Information, Capacity Constraints and Quality on Firms Competition*

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Abstract

Quality competition is a critical issue for firms, especially for the producers of food and health care. Asymmetric information is regarded as a vertical factor that significantly influences quality decisions, but input capacity constraints should also not be ignored. So, this paper investigates the combined effects of information and capacity constraints on firms' quality competition. The basic model is analyzed under eight different cases. The solutions about output quantities, prices, firms' profits, consumer surplus, and social welfare of different conditions in equilibrium are obtained. First, analysis shows that the information structures, capacity constraints, and decision structures significantly influence firms' quality decisions. Second, analysis indicates that the exogenous variables of pricing sensitive, cost-sensitive, product substitutability, and resource consumption rate impact the equilibrium solutions. Third, there are interactions between the decision-making conditions and the exogenous variables. This paper offers a system decision framework for quality competition that will enrich the theory of information economics. The corresponding policy implication is that quality regulation is a complicated matter, and the policymakers should fully consider the effects of information conditions, capacity constraints and decision structures when considering quality regulation. This is especially true for food commodities and consumer health.

Keywords: Asymmetric information; Capacity constraints; Decision structure; Quality safety; Resource consumption rate

JEL *Classification* D43, L15, Q18

Introduction

Quality is a critical commodity property, and asymmetric information analysis had become the criteria for quality competition since the "Lemon market" theory (Akerlof, 1970). Take food quality as an example. Existing studies almost attribute food quality problems to information asymmetry (Hobbs, 2003; Starbird, 2005; Kadjo, Ricker-Gilbert, Shively, et al., 2019). Recent papers showed that capacity constraint impacts firm competition and industrial development (Esó, Nocke & White, 2010; Chen, Nie & Wang, 2015). However, the effect of input capacity constraints on firms' quality decisions has been underestimated (Chen, Huang, Mishra, et al., 2018; Chen, He & Paudel, 2018). Capacity constraint is significant in quality competition. Scarcity leads to competition and generates product prices. But after the price formation, scarcity is ignored. In other words, people always suppose that the firm can make output decisions based on the first-order condition for profit maximization (Acemoglu, Akcigit, Alp, et al., 2018; Arrow, 2015). However, the effect of resource scarcity is far from what is believed to be an input capacity constraint, a concept derived from scarcity, will dramatically change firm decision (Nie & Wang, 2019; Nie & Chen, 2012; Esó, Nocke & White, 2010). Information asymmetry is only necessary for quality fraud, while resource input constraints are sufficient. For example, the 2008 milk powder melamine incident in China happened because raw milk meeting the requirements of milk powder production is not enough for the rapid growth in demand for milk powder (Chen, Zhang & Delaurentis, 2014; Kong, 2012). Recent studies also showed that a firm would reduce product quality to maintain output (Chen, Huang, Mishra et al., 2018; Chen, He & Paudel, 2018).

In sum, information asymmetry and input capacity constraints are critical to firm decisions. In addition, we argue that decision structure (independent or joint), is also an essential variable to firm decisions. Thus, this paper aims to examine the impact of information asymmetry, capacity constraints, and decision structure on output quality. The basic model uses the representative consumer's utility function and analyzes eight scenarios (see Nie, Chen & Wang, 2021; Chen, Chen & Mishra, 2020; Rey & Tirole, 2019). For simplicity, the analysis structure is presented in Table 1. Finally, a duopoly competition structure always holds.

Table 1: Analysis structure of the research

Capacity conditions	Decision structures	Information conditions
Sufficient capacity	Independent decision	Symmetric information
		Asymmetric information
	Joint decision	Symmetric information
		Asymmetric information
Insufficient capacity	Independent decision	Symmetric information
		Asymmetric information
	Joint decision	Symmetric information
		Asymmetric information

Equilibriums under eight cases and the corresponding conclusions are obtained. First, comparative analysis shows that information structure, capacity constraints and decision structure significantly influence firms' decisions. Second, comparative static analysis indicates that exogenous variables like pricing, cost-sensitive, product substitutability, and resource consumption impact the equilibrium solutions. Third, the study considers interactions between the decision-making conditions and the exogenous variables. This paper offers a system decision theory for quality competition and will enrich the theory of information economics. The corresponding policy implication is that quality regulation is a quite complicated matter. The policymaker should fully consider the effects of information conditions, capacity constraints, and decision structures in the quality regulation-making, especially for those commodities impacting peoples' daily health.

The novel contributions of the paper are mainly reflected in the following three aspects. Firstly, we construct a system decision theory framework for quality competition. Unlike prior studies, this paper highlights the synthetic effect of information asymmetry and input capacity constraints. And different decision structures are also considered. Secondly, we offer a new perspective for quality fraud, which will be helpful for quality regulation, such as food and drug safety regulation. Most existing studies and quality safety statutes only concern information asymmetry but ignore the impact of input capacity constraints on firm decisions. As a result, the intensity of regulation continues to increase, and food safety incidents still occur frequently. Finally, this paper fully considers the interaction between firm decision conditions and exogenous variables, such as price sensitivity, cost sensitivity, resource consumption rate and competition intensity.

The remainder of this paper is as follows. Basic assumptions and models are offered in section 3. The basic model implies equilibrium solutions under different cases discussed in section 4. Section 5 presents the results of the analysis. Section 6 shows an extended analysis, and we highlight the effect of the resource consumption rate and competition on quality decisions.

Literature review

Competition has a critical impact on firm quality decisions, and most quality researches employ an oligopoly structure. As an effective nonprice competition method, quality has attracted much attention since the last century (Spence, 1977; Dixit, 1979). Spence (1975) and Sheshinski (1976) were the earlier papers that revealed the relationship between quantity and quality. Furthermore, their studies have shown us the substitutability between quantity and quality is an essential cause of quality safety. Gil and Kin (2021) found that competition increases quality but keeps prices unchanged based on the US airline industry. Matsa (2011) argued that competitive pressures caused supermarkets to invest in product quality by measuring quality by product availability. Curzi, Raimondi and Olper (2014) investigated the effect of competition on quality upgrading by employing European Union data. Belleflamme and Forlin (2020) also implied competition increases equilibrium quality. Note that the food industry is very special because competition reduces the food quality (Nie & Chen, 2014).

