

The Impact of Incentives on the Number of Suppliers

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Abstract In the context of adulteration by suppliers, downstream firms need to choose between incentives and regulation to ensure product quality. Studies have shown that the adulteration behavior of suppliers increases with the degree of dispersion of suppliers, that is, the number of suppliers increases. Therefore, based on the assumption that the number of suppliers impacts quality uncertainty, this paper further introduces the number of suppliers into the incentive model to investigate the relationship between supply chain dispersion, that is, the number of suppliers, social integrity, and incentive strength. The study finds that the optimal number of suppliers depends on social integrity, regulatory cost, and incentive strength. There is a positive correlation between social integrity and the number of suppliers, while regulatory costs and incentive strength have a negative correlation with the number of suppliers. That means, the higher the social integrity, the lower the regulatory cost; and the lower the incentive intensity, the more optimal suppliers can be selected.

Keywords agency theory; the number of suppliers; incentive intensity; social integrity; regulatory costs

1 Introduction

Food safety is related to public health, governments around the world are generally concerned about food adulteration. In the past few decades, there have been many food and drug safety incidents of widespread concern around the world (especially in developing countries). In the case of China, the Sanlu “melamine” milk powder incident and the KFC fast-going chicken scandal in China are typical cases in the last decade. Because the technology used to detect protein levels cannot distinguish the difference between nitrogen in melamine and natural amino acids, dairy farmers and milk collectors have exploited this loophole by adding melamine to milk to interfere with milk protein test results and mislead consumers’ perceptions of the protein content of milk. At odds with the usual regulatory focus, in all of the above cases, the adulteration occurred in the upstream part of the supply chain.

Evaluating the quality of food products is a difficult task; for example, it is difficult for dairies to detect the full composition of milk, and usually, only the common components are

detected. Thus, the quality of milk becomes challenging to determine before testing. It is generally believed that product quality uncertainty can be influenced by both factors inherent in the production process as well as by factors outside of production^[1]. In markets such as milk, where pricing is based on product quality, dairy farmers can command a higher selling price for milk if the quality of the milk looks higher. Therefore, adulteration seems to be the most convenient way for dairy farmers (farms) to improve the perceived quality of their milk. Levi, et al.^[1] also found that quality uncertainty was related to the number of suppliers, that is, the greater the dispersion of the farm supply chain, the higher the quality uncertainty of the product. Because it is difficult for regulators to inspect every farm or track every supply unit when the farm network is dispersed, which makes it easier for farms to commit adulteration practices and thus affect product quality.

What measures can dairy companies take to prevent farmers from adulterating their milk? The previous literature has focused on incentives and regulation^[1–3]. This paper extends the classical incentive model by introducing the number of suppliers into the incentive model and thus analyzes the relationship between regulation, incentives, and the number of suppliers.

The rest of the paper is organized as follows. Section 2 describes the review of supply chain incentives and regulation. Section 3 constructs the model, which introduces the number of suppliers into the classical incentive model. Section 4 discusses the model results and analyzes the relationship between the degree of supply chain dispersion, social integrity, and incentive intensity. Finally, Section 5 is the conclusion.

2 Literature Review

2.1 Research on Supply Chain Incentives

Most economics literature focuses on the importance of variable pay as an incentive generator^[4]. It is commonly believed that incentives can coordinate supply chain management and improve supply chain performance. Therefore, supply chain incentives have attracted the attention of many researchers. Davis and Hyndman^[5] suggested that suppliers and retailers could achieve a win-win situation through relational incentives by comparing the impact of monetary incentives and relational incentives on supply chain quality and efficiency. Mishra, et al.^[6] demonstrated that setting consistent margins before information sharing could eliminate the incentive for information distortion and benefit both suppliers and retailers. Krishnan and Winter^[7] discussed the incentive adjustment of revenue-sharing contracts by allowing inventory carryover in discrete time in the context of dynamics. Krishnan and Winter^[8] found that inventory durability was vital for incentive distortion and its contractual solution under the dynamic model. Mu, et al.^[2,3] focused on milk supply chains with monopolistic or competitive collection intermediaries and investigated incentive schemes to induce higher milk quality with minimal-scale testing.

Not all incentives are positive, such as incentive conflict and incentive distortion. Maestrini, et al.^[9] argued that incentives might increase the probability of supplier speculation and thus reduce supplier performance. Qu, et al.^[10] proposed that shifting inventory control from exclusive retailer competition to manufacturers could address the incentive distortions when retailers allocate inventory. Shao, et al.^[11] argued that for incentive conflicts in decentralized supply chains with multiple products and retailers, more complex contracts could be designed to co-

ordinate customer spillovers among and within retailers. Krishnan and Winter^[7] found that, under the dynamic model, inventory durability was a key factor in determining the type of incentive distortion and its contractual solution.

