delta \theta + 3\theta^2} \right). $$

(8)

Easy to know $q^\ast < q^0$ because the quality decision is influenced by both information asymmetry and input capacity constraints. Figure 3 shows the impact of input capacity constraints.
Proposition 3  Input capacity constraints decrease quality.

Remarks Proposition 3 reveals the impacts of input capacity constraints on the quality decision neglected by most quality regulation studies. Food production firms will reduce output quality and quantity and decrease quality more than quantity because quality has a higher resource consumption. However, this can only happen under the condition of information asymmetry. Breaking through the input constraints and improving the production capacity is essential for reducing food-safety risks (Conrad et al., 2018). Keener (2010) and Varadaraj (2010) believed that food producers could minimize food-safety risks through capacity expansion.

Proposition 4 The relationships of quality among different conditions are \( q^c < q^\delta < q^\delta_i \).

Remarks Both information asymmetry and input capacity constraints impact the producer’s quality decision. The equilibrium quality is jointly determined by information asymmetry and input resource constraints. It is lower than the regulators think because they are generally unaware of capacity constraints’ adverse impacts. This neglect may fail the quality governance institution. Furthermore, this study isolates the effects of information asymmetry and input capacity constraints on quality via propositions 3 and 4.

CASES EVIDENCE

Early industrialization and urbanization seriously harmed infant nutritional health by impacting the quality of infant powdered milk (Obladen, 2014). During industrialization and urbanization, lactating mothers are working, significantly increasing the demand for infant
milk. However, raw milk and technology level (input capacity constraints) limitations made the milk supply unable to meet the demand. Input capacity constraints coupled with the influence of information asymmetry, made infant milk incidents repeated. This study selects three specific contaminated milk events during the early industrialization of the major countries; the swill milk event in the United States during the mid-19th century (Egan, 2005), the Morinaga arsenic milk event in Japan in the mid-20th century (Dakeishi et al., 2006) and the Sanlu melamine incident in China’s milk industry at the beginning of this century (Xiu & Klein, 2010) to support the theoretical framework constructed above from the application perspective. Foodborne incidents in milk industries were typically the result of the synaptic impacts of quantity-quality substitution, input capacity constraints, and information asymmetry.

**Swill milk incident in American**

Industrialization and urbanization in the United States brought about a rapid increase in milk demand. The first half of the 19th century was a period of significant development of the northern industrial economy in the United States. Many immigrants from the United States and the world poured into New York, which caused the city’s population to expand and triple from 1830 to 1860 (Egan, 2005). Industrialization and urbanization brought many newborns and nursing mothers into the workforce who wanted to work outside their homes. The fast-paced urban life made it impossible for young mothers from low-income families to feed their infants only with breast milk, and the family’s demand for milk increased rapidly. Thus, industrialization and urbanization opened the era of infant milk feeding, which sowed the seeds of milk fraud.
Dairy farms and production technology constraints have prevented milk supply from keeping up with demand expansion. Owing to the limitation of dairy farms, the supply of fresh milk in New York City mainly comes from Westchester and Orlando—major milk-producing counties. It was challenging to produce enough fresh milk to meet the strong demand during the 1850s (Egan, 2005). However, the lack of production technology and cold chain transportation equipment limits the supply of fresh milk and creates capacity constraints on milk production. By the 1850s, the supply gap for fresh milk in New York City was as high as 20%. A rapid rise in milk prices followed.