Besides competition, information asymmetry is another crucial factor affecting on firm decisions. Two studies, namely Akerlof (1970) and Tirole (1998), investigated the impact of information asymmetry on quality decisions and showed that information asymmetry inhibits quality innovation. In a recent study, Lotito, Migheli, and Ortona (2020) surveyed the impact of information on firm competition. Their study showed that full information about the relative performance in the competitive environment enhances cooperation. Asymmetric information triggers supplier encroachment in the supply chain, leading to lower quality in equilibrium (Li, Gilbert & Lai, 2014; Zhang, Li, Zhang et al., 2019). while Körpeoğlu, Şen and Güler (2013) asserted asymmetric information hinder cooperation. Yang, Lu and Xu (2016) found that the supplier's market value affects quality distortion under asymmetric quality information. The negative effect of asymmetric information in the agri-food sector is important because it seriously threatens food safety and food fraud (Ippolito, 2003; Schmit, Rickard & Taber, 2013; Ehmke, Bonanno & Boys et al., 2019).

The impact of input capacity constraints on a firm decision is also significant. For example, Esó, Nocke and White (2010) and Nie and Chen (2012) asserted input capacity constraint impacts symmetrical development of the industry. Capacity constraints enhance resource allocation efficiency, and disadvantage firm benefits from capacity constraint under Stackelberg competition (Chen, Nie and Wang, 2015). Capacity constraints significantly impact quality and innovation decisions (Yayla‐Küllü, Parlaktürk and Swaminathan, 2013; Nie & Wang, 2019). More importantly, Chen, He and Paudel (2018) found that a restaurant will reduce its product and service quality under capacity constraints if most consumers are price-sensitive. The authors concluded that food quality decreases with time. Another study by Chen, Huang & Mishra et al. (2018) shows that a firm will reduce its equilibrium quality when confronted with capacity constraints. This paper offers a new perspective on food safety problems.

Decision structure is another factor affecting firms' decisions. Merger and integration are very common in firm competition, and those behaviors influence a firm's decisions. In a recent study Chen and Gayle (2019) investigated the effects of the merger on quality with two recent airline mergers (Delta/Northwest [DL/NW] and Continental/United [CO/UA]). And they found that a U-shape relationship between change in the quality and pre-merger competition intensity. In contrast, Han, Kairies-Schwarz and Vonhof (2017) showed, using data from hospitals, a negative impact of mergers on quality. Integration can be used as an alternative strategy for product differentiation to overcome the competition, which impacts a firm's quality decision (Matsubayashi and Nobuo, 2007). Capacity constraints also impact firm merger decisions. For example, Chen and Li (2018), Froeb, Tshantz and Crooke (2003) showed that horizontal merger capacity stimulates firm mergers. Considering the impact of mergers and antitrust laws, cooperative and joint decisions are ideal strategies for weakening competition. So, Chen, Liang and Yang (2015) highlighted cooperative quality investments. In contrast, Wu and Zhu (2017) found that joint quality decisions are beneficial for enhancing quality.

Quality is an important decision variable and a vital product attribute for firms, especially in food and healthcare. Numerous studies focus on quality decisions from different perspectives, but few consider the synthetic effect of the significant quality decision variables. Furthermore, most studies highlighted the empirical evidence, while the theoretical quality decision mechanism is still not specific. Notice that empirical research is only the special case of the whole story. For example, our results show that the relationships between resource consumption rate and consumer surplus are *U*-shaped. But if the value of resource consumption rate is restricted in a small range, we will only obtain the negative correlation. Thus, the crux of this study is to present a theoretical framework for quality decisions. Based on the literature analysis above, we build the following structure (see figure 1). Information, capacity, and decision structures are the three critical factors affecting quality decisions. In contrast, resource consumption rate and competition have significant moderating effects on quality decisions.

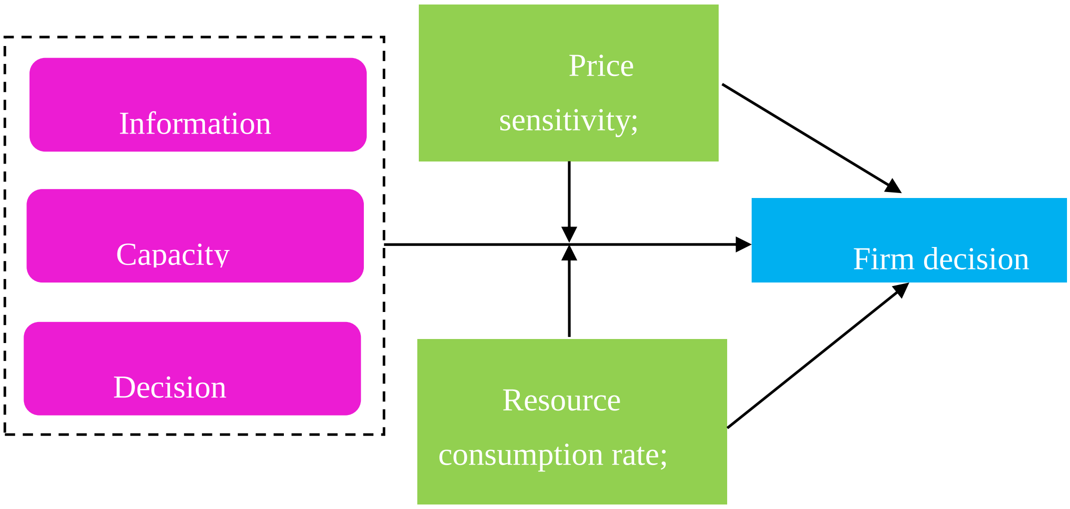

Figure 1: Quality decision structure

Assumptions and Model

Consumer. Oligopoly, especially the duopoly model, has a natural advantage in capturing competitive strategy (Beviá, Corchón, & Yasuda, 2020; Jeitschko, Liu & Wang, 2018; Gilbert, Riis & Riis, 2018; Chen, Nie & Wang, 2021). The basic model is based on duopoly competition, but conclusions can be easily expanded to other market structures. The major variables and parameters in this paper are outlined as follows:

Table 2: Nomenclatures

Notation	Description	Notation	Description
l	Low-quality firm	h	High-quality firm
α	Market size	γ	Product Substitutability
δ	Price sensitivity	c	Cost sensitivity
θ	Resource consumption rate	R	Input capacity constraints
x	Output quantity	p	Price
CS	Consumer surplus	SW	Social welfare
π	Profits		

Assume that quality is an exogenous variable and products are divided into two categories, high-quality and low-quality. Consumer utility comes from a selected commodity, other commodities are standardized to zero, and the income constraint of the consumer is also ignored in this paper. In other words, a consumer can always make a purchase decision based on the first-order optimal condition for utility maximization. According to most existing research, a leaner inverse demand function is employed in this study (Hajdinjak, 2021; Beviá, Corchón, & Yasuda, 2020; Chen, Chen & Mishra, 2020). Then the utility function of the representative consumer is:

$$U = \alpha x_l - \frac{1}{2}x_l^2 - \gamma x_h + \delta(\alpha x_h - \frac{1}{2}x_h^2 - \gamma x_l). \quad (1)$$

In function (1), x_l and x_h represent low- and high-quality commodities a consumer purchased, while α, δ and γ means market capacity, price sensitivity of the high-quality products and product substitutability, respectively[1]. Larger γ represents fiercer competition. Furthermore, we assume $1 < \delta \le 2$ that the price sensitivity of the high-quality products is higher but is no higher than twice that of the low-quality products. Notice that $\delta = 1$ means asymmetric quality information and $\delta > 1$ indicates symmetric information. The increase of δ means price sensitivity improving and advantage enhancing for the high-quality producer. Function (1) implies the following inverse demand functions:

$$\begin{cases} p_l = \alpha - x_l - \gamma x_h, \\ p_h = \delta(\alpha - x_h - \gamma x_l). \end{cases} \quad (2)$$

Producer. Assume there are two producers for the same kind of commodity. One is a high-quality producer, while the other is the low-quality one. The two firms compete with quantity in the market. For the producers, they subject to the following objective:

$$\begin{cases} \pi_l = (\alpha - x_l - \gamma x_h)x_l - \frac{1}{2}x_l^2, \\ \pi_h = \delta(\alpha - x_h - \gamma x_l)x_h - \frac{c}{2}x_h^2, \end{cases} \quad (3)$$
$$s.t. \quad x_l + \theta x_h \le R.$$

Function (3) is a constrained optimization problem. Two firms produce with only one input resource with the maximum value *R*, which means two producers are confronted with the

[1] Price sensitivity of the low-quality products is standard to be 1.

joint input resource capacity constraints. $x_l + \theta x_h < R$ means no constraints and $x_l + \theta x_h \geq R$ indicates binding constraints. $\theta \geq 1$ is the resource consumption rate of the high-quality product.[2] Assume product costs are quantity sensitive and the cost sensitivity of the high-quality is c and $1 < c \leq \delta$, which indicates cost sensitivity of the high-quality product are small than its price sensitivity but higher than the parameter of the low-quality product[3].

Model Setup

Furthermore, the constraint boundary R equals 1/3 of the market capacity ($R = \alpha / 3$) and the benchmark analysis4. The primary model function (3) will be solved under eight cases (2 information structures $\times$ 2 capacity conditions $\times$ 2 decision structures). The quantities, prices in the equilibrium and their corresponding numerical simulation results (based on δ) of the 8 cases are outlined as follows[5]:

$$x_l = \begin{cases} \dfrac{2(3\delta + 2c)\alpha}{23\delta + 12c} \\ \dfrac{2(2c + 3\delta - \delta^2)\alpha}{-1 + 12c + 22\delta - \delta^2} \\ \dfrac{(5 + 2c - 2\delta)\alpha}{3(5 + 2c + 3\delta)} \\ \dfrac{(5 + 2c - 3\delta)\alpha}{6(2 + c + \delta)} \end{cases}, \qquad x_h = \begin{cases} \dfrac{10\delta\alpha}{23\delta + 12c} \\ \dfrac{2(5\delta - 1)\alpha}{-1 + 12c + 22\delta - \delta^2} \\ \dfrac{5\delta\alpha}{3(5 + 2c + 3\delta)} \\ \dfrac{(5\delta - 1)\alpha}{6(2 + c + \delta)} \end{cases}. \tag{4}$$

[2] Resource consumption rate of the low-quality is 1. So, $\theta > 1$ means high-quality products are resource-intensive.

[3] Cost parameter of the low-quality product is normalized to 1 again.

[4] The additional assumption for the resource constraint boundary is to guarantee non-zero equilibrium solutions under constrained condition and some other boundary values, such as $\alpha / 4$ are also acceptable. The assumption about the competitive intensity and input-output conversion efficiency will be relax in the expand analysis section.

[5] Those are the solutions for symmetric information and let $\delta = 1$ for the other 4 cases under asymmetric information condition.

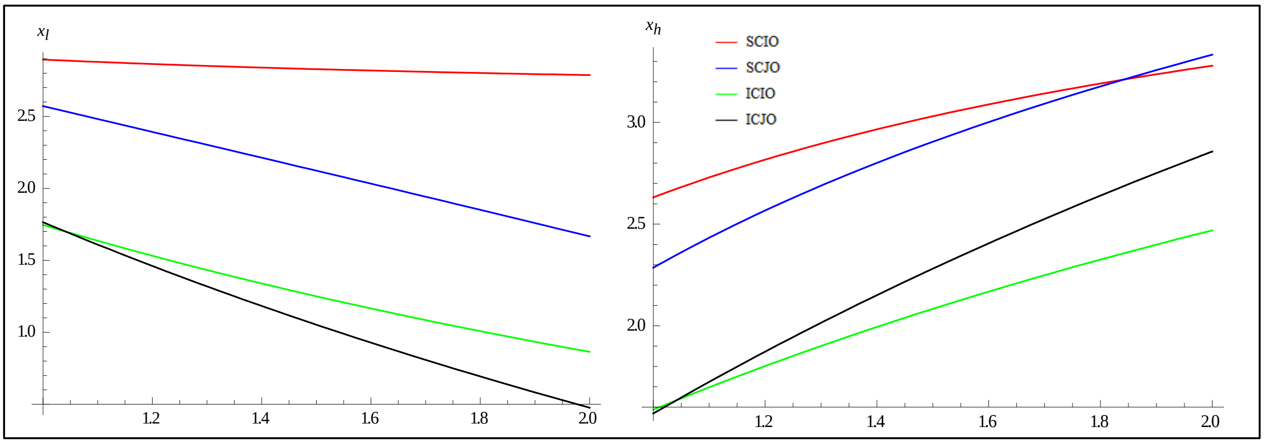

Figure 2 Numerical simulation results of equilibrium quantity

Notes: SCIO,SCJO, ICIO and ICJO, represent independent decisions with sufficient capactiy, joint decision with sufficient capacity, independent decisions with insufficient capactiy, joint decision with insufficient capacity, respectively. $\alpha=10$, $c=5/4$.