2.2 Research on Quality Regulation of Supply Chain

As Bengt^[12] pointed out that no matter what variable compensation scheme a firm chooses, the firm must pay attention to the trade-off between risk and uncertainty. For a long time, classical agency theory has not only focused on supply chain incentives but has also extensively discussed the questions of uncertainty and monitoring. Early scholars explored the relationship between monitoring and buyer-supplier relationships, supplier evaluation, the procurement process, uncertainty reduction, and how monitoring characteristics affect supplier behavior, among others (e.g., Carr and Pearson^[13]; Heide, et al.^[14]; Huang and Keskar^[15]; Krause, et al.^[16]; Jeschonowski, et al.^[17]).

In recent years, the research on regulation has become more in-depth. Some studies have explored the role of regulatory tools, for example, Babich and Tang^[18] analyzed the role of tools such as deferred payment and inspection mechanisms in assisting manufacturers to deter supplier adulteration. Wang, et al.^[19] studied optimal reward and inspection policy for regulators who motivate companies to disclose privately observed randomly occurring environmental hazards voluntarily. Chen and Lee^[20] showed how a company uses contingency payment, supplier certification, and process audit to prevent suppliers from unethical behavior. Caro, et al.^[21] examined jointly versus shared audits and collective penalties and analyzed if and when joint audits lead to better supplier compliance. Ibanez and Toffel^[22] found that the inspector schedules could affect inspection quality, and inspectors are affected by inspection results of establishments they have previously inspected.

Investment and technological advances in regulation are also important for companies. Aron et al.^[23] examined how advances in information technology have led to real-time monitoring of processes at supplier sites by global buyers. Saali Alexander^[24] showed that investment in a traceability system for supply chain quality is effective in identifying suppliers with quality defects and reduces overall profitability. Fu, et al.^[25] argued that improvements in information technology might reduce regulatory costs, allowing larger teams with relatively more intangible assets and potentially higher regulatory costs to make the company smaller.

In addition, other studies have explored other regulatory-related issues. Rodrigues, et al.^[26] suggested that the availability of federal agencies and local resources and the heterogeneity of slaughterhouses inspected are key institutional factors for effective regulatory control and detection of contamination incidents in Brazilian beef source producers. Cho, et al.^[27] examined how factors such as external monitoring and penalty schemes of information disclosure, loss of goodwill, regulatory costs, non-governmental organizations affected the incentives for companies to use different strategies to combat the use of child labor. Chen, et al.^[28] showed that the dispersed supply chain structure may distort product quality. They explored the impact of different pricing and regulatory options of vertical control on product quality and total profit distribution.

The research question in this paper is mainly inspired by the findings of Levi, et al.^[1] revealed the correlation between supply chain dispersion and supplier adulteration by examining

decentralized dairy farms and adulteration. The so-called supply chain dispersion degree refers to the number of suppliers. The greater the number of suppliers, the more fragmented the supply chain. In a fully traceable supply chain, in the case of imperfect detection, the more dispersed the supply chain, that is, the greater the number of suppliers, the higher the risk of adulteration. However, increasing the frequency of testing has a limited effect on reducing the risk of adulteration in a fragmented supply chain. Of course, Holthausen^[29] explored the issue of incentive regulation and analyzed the effect of regulation on incentive parameters and changes in the firm by creating an incentive system and considering regulatory factors. Although his research is relatively simple, his model design also provides a theoretical basis for our research.

A common feature of these literature is their focus on the incentives and monitoring of quality risks within and outside the supply chain and endogenous actions within the supply chain^[30,31]. Unfortunately, supply chain incentives and regulation studies have not paid much attention to the influence mechanism between the degree of supply chain dispersion and uncertainty and the relationship between the degree of supply chain dispersion, social integrity, and incentive intensity, in which the complex mechanism has not yet to be studied. And this is where the innovation of our study lies. This paper introduces the number of suppliers into the classical incentive model and explores the relationship between the degree of supply chain dispersion, social integrity, and incentive intensity, which has general significance.

3 Model

3.1 Basic Incentive Model

We consider a supply chain, such as a milk supply chain, where dairy farmers are suppliers and milk companies are manufacturers. Referring to the design idea of linear production function in the classical incentive model^[12], a simple linear production function is established as follows:

$$y(a, \varepsilon) = f \cdot a + \varepsilon, \quad (1)$$

where y represents the output of suppliers, that is, dairy farmers. a represents the behavior of the supplier (upstream firm). f represents the marginal contribution of the upstream firm's (supplier's) behavior to the output. $\varepsilon \sim N(0, \sigma_\varepsilon^2)$ represents the random risk, which is beyond the control of the parties and is the impact of the surrounding environment on output. In the milk supply chain, although many random risk factors can affect the uncertainty of product quality, adulteration is the main source of random risk that causes uncertainty in the quality of milk products. Consequently, the random risk here is mainly affected by the adulteration behavior of suppliers.