The gap between supply and demand (capacity constraints) and the unknown process of milk products by the consumers (information asymmetry) leads to adulteration and fraud in the milk industry. The shortage of milk supply and demand led to a continuous increase in profits, while the temptation of excess profits stimulated bad intentions among milk producers. Milk producers were racking their brains to increase milk production by adulteration and fraud using the substitute of quantity and quality. First, they fed the cows with stillage to produce more milk. Second, dairy farmers kept thousands of cows confined to increase milk production by reducing cow activity. Terrible conditions considerably impacted cow health and milk quality. Even so, the supply of fresh milk still could not meet the increased demand for milk. Thus, the milk merchants adulterated the milk with sewage, rotten eggs, and starch, altering the milk’s color and smell without consumers knowing. Dairy farmers added gypsum, honey, and syrup to cover up the abnormal color and odor of the problematic milk. Thus, the infamous glutinous milk was born and ironically sold under the label “Children’s Hygiene Milk.”
Substitutable between quantity and quality, input capacity constraints and information asymmetric led to the swill milk incident. The swill milk caused many infants and young children to become sick and die. After multiple additions, the milk was thin and dirty. The fat content of slop milk is only 30% to 50% of that of ordinary milk, and the harmful substances and bacteria in the milk were significant. The result was sicknesses such as scrofula, cholera, and even the death of many infants and young children. Frank Leslie’s illustrated newspaper revealed that in 1958 alone, over 8,000 infants died from slop milk. More seriously, slop milk increased New York City’s under-five mortality rate from 30% in 1830 to 60% in 1956 (Egan, 2005). After the ongoing efforts of many social figures and the media, the swill milk incident was fundamentally controlled in the early 20th century. Its distinctive sign was the Food and Drug Act, passed in 1906.

**Arsenic poisoning milk incident in Japan**

Arsenic milk is another primary foodborne incident resulting from input capacity constraints and information asymmetry. The Morinaga Milk Company’s arsenic poisoning milk incident occurred during Japan’s rapid development after the Second World War. According to official records, 130 infants died, making the arsenic poisoning milk incident the most serious one in Japan (Nishida, 1970).

Powdered milk in Japan increased rapidly during the middle of the 20th century. After the Second World War, the number of babies born quickly grew, but food was extremely scarce in Japan (Shoji and Sugai, 1992). Powdered milk was employed for anti-food shortages. People from all walks of life in Japan, including the government, media, and businesses, publicized bottled powdered milk to feed babies. They also declared that the artificial milk
was healthier than breast milk. A “National Baby Contest” was organized under the auspices of the Ministry of Health and Welfare and the Yomiuri Shimbun to enhance baby health and proper nutrition of children. Moreover, more nursing mothers participated in work (see Table 1). As a result, the demand for milk powder in Japan increased rapidly, and the proportion of infants fed formula milk increased from 10% in 1920 to 70% in 1970.

Two significant factors limited the infant milk supply. They are called input capacity constraints. The first limitation was the constraints of raw milk availability and cold chain logistics technology limitation. The number and size of pastures imposed significant constraints on raw milk production. Raw milk must travel long distances before being made into powdered milk, while the lack of cold chain logistics technology made the raw milk challenging to keep fresh. Thus, during transportation, the acidity increases, and the milk thickens quickly, making it difficult to dissolve in water and unable to be made into milk powder. Second, the amount of imported raw milk was reduced. Japan imported a large amount of milk powder from the United States. However, after 1950, affected by the recession in the United States, the amount of milk powder imported to Japan from the United States decreased significantly. The competition for raw milk between companies increased milk product prices by 50% (Shoji Sugai, 1992).

Sodium phosphate, an industrial-grade material, was added to milk products to increase production based on the substitutability between quantity and quality, and information
asymmetric. Stabilizers must be added to avoid acidification and coagulation of milk during transport. However, the industrial additive sodium phosphate, which was one-third of the regular cost of edible additive, was added to milk by one of the three major powder infant milk producers, the Morinaga Milk Company. Unfortunately, sodium phosphate is unstable and quickly decomposes into toxic arsenic dioxide. People are poisoned within 10 minutes of taking arsenic dioxide. Chronic arsenic poisoning initially only irritates the mucous membranes, causing nasopharyngeal dryness, rhinitis, and other difficult-to-detect symptoms.

Finally, 13,389 infant victims emerged, with over 600 deaths. The “arsenic infant” looks like a cold and heat stroke initially, but as the intake increases, severe poisoning or even death eventually happens. In addition to the poisoning mentioned above and deaths, 6,039 infants suffered from ongoing health problems, intractable retardation, such as eyesight problems, central nervous system involvement, skin diseases, irregular physical development, mental disorders, and difficulties in studying (Shoji and Sugai, 1992) the arsenic milk poisoning incident in Japan. Over 600 older than 50 surviving victims had been reported to suffer from mental disorders and neurological diseases (Dakeishi et al., 2006).