$$p_l=\begin{cases}\dfrac{4(3\delta+2c)\alpha}{23\delta+12c}\\ \dfrac{(8c+11\delta+\delta^2)\alpha}{-1+12c+22\delta-\delta^2}\\ \dfrac{(20+8c+17\delta)\alpha}{6(5+2c+3\delta)}\\ \dfrac{(15+8c+13\delta)\alpha}{12(2+c+\delta)}\end{cases},\qquad p_h=\begin{cases}\dfrac{10\delta(c+\delta)\alpha}{2(3\delta+12c)}\\ \dfrac{(1+10c+9\delta)\delta\alpha}{-1+12c+22\delta-\delta^2}\\ \dfrac{5(5+2c+2\delta)\delta\alpha}{6(5+2c+3\delta)}\\ \dfrac{(21+10c+5\delta)\alpha}{12(2+c+\delta)}\end{cases}. \tag{5}$$

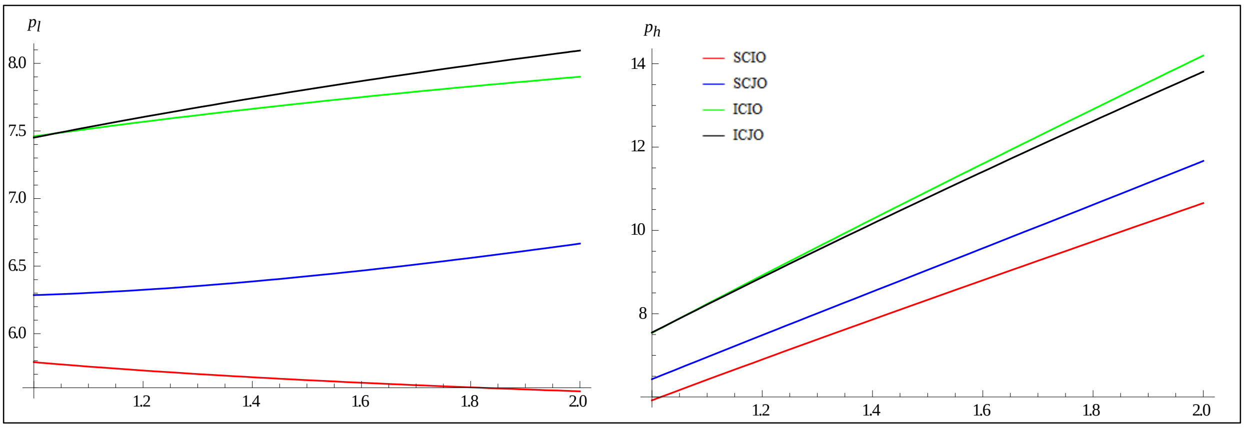

Figure 3 Numerical simulation results of equilibrium prices

The cases sequential of the solutions is insufficient capacity with the independent decision, low capacity with a joint decision, sufficient capacity with an independent decision structure, and sufficient capacity with a joint decision structure. Substitute equations (4) and (5) into (3), we can obtain profits in the equilibrium of the two firms as:

$$\pi_l=\begin{cases}\dfrac{6(3\delta+2c)\alpha^2}{(23\delta+12c)^2},\\ \dfrac{4(2c+3\delta-\delta^2)(3c+4\delta+\delta^2)\alpha^2}{(-1+12c+22\delta-\delta^2)^2}\\ \dfrac{(5+2c-2\delta)(15+6c+19\delta)\alpha^2}{18(5+2c+3\delta)^2}\\ \dfrac{(5+2c-3\delta)(5+3c+8\delta)\alpha^2}{36(2+c+\delta)^2}\end{cases},\qquad \pi_h=\begin{cases}\dfrac{50(c+2\delta)\delta^2\alpha^2}{(23\delta+12c)^2}\\ \dfrac{2(5\delta-1)(c+\delta+5c\delta+9\delta^2)\alpha^2}{(-1+12c+22\delta-\delta^2)^2}\\ \dfrac{25(5+2\delta+c)\delta^2\alpha^2}{18(5+2c+3\delta)^2}\\ \dfrac{(5\delta-1)(c+5c\delta+21\delta+5\delta^2)\alpha^2}{72(2+c+\delta)^2}\end{cases}. \tag{6}$$