The output y is a function of controllable behaviors (the behavioral choices a of suppliers) and an uncontrollable event (risk ε). In the classical agency theory model, the principal's problem is to design an incentive contract for the agent with a stated reward plan. Now, suppose that the manufacturer (downstream firm) as the principal needs to incentivize the supplier to influence its behavior. At this time, manufacturers provide suppliers with compensation (which can also be called payoff) in the following form:

$$w = s + by, \quad (2)$$

where s is the basic remuneration, which can be interpreted as the retained utility of the supplier, b is the output share shared by the supplier.

In order to facilitate the calculation, following the model proposed by Gibbons^[32], we assume that the marginal contribution of suppliers' behavior to output is $f = 1$, then the equation for $y(a, \varepsilon)$ can be rewritten as $y(a, \varepsilon) = a + \varepsilon$.

Here, the supplier's benefits are given by Equation (3):

$$M = w - c(a) = s + b \cdot (a + \varepsilon) - c(a), \quad (3)$$

where $c(a)$ is the supplier's cost of taking action a .

Next, we assume that suppliers are risk-averse, and the parameter r represents the degree of suppliers' risk aversion, and certainty equivalent of the supplier can be calculated as:

$$CE(s, b) = s + b \cdot a(b) - c(a) - \frac{1}{2}rb^2\sigma^2. \quad (4)$$

After differentiating $CE(s, b)$ concerning a , we obtain Equation (5):

$$\frac{dE(M)}{da} = b - \frac{dc}{da} = 0. \quad (5)$$

Rewriting Equation (5), we get:

$$\frac{dc}{da} = b. \quad (6)$$

After continuing to find the second derivative, we have:

$$\frac{d^2c}{da^2} = \frac{1}{\frac{da}{db}}. \quad (7)$$

Similarly, the benefit of manufacturers (principals) is:

$$\Pi = y - w. \quad (8)$$

Here, the expected return of the manufacturer is given by Equation (9):

$$E\Pi(s, b) = (1 - b) \cdot a(b) - s. \quad (9)$$

The above modeling ideas are shown in Figure 1.

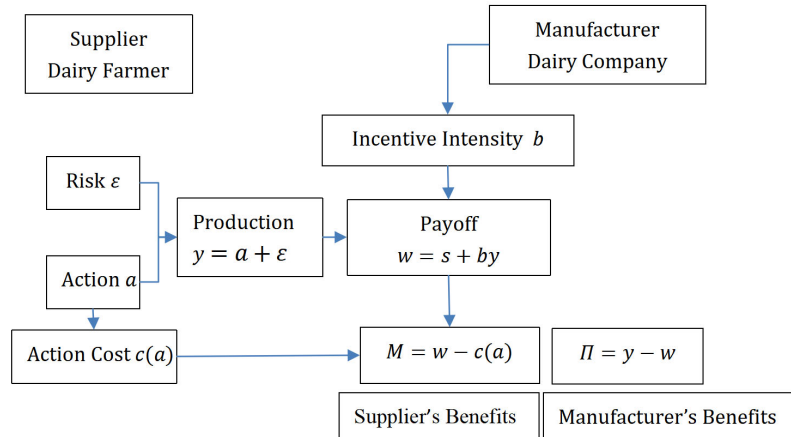


Figure 1 Model diagram

3.2 Decentralized Decision Making

As in the classic incentive model, the agent and the principal are one, within the enterprise. But in the supply chain, the principal (dairy company) and the agent (dairy farmer) are independent of each other. Therefore, we first consider the case of decentralized decision-making, where suppliers and manufacturers pursue their profit maximization, respectively. Under decentralized decision-making, we know that the supplier has decided on its own best behavior, which is determined by the manufacturer's incentive intensity and its behavior cost, which is the result of formula (6) $dc/da = b$. According to this relationship, the incentive strength of the manufacturer's profit maximization can be obtained, and the supplier's behavior can be determined.

Taking the derivative of Equation (9) to b , we can obtain:

$$\frac{dE\Pi(s, b)}{db} = -a + (1 - b)\frac{da}{db} = 0. \quad (10)$$

Rewriting Equation (10) and substituting Formulas (6) and (7), the following results can be calculated:

$$a = \frac{1 - \frac{dc}{da}}{\frac{d^2c}{da^2}}. \quad (11)$$

At this point, we get the optimal incentive (that is, the output share shared by suppliers) $b^* = dc/da$; under decentralized decision-making and the optimal behavior $a^* = (1 - \frac{dc}{da})/\frac{d^2c}{da^2}$; of suppliers. The above results show that under fully decentralized decision-making, risk factors do not affect decision-making.