**Melamine milk powder incident in China**

On September 1st, 2008, the Information Office of China’s Ministry of Health issued a document titled “Sanlu Infant Formula is Contaminated, and Relevant Departments of the State Council Are Carrying out Economic Investigation,” officially bringing the poisoned milk incident into the public eye. The document stated: “Gansu and other places have reported several cases of urinary calculi in infants and young children. The investigation found that the children had a history of eating Sanlu infant formula milk powder. After an
investigation by relevant departments, it was highly suspected that the Shijiazhuang Sanlu Group Co., Ltd. produced the Sanlu infant formula milk powder was polluted by melamine.” Further special inspections of 109 infant formula manufacturers across the country showed that melamine was detected in 69 batches of products from 22 companies. In other words, melamine addition was an industrial behavior. Additionally, well-known domestic brands such as Mengniu, Yili, Yashili, and Shengyuan all have melamine addition behavior, and the addition amount is closely behind Sanlu (Zhang, 2009). The foodborne incident ultimately resulted in the deaths of six infants. Melamine milk is another typical foodborne incident resulting from input capacity constraints and information asymmetry.

China’s economic development and rising income have significantly increased residents’ demand for milk, boosting the milk industry’s development. Since the reform and opening in 1987, China’s economy has achieved rapid growth, and with the increase in income, people’s demand for food has gradually increased. Milk is considered an essential food for nutrition and health. All sectors of society are also strongly recommending milk consumption, “A glass of milk every day can make people stronger” (Zhang and Kong, 2009). China’s milk demand experienced rapid growth from 1996 to 2002 (Figure 4). Thus, China’s per capita annual dairy consumption increased from 4kg in 2000 to 10kg in 2007. Especially, the continuous deepening of the dual-income family concept and the participation of many lactating mothers in the workforce has increased the demand for infant milk powder.

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Insert Figure 4 about here

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The increase in domestic milk production cannot meet the rapidly expanding demand because of input capacity constraints. The number of dairy cows in China jumped to the forefront of the world in 2007, but small farmers farmed 80% of them. The proportion of dairy cows above 20 in the country was only 28.9%, while the proportion of fewer than five cows was as high as 76%. Raw milk product efficiency is extremely low. In 2007, China had 14.7 million dairy cows, and raw milk output was approximately 36.8 million tons. However, the average annual yield of dairy cows was only 2.5 tons. In contrast, the average yearly production of dairy cows in Europe and the United States was 8–9 tons, three times the output of dairy cows in China. A 10% lower milk production growth than the growth demand from 1996 to 2002 created tremendous pressure and stimulated the development of China’s milk industry (Figure 4). Therefore, from 2001 to 2007, China’s total milk production and per capita milk share were in a stage of rapid growth, with an average annual increase of 26% in dairy products (Ke, 2009). To promote the development of the milk industry, the government provided many subsidies (Zhang, Kong, 2009). As a result, just as Figure 4 shows, the relationship between the growth of milk production and demand reversed after 2003. However, the rapid growth of milk supply was based on quality fraud, which laid a massive blow to the industry’s development.

Meeting the rapidly expanding milk demand has become the primary goal of significant milk producers. Most dairy production enterprises follow the development concept of “Market first, factory later.” Milk production increased rapidly before 2008, while the import of dairy products grew quickly following the milk incident (Figure 5). In contrast, the quality did not obtain enough concerns, and the Hebei Sanlu Group is a typical representative. With
the help of the decentralized supply chain model: dairy farmer-milk purchase agent company

Sanlu Group quickly developed from a small enterprise with only 18 farmers, 30 cows, and 170 sheep in 1983 to the largest milk powder manufacturer in China with total assets of $324 million in 2004 (Hu, 2009; Chen, Zhang & Delaurentis, 2014). The distinctive feature of this model is that the company signs milk contracts with farmers and purchases milk through intermediary agents. The main advantage is that it can quickly unite numerous small farmers to supply milk to the downstream company. The major drawback is that it increases information asymmetry and quality risk.