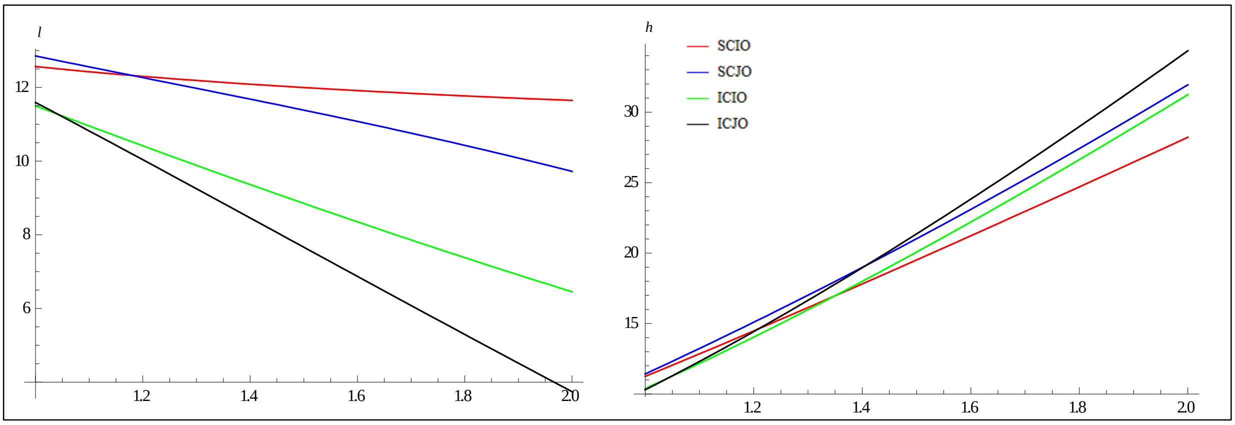

Figure 4 Numerical simulation results of equilibrium profits

Define consumer surplus (*CS*) to the total utility from commodity consumption minus the corresponding expenditures $CS=U-px$. And social welfare (*SW*) to consumer surplus adds firms' profits $SW=CS+\pi$. Then we have:

$$CS=\begin{cases}\dfrac{2(4c^2+12c\delta+9\delta^2+25\delta^3)\alpha^2}{(12c+23\delta)^2}\\ \dfrac{2(4c^2+\delta+12c\delta-\delta^2-4c\delta^2+19\delta^3+\delta^4)\alpha^2}{(-1+12c+22\delta-\delta^2)^2}\\ \dfrac{(25+20c+4c^2-20\delta-8c\delta+4\delta^2+25\delta^3)\alpha^2}{18(5+2c+3\delta)^2}\\ \dfrac{(25+20c+4c^2-29\delta-12c\delta-\delta^2+25\delta^3)\alpha^2}{72(2+c+\delta)^2}\end{cases}.$$

(7)

and

$$SW = \begin{cases} \dfrac{2(16c^2+48c\delta+36\delta^2+25c\delta^2+75\delta^3)\alpha^2}{(12c+23\delta)^2} \\ \dfrac{2(-c+16c^2+46c\delta+19\delta^2+19c\delta^2+62\delta^3-\delta^4)\alpha^2}{(-1+12c+22\delta-\delta^2)^2} \\ \dfrac{(100+80c+16c^2+45\delta+18c\delta+91\delta^2+25c\delta^2+75\delta^3)\alpha^2}{18(5+2c+3\delta)^2} \\ \dfrac{(75+69c+16c^2+2c\delta+51\delta^2+25c\delta^2+50\delta^3)\alpha^2}{72(2+c+\delta)^2} \end{cases}.$$

(8)

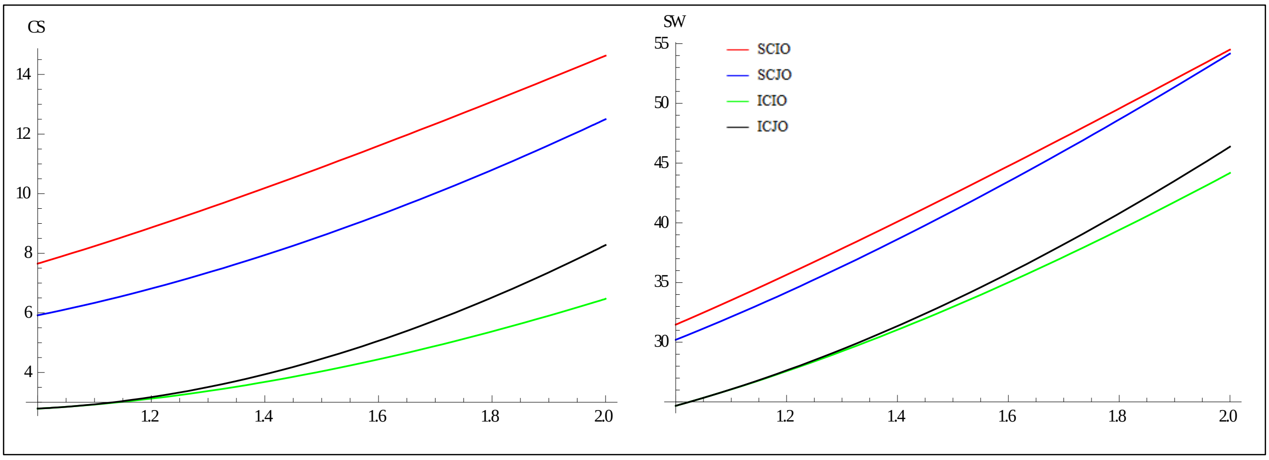

Figure 5 Numerical simulation results of consumer surplus and social welfare

Main results

Equilibrium quantity. Quantity is the most important variable. Information characteristics critically impact equilibrium because we can learn that high-quality products are more than those in equilibrium under symmetric information. In contrast, asymmetric information will inverse this relationship. This is a common conclusion called "Gresham's Law" or "The market for lemons." First, we investigate the effects of the high-quality product's price sensitivity and cost sensitivity on the equilibrium quantity.

Proposition 1 $\dfrac{dx_h}{d\delta} > 0$, $\dfrac{dx_l}{d\delta} < 0$; $\dfrac{dx_h}{dc} < 0$, $\dfrac{dx_l}{dc} > 0$.

Price sensitivity boosts the quantity of high-quantity products but reduces the quantity of low-quality ones. At the same time, the cost parameter has inverse effects as the price sensitivity on equilibrium quantity. Those conclusions are easy to understand. For the high-quality producer, price sensitivity increases its advantage, while the rise in cost sensitivity decreases it. But for the low-quality firm, the situation is just the opposite[6].

Here we define a new variable quantity deviation $\Delta x / \Sigma x$, equal to the quantity gap between high-quality products, divides the quantity aggregation. Then we obtain the following lemma.

Lemma 1 $\frac{d(\Delta x / \Sigma x)}{d\delta} > 0$, $\frac{d(\Delta x / \Sigma x)}{dc} < 0$.

The conclusions in the lemma can be easily inferred from proposition 1. Lemma reveals the effect of price sensitivity and cost sensitivity from a different perspective from the proposition. Lemma 1 shows that price sensitivity larges the quantity deviation, while cost sensitivity smalls it. Those conclusions make more sense if the number of firms is more than two.