Theorem 1 *Under decentralized decision-making, optimal incentives is $b^* = dc/da$, and optimal behavior of suppliers is $a^* = (1 - \frac{dc}{da})/\frac{d^2c}{da^2}$.*

3.3 Centralized Decision-Making

Next, we consider the principal (milk company) and agent (dairy farmer) as a whole to maximize the overall profit of the supply chain and avoid the double-border phenomenon. Following the assumption of the rational person in economics, manufacturers and suppliers will pursue the goal of maximizing profits together. And this is also a common consideration in classical incentive models. Therefore, the expected benefit of the union between the manufacturer and the supplier can be obtained as:

$$\begin{aligned} T &= CE(s, b) + E\Pi(s, b) \\ &= a(b) - c(a(b)) - \frac{1}{2}rb^2\sigma^2. \end{aligned} \quad (12)$$

The first-order condition for the joint expected benefit T to achieve the maximum value is:

$$\frac{dT}{db} = \frac{da}{db} - \frac{dc}{da} \frac{da}{db} - rb\sigma^2 = 0. \quad (13)$$

Substituting Equations (6) and (7) into Equation (13), we can get:

$$\frac{1}{\frac{d^2c}{da^2}} - b\frac{1}{\frac{d^2c}{da^2}} - rb\sigma^2 = 0. \quad (14)$$

Solving b according to Equation (14), Equation (15) is obtained:

$$b^* = \frac{1}{1 + r\sigma^2 \frac{d^2c}{da^2}}. \quad (15)$$

Equation (15) is the result of the classical incentive model^[33]. Meanwhile, the incentive intensity is determined by risk and behavioral cost.

3.4 The Influence of the Number of Suppliers

Next, we consider the effect of the number of suppliers in the model. Levi, et al.^[1] found that when the supply chain is more dispersed, that is, the number of suppliers is larger, the supervision is more difficult, and the effect of improving quality becomes less obvious. That is, the greater the number of suppliers, the greater the degree of uncertainty in quality results due to regulatory difficulties, which means that the effect of regulation on improving quality becomes insignificant when the number of suppliers is large. And there is a positive relationship between the number of suppliers and uncertainty in quality. So we get the following assumption.

Assumption 1 According to Levi, et al.^[1], there is a positive correlation between the number of suppliers and quality uncertainty.

Therefore, for the convenience of calculation, in the present model, we further assume that the variability (i.e., the uncertainty of quality) and the number of suppliers have positive linearity to represent this positive correlation, and by introducing the number of suppliers n into the model, resulting in the following equation:

$$\sigma^2(n) = \alpha + \beta n, \quad (16)$$

where α reflects the integrity of society, and the smaller the value of α is, the easier it is for manufacturers to regulate; conversely, the more difficult it is to supervise. β reflects the basic regulatory technical conditions. The smaller the value of β is, the stronger the regulatory technology is, the cheaper the regulatory costs, and the easier it is to achieve regulation of more suppliers; on the contrary, the more difficult it is to supervise more suppliers. This design ensures that the term $\sigma^2(n)$ has a negative correlation with both α and β . This is because when the social integrity is high or the regulatory technology is strong, the random risk in production will decrease; otherwise, the production random risk will grow.

Substituting Equation (16) into (14) yields the following equation:

$$\frac{1}{\frac{d^2c}{da^2}} - b \frac{1}{\frac{d^2c}{da^2}} - rb \cdot (\alpha + \beta n) = 0. \quad (17)$$

Rewriting the above equation, we can get Equation (18):

$$\frac{1}{\frac{d^2c}{da^2}} - b \frac{1}{\frac{d^2c}{da^2}} - rb\alpha - rb\beta \cdot n = 0. \quad (18)$$

Solving for n by Equation (18), we can calculate the optimal number of suppliers n^* in the supply chain:

$$n^* = \frac{1}{rb\beta \frac{d^2c}{da^2}} - \frac{1}{r\beta \frac{d^2c}{da^2}} - \frac{\alpha}{\beta}$$

$$= \frac{1}{\beta} \left(\frac{1}{rb \frac{d^2c}{da^2}} - \frac{1}{r \frac{d^2c}{da^2}} - \alpha \right). \quad (19)$$

Theorem 2 Under Assumption 1, the optimal number of suppliers: $n^* = \frac{1}{\beta} \left(\frac{1}{rb \frac{d^2c}{da^2}} - \frac{1}{r \frac{d^2c}{da^2}} - \alpha \right)$.

From Equation (19), it can be seen that the optimal number of suppliers n^* is determined by factors such as the society integrity α , the regulatory technical conditions β , the incentive intensity b . Further differentiating Equation (19) to α , β and b , respectively, the following equation can be obtained:

$$\frac{dn^*}{d\alpha} < 0, \quad \frac{dn^*}{d\beta} < 0, \quad \frac{dn^*}{db} < 0. \quad (20)$$

Theorem 3 The optimal number of suppliers decreases with the increase of α , β and b , respectively.

4 Results and Discussion

4.1 Discussion

According to Equation (20), $dn^*/d\alpha < 0$, it shows that the larger α is, the smaller n^* is; otherwise, the greater n^* is. That is to say, under a determined level of product quality, the lower the integrity of the society (a large value of α), the fewer suppliers can be selected in the supply chain. On the contrary, the higher the society integrity (a smaller value of α), the larger the number of suppliers available in the supply chain. It can be seen that increasing social integrity is also very critical under the premise of pursuing certain quality goals because it reduces the economic adulteration motive of upstream firms (suppliers). And suppliers with lower economic adulteration motives can reduce the probability of adulteration, which ultimately increases the number of suppliers (upstream firms) available to manufacturers (downstream firms) in the supply chain.