The rapid expansion of the enterprise scale has brought about the shortage of milk supply, the reduction of quality requirements, and the lack of quality control in milk purchase. Additionally, the need for high-quality raw milk, the rapid expansion of social demand for dairy products, and price regulation have brought about a rapid rise in the price of raw milk. To reduce the cost of purchasing raw milk and meet the demand of enterprises for the quantity of raw milk, some milk purchasing agents chose to add water and melamine to raw milk. Although the Sanlu Group knew that the agent had added melamine to raw milk, it was forced to meet the rapidly expanding market demand and chose not to stop the fraudulent behavior. Unfortunately, poor parents had no knowledge of the contaminated milk. As a result, over 29 thousand infants were poisoned by melamine milk, suffered from diseases such as kidney stones, and at least six died (Xu and Klein, 2010). Because of the severe impact of
food-safety incidents, the Chinese government formulated the “Food-Safety Law” and some regulations specifically for the dairy industry in 2009.

**Cases summary**

The common point of the above cases is that these milk events that occurred in different periods of the world resulted from the combined effect of information asymmetry and resource input constraints under the premise that the quantity and quality of products can be substituted. Rapidly growing demand and limited supply created capacity constraints; unknown production process by the consumer led to information asymmetry. Information asymmetry is a necessary condition for food fraud. Input capacity constraints are the fundamental condition, while quantity-quality substitutability is the sufficient condition. Thus, a penalty may not be sufficient for food quality regulation. An effective quality regulation system should combine the penalty and reward.

**FOOD- SAFETY RISK GOVERNANCE DESIGN**

This section will design a quality regulation institution and outline some basic principles in food-safety risk governance.

**Quality regulation design**

Suppose there are \( n \) firms and \( m \) supervisors in the food production section. A supervisor chooses only one producer to inspect (Chen, Huang, Mishra, et al., 2018; Basu and Dixit, 2017). Thus, the probability for a firm to be inspected is:

\[
p = \frac{n-1}{n} \cdot \frac{n-2}{n-1} \cdots \frac{n-m}{n-(m-1)} = \frac{n-m}{n}.
\]  

(12)

\( \pi_h \) and \( \pi_l \) represent the producer’s profit to provide high-quality products and low-quality
products, respectively. If a producer is found to be offering low-quality products, its profits will be forfeited and fined $c$. However, if a firm is a high-quality provider, it will receive $s$ rewards. A successful regulatory system must meet the following condition:

$$p\pi_i + (1-p)(0-c) \leq \pi_h + s.$$

(13)

Substituting function (12) to inequality (13), this study obtains the final condition for a producer to produce high-quality products as follows.

$$\frac{m}{n} > \frac{\pi_i - (\pi_h + s)}{\pi_i + c}.$$

(14)

**Proposition 5** Both penalty and reward stimulate a firm to raise quality, and reward is more effective in quality regulation.

**Remarks** The results in proposition 5 can be obtained from inequality (14) quickly. The conclusions indicate that both penalty and reward are helpful in quality risk regulation. More importantly, the reward is for high efficiency. Unfortunately, most quality regulation institutions only employ penalties. Of course, increasing supervisors or reducing producers is generally helpful. Next, we will further prove that the quality regulation system with only penalties is ineffective with the help of Figure 6.

Figure 5 shows that total quality decreases $\Delta q$ can be separated into two parts as equation (15).

$$\Delta q = (q^s - q^h) + (q^h - q^*) .$$

(15)
The former part $q^\delta - q^0$ to the right of equation (15) represents the effects of information asymmetry, while the latter $q^\delta - q^c$ indicates the impacts of input capacity constraints. A penalty can only alleviate the effects of information asymmetry, moving the equilibrium point from $A$ to $B$. However, the reward further alleviates the impacts of input capacity constraints and makes the final equilibrium move to $C$. This means that if the safety quality level specified by the regulation is higher than $q^\delta$, the penalty-only food governance institution system will be destined to fail. That is why while China is increasing supervision and penalty, food-safety incidents are still frequent (Xue, and Zhang, 2013). So, an efficient regulatory system should combine rewards with a penalty. More importantly, inequality (14) implies that a reward has higher regulation efficiency than an equal penalty, which means a reward is an essential element in quality regulation institution design.