Proposition 2 $x_h^J < x_h^I$ *under sufficient capacity;* $x_h^J < x_h^I$ *for* $\delta < \underline{\delta}$, $x_h^J > x_h^I$ *for* $\delta > \underline{\delta}$ *under insufficient capacity* $x_l^J < x_l^I$.

The high-quality products quantity of the independent decision case is higher than that of joint decisions case under sufficient capacity (non-tight bound condition). But this relationship is more complex for an insufficient capacity case because the relationship for the high-quality product quantity of different decision structures is the same as that under sufficient capacity for small price sensitivity $\delta < \underline{\delta}$. But this relationship will turnover for larger price sensitivity $\delta > \underline{\delta}$. The value $\underline{\delta}$ is dependent on c and $\underline{\delta} = \sqrt{26+10c} - 1/5$. J represents a joint decision, and I means independent decision. Proposition 2 implicates decision structure has a critical impact on the firm decision, and the price sensitivity impacts the effect of decision structure. Here, we compare the quantity of different quality products supplied and then obtain the following proposition.

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[6] All the conclusions in the propositions and lemma can be easily obtained from the equilibriums, so they are ignored in this study.

Proposition 3 The gap between a high-quality and low-quality products is larger under insufficient capacity than under sufficient capacity $x^i > x^s$.

In proposition, *i* represent insufficient capacity (tight bound constraint) while indicates sufficient capacity (non-tight bound constraint). Proposition 3 shows the impact of capacity constraints on the quality competition. Interestingly, capacity constraint increases the relative quantity of high-quality products if quality information is symmetric for consumers. The conclusion of proposition 3 reveals the impact of capacity constraints on quality decisions.

Equilibrium price. A high-quality commodity price is always higher than the price of a low-quality product in equilibrium from equation (5). The most convincing explanation for $p_h > p_l$ is that the unit cost of a high-quality product is higher than that of the low one, so a high-quality producer should claim a higher price to cover the cost, even under asymmetric information. From equation (5), we have the following proposition.

Proposition 4 $\frac{dp_l}{d\delta}<0$, $\frac{dp_l}{dc}>0$, $\frac{dp_h}{d\delta}>0$ *and* $\frac{dp_h}{dc}>0$ *sufficient capacity;* $\frac{dp_l}{d\delta}>0$, $\frac{dp_l}{dc}<0$, $\frac{dp_h}{d\delta}>0$ *and* $\frac{dp_h}{dc}>0$ *insufficient capacity.*

Proposition 4 illustrates the impact of price sensitivity and cost sensitivity on equilibrium. Cost sensitivity raises both high-quality product price and low-quality product price, but the mechanism. For the high-quality producer, higher cost represents competition disadvantage and it should require a higher price to cover it. For the low-quality producer, the higher cost of the competitor means an advantage, and it can ask for a higher price to increase its profits. For the price sensitivity, things are different.

On the one hand, price sensitivity always boosts high-quality product prices because a higher price sensitivity itself means a higher price. On the other hand, under insufficient capacity conditions, a low-quality producer can also raise its price for the limitation of total output. But if input resources are sufficient, the increase of high-quality product's price sensitivity will curb the low-quality product's price for its quality disadvantage.

Proposition 5 $\Delta p^i > \Delta p^s$ *for* $\delta > 1$ *and* $\Delta p^i > \Delta p^s$ *for* $\delta = 1$.

Increasing price sensitivity enlarges the price gap between different quality products. And information structure has an interaction effect with the capacity condition on equilibrium. Under symmetric information ($\delta > 1$), insufficient capacity will lead to a larger price gap than sufficient capacity and the situation is just inverse for asymmetric information.

Equilibrium profit. Profit is the most critical variable for the producer. The results show that price sensitivity, cost sensitivity, information structure, capacity constraint, and decision structure critically impact firms' profit. First, we investigate the effects of price and cost sensitivity by proposition 6.

Proposition 6 $\frac{d\pi_h}{d\delta} > 0$, $\frac{d\pi_l}{d\delta} < 0$; $\frac{d\pi_h}{dc} < 0$, $\frac{d\pi_l}{dc} > 0$

Proposition 6 indicates the aggregate impacts of price and cost sensitivity on producers' profits. The increase of price sensitivity enhances the advantage, while cost sensitivity increasing weaken the competition power of the high-quality because price sensitivity has a positive. Still, cost sensitivity shows a negative impact on high-quality profits. The effects of price sensitivity and cost sensitivity on low-quality producers are the opposite as they impose on the high-quality firm.

The influences of information structure, capacity constraints and decision structure are outlined by proposition 7.

Proposition 7 (i) $\pi_h < \pi_l$ *for* $\delta = 1$; $\pi_h > \pi_l$ *for* $\delta > 1$; *(ii)* $\Delta\pi^i > \Delta\pi^s$; *(iii)* $\Delta\pi^J > \Delta\pi^I$.

The first part of this proposition shows the effects of information structure on firms' profit. Low-quality producer benefits from symmetric information because it produces low-quality commodities with a lower cost than, but sells them at the same price as the high-quality producer. However, this competitive advantage for the low-quality producer will despair. The high-quality producer can supply high-quality goods higher than the low-quality one to improve its profits under symmetric information. As a result, the high-quality firm obtains higher profits under symmetric information, while the low-quality firm earns higher profits under asymmetric information.

Part (ii) and (iii) of proposition 7 reveal the impacts of capacity and decision structures on firms' profit. From proposition7, we know that capacity constraint and joint decision are conducive for the high-quality product. The profit gap between high-quality and low-quality products is larger in constrained capacity and joint decision than sufficient capacity and independent decision, respectively. A reasonable reason is that insufficient capacity and the joint decision will improve the resource allocation efficiency. It is worth noting that the results of proposition 7 are in contrast with Chen, Huang, Mishra et al. (2018), Chen, He and Paudel (2018), and Nie, Wang and Yang (2019). The difference is that quality is exogenous in their studies but is considered endogenous in the present study.

Social welfare. If the company is concerned with maximizing its interests, then the regulator's (policymakers) focus is on the total welfare of society, in general. So, consumer surplus and social welfare are investigated here.