Proposition 1 At a certain level of product quality, the lower the integrity of the society (a large value of α), the fewer suppliers can be selected in the supply chain. On the contrary, the higher the society integrity (a smaller value of α), the larger the number of suppliers available in the supply chain.

$dn^*/d\beta < 0$, indicating that the larger β is, the smaller n^* is; conversely, the larger n^* is. This suggests that the more technologically advanced the regulation (the smaller value of β), the more suppliers can be supervised by the manufacturers simultaneously, and thus the more suppliers can be selected in the supply chain. Levi, et al.^[1] argued that suppliers would be more willing to adulterate in the case of incomplete detection due to the low probability of adulteration being detected. The advanced regulatory technologies, especially with the application of information technology, Internet of things technology, and block-chain technology in regulation, will further expand the coverage of regulation, and the cost of regulation will also be greatly reduced, thus effectively curbing suppliers from adulteration and alleviating the regulatory input of manufacturers, and ultimately leading to an increase in the number of available suppliers in the supply chain. Of course, this also reflects that with the increase of social integrity and the development of regulatory technology, the scale of manufacturers will

become larger but their number will decrease under the condition of certain quality targets.

Proposition 2 *The more advanced the technology supervised (the smaller value of β), the more suppliers can be supervised at the same time by the manufacturer, and the more suppliers can be selected.*

$dn^*/db < 0$, indicating that the larger b is, the smaller n^* is; conversely, the greater n^* is. That is, the greater the incentive intensity for the supplier (a large value of b), the smaller the number of suppliers available to the manufacturer in the supply chain. This finding is consistent with the prediction of the classical incentive model, that the benefit of the manufacturer (principal) will decrease when b rises, and the manufacturer will reduce the number of suppliers in the supply chain.

Proposition 3 *The greater the incentive intensity for the supplier (a large value of b), the smaller the number of suppliers in the supply chain that the manufacturer can choose from.*

Under the condition that manufacturers and suppliers pursue the goal of obtaining the maximum benefit together, the result of the optimal incentive intensity is given by Equation (15), that is, $b^* = 1/(1 + r\sigma^2 d^2 c/da^2)$. According to the relationship $\sigma^2(n) = \alpha + \beta n$ given by Formula (16), when the number of suppliers available for selection n is larger, the uncertainty $\sigma^2(n)$ will be larger and thus will lead to the decrease of b^* , that is, the incentive intensity for suppliers will eventually be reduced. It should be pointed out that different from the classical model, our model introduces the concept of the number of suppliers, and the incentive strength is related to the number of selected suppliers so that there is no unique optimal incentive intensity.

4.2 Numerical Analysis

In this section, we present simulation results for numerical examples. Suppose that the supplier's cost function for taking action a is $c(a) = ka^2/2$, and the risk aversion degree of suppliers is $r = 0.5$. First, we examine the impact of changes in social integrity α on the number of suppliers n . In the case of assuming $k = 1$, $\beta = 0.25$, and $b = 0.3$, we observe the corresponding value changes of n when the value of α takes 0.1, 0.3, and 0.9, respectively. From the results shown in Table 1, it can be seen that as the value of α increases from 0.1 to 0.9, the value of the number of suppliers n decreases.

Table 1 Numerical simulation results on suppliers number

k	r	α	β	b	n
1	0.5	0.1	0.25	0.3	10.26666667
1	0.5	0.3	0.25	0.3	5.02222222
1	0.5	0.9	0.25	0.3	2.62222222
1	0.5	0.1	0.5	0.3	2.91111111
1	0.5	0.1	0.75	0.3	2.26666667
1	0.5	0.1	0.25	0.8	0.26666667

Second, we calculate the impact of changes in regulatory technical conditions β on the number of suppliers n . Under the assumptions of $k = 1$, $\alpha = 0.1$, and $b = 0.3$, we observe

changes in the value of n when β equals 0.25, 0.5, and 0.75, respectively. The numerical calculation results in Table 1 show that as the value of β increases from 0.25 to 0.75, the value of n falls.

Finally, the influence of the change of the incentive intensity b on the number of suppliers is calculated. The numerical calculation results show that under the assumptions of $k = 1$, $\alpha = 0.1$, and $\beta = 0.25$, the value of the corresponding number of suppliers n drops from more than 10 to close to 0 when b is 0.3, 0.5 and 0.8.