**Quality governance framework**

A practical framework for food-safety risk governance is summarized here. The risk formation mechanism, quantity-quality interaction, information asymmetry, and input capacity constraints should all be considered because they jointly elevate food-safety risks and foodborne incidents. For the regulation institution, penalties and rewards should be employed.

Furthermore, three critical principles for food risk governance should be followed:

- Combine a penalty with a reward.
- Follow the optimal quality rule.
- Adjust policies based on reality.

First, a penalty is used to mitigate the effects of information asymmetry, and a reward or
subsidy is employed to alleviate the influences of input capacity constraints. Second, for the substitute between quantity and quality and input capacity constraints, excessive quality reduces food quantity, raising food-safety risks because of food quantity limitations. Finally, the quality regulation institution should continuously adjust to maintain an efficient food risk governance system. For example, a quality enforcement institution (penalty) can be used if the producers are incapable and unconscious of food quality improvement. However, guidance (reward and subsidy) institutions should be employed when the producers are capable and conscious of quality enhancement.

CONCLUSION AND DISCUSSION

Food-safety is a major livelihood issue and has received extensive concerns. This paper aims to construct a food-safety risk governance system by surveying the formation mechanism of food-safety risk and designing an efficient regulation institution. Firstly, it theoretically reveals that the food-safety risk formation mechanism by integrating the joint effects of quantity-quality interaction, input capacity constraints, and information asymmetry. Then we employ three typical milk incidents in the United States, Japan, and China to verify the theoretical framework from an application perspective. Finally, this study designs a critical quality regulation institution by combing penalty with reward systems.

This study shows that quantity-quality interaction, input capacity constraints, and information asymmetry are sufficient, fundamental, and necessary conditions for foodborne incidents. The results further show that penalty-oriented regulation alleviates the effects of information asymmetry, while reward-oriented institution helps relieve input capacity constraints impacts. Therefore, a successful quality regulation system should combine
enforcement (penalty) with guidance (reward and subsidy). Furthermore, it should follow the optimal-quality principle in food risk governance for the effects of input capacity constraints, and the substitutability between quantity and quality. Otherwise, too strict quality requirements will increase the safety risk in turn.

The contributions of this study are reflected in two aspects. In theory, this study constructs a theoretical framework for food-safety risk governance. It expands food-safety theory by introducing input capacity constraints and quantity-quality interaction. To the best knowledge of us, this is the first study that isolates the effects of input capacity constraints and information asymmetry on food-safety risk. In application, it shows that the regulator should add a reward mechanism to a penalty in quality regulation system design to enhance the efficiency for that penalty cannot eliminate the negative impacts of input capacity constraints.

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Figure 1

The production possibility curve under substitution
Notes: $\delta_h$ represents high information symmetry (symmetric information), $\delta_l$ indicates low information symmetry (asymmetric information).
Figure 3

The influence of input capacity constraints

Notes: \( q^u \) represents equilibrium quality under no input capacity constraints condition, while \( q^c \) indicates the quality under constraints case.
Figure 4

Growth of milk production and consumption in China (1996–2020)

Figure 5

Milk production and import of dairy products in China (2000–2020)

Source: National Bureau of Statistics of China
Figure 6

Food risk governance system

![Diagram of food risk governance system]

- Over safe food
- Unsafety food
- Normal food

Greek letters and variables:

\[ \Delta q \]

\[ q^h \]

\[ q^f \]

Showing the relationship between quality and quantity with points A, B, and C indicating different states of food risk governance.
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<th>Female</th>
<th>Total</th>
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<th>Female labor force participation rate %</th>
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