Proposition 8 $\frac{\partial CS}{\partial \delta} > 0$, $\frac{\partial SW}{\partial \delta} > 0$; $\frac{\partial CS}{\partial c} < 0$, $\frac{\partial SW}{\partial c} < 0$.

Price sensitivity increases consumer surplus and social welfare. In contrast, cost sensitivity decreases consumer surplus and social welfare. Production cost is not only the producer's cost, but it also impacts the spending of the consumer and society. So, the increase of cost sensitivity reduces consumer surplus and social welfare. Interestingly, the rise in price sensitivity improves consumer surplus and social welfare. Price sensitivity increasing means the upgrading of commodity under symmetric information. This study obtains the following proposition by comparing consumer surplus and social welfare.

Proposition 9 $CS^{sJ} < CS^{sI}$, $SW^{sJ} < SW^{sI}$; $CS^{iJ} > CS^{iI}$, $SW^{iJ} > SW^{iI}$.

Decision structure impacts consumer surplus and social welfare, while their relationships are influenced by capacity structure. Specifically, consumer surplus and social welfare of independent decision structure are higher than that of joint decision under sufficient capacity. But the situations are reversed if producers are confronted with capacity constraints. Thus, consumer surplus and social welfare of joint decision structure are higher than independent condition.

Extended analysis

The conclusions in the main results section are obtained by fixing the product substitutability and resource consumption rate, which means those conclusions do not consider the effects of competition sensitivity and efficiency sensitivity. So, this section will relax the constant assumption to capture the impacts of competition and conversion efficiency on firms' decision behaviors. To simplify the analysis process, we assign values to other parameters $\alpha = 10$ $R = 10/3$, $\delta = 7/4 > c = 5/4$. Market capacity α only has a level effect, and different values have no substantial impact on the conclusion. In contrast, the constraint boundary is assumed to the $\alpha/3$. So, we give 10 and 10/3 to α and *R*, respectively. Based on the assumption $1<c<\delta\leq 2$, we value δ and c 7/4 and 5/4.

The effects of competition. Competition intensity is no doubt the critical factor in the firm decision. Here, we derivate all the endogenous valuables γ to investigate the impact of competition intensity. The results are outlined in table 3. $\delta=1$ and $\delta>1$ represent asymmetric information and symmetric information. *SC* and *IC* mean sufficient and insufficient capacity, while IO and JO imply independent and joint decisions, respectively. <0 and >0 indicate monotonically decreasing and monotonically increasing. Finally, *U*-shape means decreasing first and increasing after a point.

Table 3: Derivation results of competition intensity

	$\delta=1$				$\delta>1$			
	SC		*IC*		*SC*		*IC*	
	IO	*JO*	*IO*	*JO*	*IO*	*JO*	*IO*	*JO*
$dq_l/d\gamma$	<0	<0	>0	>0	<0	<0	<0	<0
$dq_h/d\gamma$	<0	<0	<0	<0	<0	*U*-shape	>0	>0
$d\Delta q/d\gamma$	>0	>0	>0	>0	>0	>0	>0	>0
$dp_l/d\gamma$	<0	<0	<0	<0	<0	<0	<0	<0
$dp_h/d\gamma$	<0	<0	<0	<0	<0	*U*-shape	<0	<0
$d\Delta p/d\gamma$	<0	<0	<0	<0	<0	*U*-shape	>0	*U*-shape
$d\pi_l/d\gamma$	<0	<0	<0	<0	<0	<0	<0	<0
$d\pi_h/d\gamma$	<0	<0	<0	<0	<0	*U*-shape	<0	>0
$d\Delta\pi/d\gamma$	>0	>0	>0	>0	<0	*U*-shape	<0	>0
$dCS/d\gamma$	<0	<0	>0	>0	<0	*U*-shape	>0	>0
$dSW/d\gamma$	<0	<0	<0	<0	<0	*U*-shape	<0	*U*-shape

Table 3 shows that information structure, capacity condition, and decision structure significantly impact the effects of competition intensity. For example, under asymmetric information conditions, the increase of substitutes decreases low-quality products' insufficient capacity, but it will increase the low-quality product in low capacity cases. For the high-quality product, product substitutability reduces high-quality product quantity under asymmetric information. However, this relationship will inverse or become a *U*-shape relationship if the information is symmetric. Besides, symmetric information combined with sufficient capacity and the joint decision is unique because endogenous variables appear in U-shape relationships with competition intensity.

Furthermore, the increase of competition intensity enlarges the output gap. But competition narrow price gap only under asymmetric information condition. The relationships between price gap and competition intensity are complex for symmetric information because the relationships are just contrary between sufficient and insufficient capacity. In contrast, the U-shape relationships arise again if firms choose joint decisions. The competition always reduces low-quality producers' profits but increases high-quality firms' profits if firms agree to make a joint decision. Interestingly, we find that increased competition reduces consumer surplus for sufficient capacity cases. Oppositely, consumer surplus will improve by the increase of competition if capacity is insufficient. Unfortunately, competition decrease total welfare, and the only chance to change the result is to choose a joint decision under symmetric information. The conclusions about the relationships between competition and social welfare are different from other studies. A reasonable explanation is that this research involves exogenous quality competition, and greater competition is harmful to a high-quality producer, primarily in asymmetric information cases.

The effects of resource consumption rate. If firms produce with input capacity constraint, then the efficiency of input-output conversion is critical, and the resource allocation efficiency needs to be improved. The variable conversion efficiency of a high-quality product $\theta \in [1,3]$ is concerned here. The larger θ, the low-resource conversion efficiency is. Resource expenditure of the high-quality product is no less but no more than triple of the low-quality product. Furthermore, larger θ means higher cost *c*. The effects of θ are outlined in the following table (table 4).