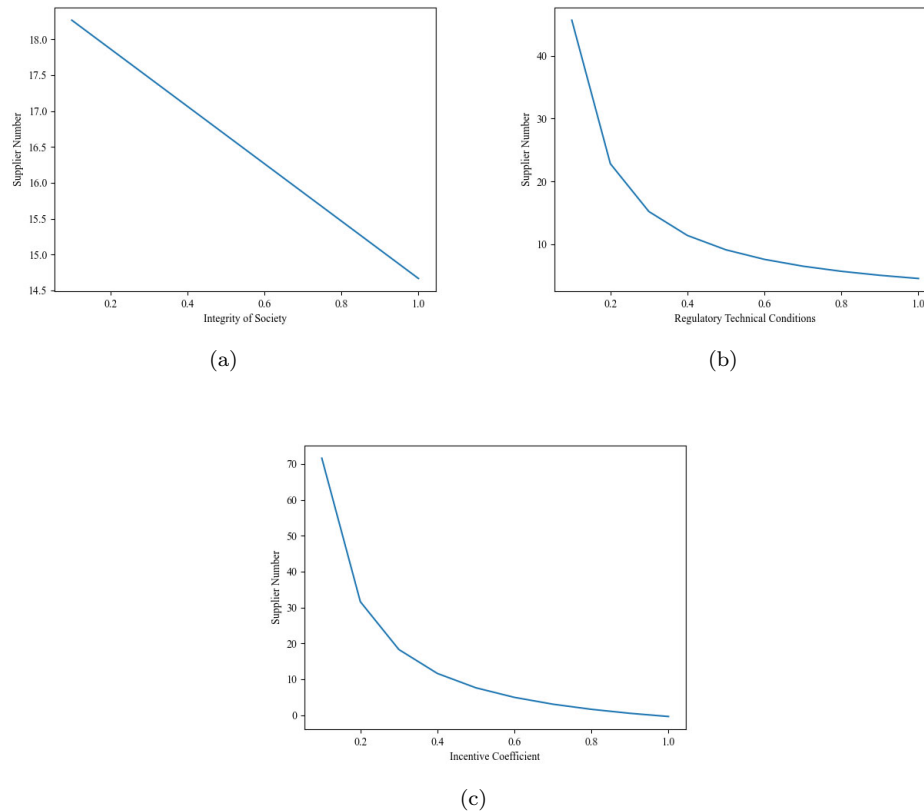


Figure 2 Changes in the number of suppliers with the growth of social integrity, regulatory technical conditions, and incentive strength. Figure 2(a): The change in the number of suppliers caused by the increase in the value of social integrity; Figure 2(b): The change in the number of suppliers when the value of the regulatory technical condition increases; Figure 2(c): The number of suppliers increases with changes with the increase in the value of the incentive strength

On the basis of numerical simulation calculation, this paper further draws the relationship respective between α , β , and b and the number of suppliers n . Figure 2(a) depicts the effect of changes in α on n : As the value of α raises, the value of n decreases linearly. It can be seen from Figure 2(b) that with the increase of β , the value of n shows a downward trend, and this downward trend gradually slows down under a large value of β . Figure 2(c) shows that the change in the value of b has a similar impact on the number of suppliers n as β . As the value of

b increases, the value of n slips, and this sliding trend gradually been slowing with the increase of the value of b .

Next, focus on the relationship between the supplier's action a and the incentive intensity b , the social integrity α and the regulatory technical condition β . First, by $c(a) = a^2/2$, the derivative of $c(a)$ to a gives $c'(a) = dc/da = a$. Also, combining with the result of Equation (6) $c'(a) = dc/da = b$, we can get $a = b$, which means that the supplier's action is positively and linearly related to the incentive intensity. At this point, the supplier's action satisfies the incentive compatibility constraint, i.e., $s + b \cdot a(b) - c(a(b)) - rb^2\sigma^2/2 \geq \text{CE}$.

From $c(a) = a^2/2$ and further combining Equations (15) and (16), the relationship between the supplier's action a and the society integrity α and regulatory technical conditions β can be obtained.

$$a = b = \frac{1}{1 + r \cdot (\alpha + \beta \cdot n)}. \quad (21)$$

Differentiating the supplier's action a concerning α , we get:

$$\frac{da}{d\alpha} = -\frac{r}{[1 + r \cdot (\alpha + \beta \cdot n)]^2}. \quad (22)$$

The term $da/d\alpha < 0$ indicates that there is a negative correlation between the supplier's action a and the social integrity α , that is, the value of the supplier's action a decreases as the value of α increases.

Now, taking the derivative of the supplier's action a to β , we can obtain:

$$\frac{da}{d\beta} = -\frac{r \cdot n}{[1 + r \cdot (\alpha + \beta \cdot n)]^2}. \quad (23)$$

The term $da/d\beta < 0$ indicates that the supplier's action a has a negative correlation with the regulatory technical condition β , which means that the value of a falls as β raises.

Similarly, the relationship between α and β and supplier behavior a is calculated by numerical simulation and the relationship diagram is further drawn. First, the change in the value of a is calculated at α equals 0.1, 0.3 and 0.9 by assuming $r = 0.5$, $n = 20$, and $\beta = 0.25$, respectively. According to the results in Table 2, as the value of α grows from 0.1 to 0.9, the value of a slips.

Then, assuming the case of $r = 0.5$, $n = 20$, and $\alpha = 0.1$, when β takes the values 0.25, 0.5, and 0.75, respectively, we calculate the change in the value of a . The results in Table 2 show that the value of the corresponding suppliers action a slides as the value of β increases from 0.25 to 0.75.

The graph of the relationship between α , β , and the suppliers action of a is shown in Figure 3. Figure 3(a) depicts the effect of the change in α on a : As the value of α increases, the value of a shows a linear decrease. From Figure 3(b), it can be seen that the value of a presents a downward trend as the value of β increasing, and with the value of β increases, this downward trend gradually slows down.

Table 2 Numerical simulation results on supplier's actions

r	α	β	n	a
0.5	0.1	0.25	20	0.28169014
0.5	0.3	0.25	20	0.2739726
0.5	0.9	0.25	20	0.25316456
0.5	0.1	0.5	20	0.16528926
0.5	0.1	0.75	20	0.11695906

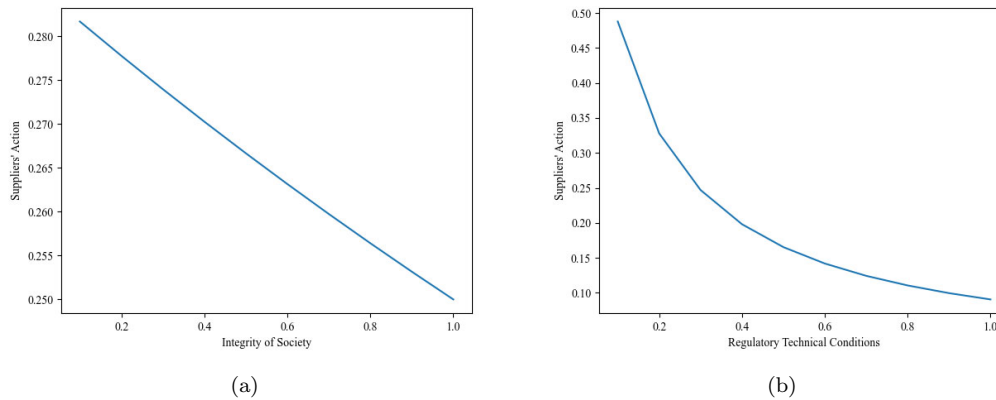


Figure 3 Changes in the supplier's action with the growth of social integrity and regulatory technical conditions. Figure 3(a): The change in the supplier's action caused by the increase in the value of social integrity; Figure 3(b): The change in the supplier's action

5 Management Cases and Inspiration

In this chapter, we further illustrate the theoretical conclusions of this paper using the data and findings of empirical research used in Yu's^[34] doctoral dissertation. Yu^[34] argued, from the perspective of the scale of dairy farming, that dairy farming in China could be classified into four categories, that is, free-range (1–9), small-scale (10–49), and medium-scale (50–499) and large-scale breeding (more than 500 cows). If it is classified according to different organizational models and breeding methods, China's dairy farming can be roughly divided into family-style free-range farming, community-style centralized farming, professional dairy farms, and large-scale farms owned by dairy processing enterprises. According to the data compiled, in 2008, when the melamine incident occurred, the number of free-range dairy farmers in China was 2.3695 million, accounting for 91.59% of the total number of dairy farming households in the country at that time, and the dairy stock of free-range dairy farmers was 776.1 million head, which was more than 50% of the total stock; while the total number of medium-scale farmers and large-scale farmers was less than 1% of the total number of dairy farming households in the country in that year, and the total dairy farming stock of both accounts for only a quarter of the total national dairy farming stock^[34].

At this time, the large number of dairy stations is a bridge to help connect China's huge

number of family-owned free-range farms with dairy processing companies. Dairy stations, sandwiched between the dairy farms and the dairy enterprises, are faced with a large number of dairy farmers who have sufficient incentive to adulterate their milk to maximize their profitability, and on the other hand, the demands of the dairy processors to continuously improve the quality and safety of their raw milk. Under double pressure, dairy stations also had sufficient incentives to adopt adulteration to maximize their profitability, which is considered by scholars to be the direct trigger of the melamine incident in China in 2008^[34]. An empirical study by Yu^[34] found that feeding scale had a significant positive effect on farmers' safe production behavior and that the overall safe production behavior, production and health environment, and epidemic prevention behavior of farmers in large-scale dairy farming communities were better than those of free-range dairy farmers overall. The occurrence of melamine adulteration in China in 2008 was associated with too many free-range farmers and too fragmented supply chains. This finding is consistent with the hypothesis of this paper.

After the melamine adulteration incident in China in 2008, the Chinese government realized that the problems were caused by a large number of scattered dairy farmers across the country, the most important problem was that it made supervision and management by government departments very difficult. In November 2008, the "Outline of the Plan for the Consolidation and Revitalization of the Dairy Industry" called for the promotion of the scale and standardization of dairy farming, and in June 2013, the Opinions on Further Strengthening the Quality and Safety of Infant Formula Milk Powder called for the promotion of the standardization, scale, and modernization of enterprises, by encouraging and Support the merger and re-new of enterprises to improve the concentration of the industry. Through policy adjustments and government guidance, China's dairy farming is gradually shifting to scale. For example, the proportion of small-scale free-range farmers to total farmers in China fell from 91.59% in 2008 to 89.71% in 2011, and the dairy stock of small-scale free-range farmers plummeted from 50.67% of the country to 37.01%. The proportion of large-scale cattle farmers increased from 0.06% in 2008 to 0.14% in 2011, and the dairy stock increased from 10.05% to 20.79%. The trend of large-scale and standardized dairy farming is becoming clearer.

Table 3 Comparison of China's dairy farming in 2008 and 2011

	2008	2011
Proportion of small-scale free-range farmers to total farmers	91.59%	89.71%
proportion of dairy cows in small-scale free-range farmers	50.67%	37.01%
Proportion of large-scale cattle farmers in total farmers	0.06%	0.14%
Proportion of dairy cows in large-scale cattle farmers	10.05%	20.79%

According to Proposition 1, milk supply chains need to be centralized when the integrity of society is low. According to Proposition 2, the milk supply chain also needs to be centralized when the regulatory technology is not advanced enough and regulation is difficult. According to Proposition 3, milk supply chains also need to be centralized when milk processors want to share more benefits with dairy farmers. Overall, this paper further theoretically justifies the idea that the government is correct in promoting milk supply chain centralization and needs to

further promote the process of dairy farming scale and standardization.

6 Conclusion

In the case of supplier adulteration, it is important for downstream companies to choose between incentives and regulation to ensure the quality of their products^[30]. Existing studies have revealed that there is a correlation between supplier adulteration and the number of suppliers^[1]. Therefore, this paper assumes that the number of suppliers can affect the quality uncertainty. We construct a regulatory-based incentive model, and incorporate the number of suppliers into the model to investigate the relationship between supply chain dispersion, regulation, social integrity, and incentive strength, and obtain conclusions with general significance. The model analysis found that the optimal number of suppliers depends on social integrity, regulatory costs, and incentive strength under the determined quality objectives. Among them, the higher the social integrity, the higher the optimal number of suppliers; the more advanced the regulatory technology, the higher the optimal number of suppliers; the lower the incentive strength for managers (suppliers), the higher the optimal number of suppliers. In addition, social integrity and regulatory technology also affect the suppliers action. The higher the social integrity (the smaller the value of α), the better the suppliers action (the larger the value of a); the more advanced the regulatory technology (the smaller the value of β), the better the suppliers action (the larger the value of a).

Our study provides new insights and ideas for policymakers and business entities in the food supply chain to more fully understand the relationship between the number of suppliers and product quality, incentives, and regulation. First, based on the correlation between supplier adulteration and the number of suppliers, we further reveal that there is an optimal number of suppliers with a defined level of quality, and the optimal number of suppliers is affected by social integrity, regulatory costs, and incentive strength. This shows that there is a more complex influencing mechanism on the relationship between supplier adulteration and the number of suppliers. It is not simply based on the number of suppliers to determine whether the quality is high or low. For example, through advances in regulatory technology, product quality can be guaranteed when the number of optimal suppliers is relatively large. Secondly, this study constructs an incentive model based on regulation while introducing social integrity and studying both incentive and regulation. We find that the higher the social integrity, the lower the regulation costs, the lower the incentive intensity, and the greater the number of optimal suppliers that can be selected. This indicates that increasing social integrity, promoting regulatory technology advancement, and adopting reasonable incentive strength are crucial to the selection of the number of suppliers. At the same time, unlike the classical model, there is no unique optimal incentive strength in our model.

Our findings have important practical implications and suggest new directions for future research. We suggest that the possibility of adulteration and the quality of suppliers cannot be judged simply based on the number of existing suppliers. It is also necessary to comprehensively consider factors such as social integrity, incentive strength, and advances in regulatory technology within the industry to achieve an optimal number of suppliers and build a suitable supply chain while balancing incentives and regulation. It should be pointed out that our study is not

able to empirically analyze and validate our findings using real-world data in order to better understand the relationship and influence paths between the number of suppliers and supplier adulteration, incentives, and regulation. In addition, future research could build on our model to further examine other relevant supply chain settings. For example, what degree of supplier dispersion is beneficial in reducing regulatory costs and improving quality for manufacturers. For regulators, our study is important and positive for reversing the drawbacks of regulators' excessive focus on sampling and testing of final goods, further emphasizing the importance and positive implications of collecting data from upstream segments and analyzing manufacturers' procurement supply chains in quality regulation.

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