Table 4: derivation results of resource consumption rate

	$\delta=1$		$\delta>1$	
	IO	*JO*	*IO*	*JO*
$dq_l/d\theta$	*U-shape*	*U-shape*	*U-shape*	*U-shape*
$dq_h/d\theta$	<0	<0	<0	<0
$d\Delta q/d\theta$	<0	<0	<0	<0
$dp_l/d\theta$	*Inverse U-shape*	*Inverse U-shape*	*Inverse U-shape*	*Inverse U-shape*
$dp_h/d\theta$	>0	>0	>0	>0
$d\Delta p/d\theta$	>0	>0	>0	>0
$d\pi_l/d\theta$	*U-shape*	*U-shape*	*U-shape*	*U-shape*
$d\pi_h/d\theta$	<0	<0	<0	<0
$d\Delta\pi/d\theta$	<0	<0	<0	<0
$dCS/d\theta$	*U*-shape	*U*-shape	*U*-shape	*U*-shape
$dSW/d\theta$	<0	<0	<0	<0

Notes: $\Delta q = q_h - q_l$ and $\Delta\pi = \pi_h - \pi_l$ for $\delta=1$, while $\Delta q = q_l - q_h$ and $\Delta\pi = \pi_l - \pi_h$ for $\delta>1$. Actually, Δ is the absolute value of the corresponding variable gap.

From table 4, we obtain the following conclusions.

(i) The relationship between low-quality product quantity and the resource consumption rate is U-shape, while high-quality product quantity decreases with the resource consumption rate.

(ii) The relationship between the low-quality product price and the resource consumption rate is inverse U-shape, while high-quality product price increases with the resource consumption rate.

(iii) Quantity gap, price gap, and profit gap between the high- and low-quality firm increases with the resource consumption rate.

(iv) The relationship between the low-quality firm's profits and the resource consumption rate is U-shape. In contrast, the profits of the high-quality firm decrease with the resource consumption rate.

(v) The relationship between consumer surplus and the resource consumption rate is U-shaped, but social welfare decreases with the resource consumption rate.

Figure 6 shows the numerical simulation between low-quality producer's quantity, price, profits, consumer surplus, and resource consumption rate.

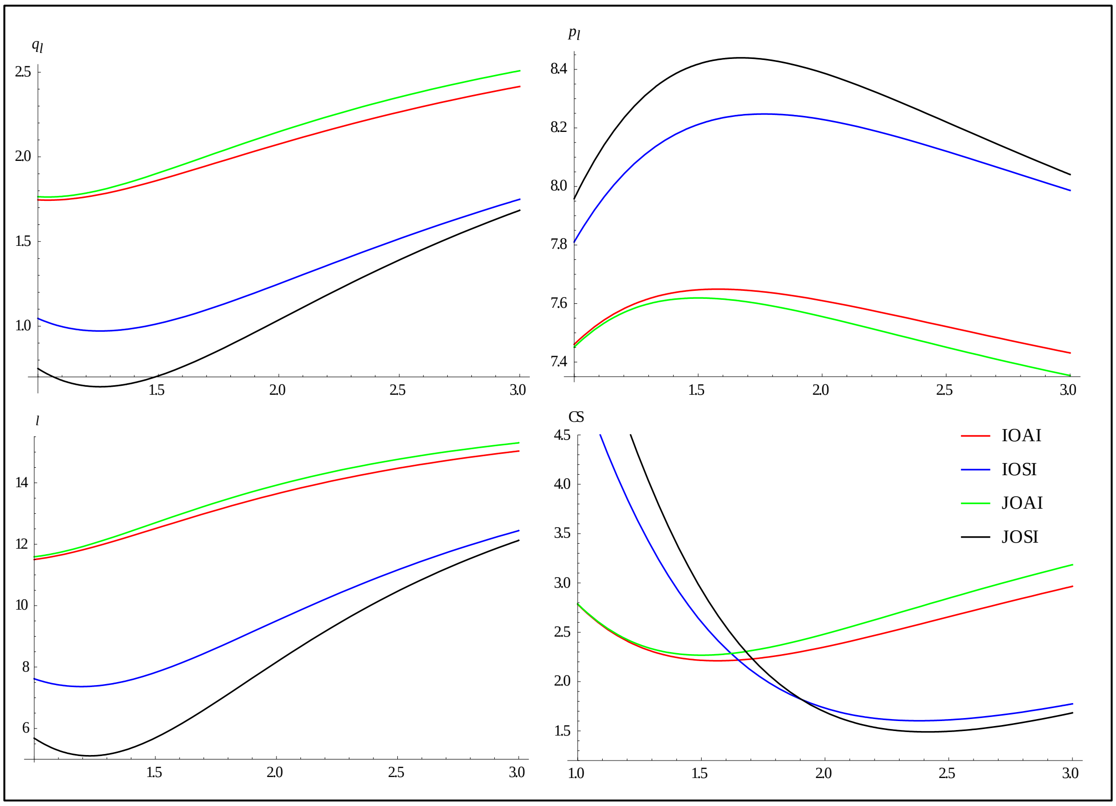

Figure 6: Numerical simulation results

Notes: IOAI, IOSI, JOAI and JOSI, represent independent decisions with asymmetric information, the independent decision with symmetric information, a joint decision with asymmetric information, and a joint decision with symmetric information, respectively.

The increase of resource consumption rate enlarges the competitive disadvantage of the high-quality producer because it raises its cost and price but low the profit. The low-quality firm can only benefit from the resource consumption rate when it exceeds the threshold value. *U*-shape between low-quality product quantity and resource consumption rate combined with inverse *U*-shape between low-quality product price leads to the U-shape between low-quality product profits and resource consumption rate. More interesting, although social welfare decreases with the increase of resource consumption rate, the rise in resource consumption rate will raise consumer surplus when it exceeds the threshold value. In other words, increasing resource consumption rate is bad for total social welfare but not always bad for the consumers.

Conclusions and discussions

The quality decision is a major theme in economics requiring more investigations. Most of the existing researches surveyed this issue based on the framework of information economics. The most significant contribution of this paper is to integrate capacity constraints and corporate decision-making structure into information asymmetry theory which is helpful to enrich quality decisions and information theory. We presented a study about quality decisions by considering eight different cases. Interestingly, numerous studies highlighted the empirical research while ignoring the theoretical foundation. However, this paper explained the significance of a theoretical study. Take the effects of resource consumption rate as an example. If only a narrow value range, such as 1 to 2, is investigated, most of the *U*-shape or inverse *U*-shape relationships revealed in this study will be mistaken for lineal. However, most data employed by empirical studies cannot show the overall sample characteristics. As a result, the conclusions in those papers will only be a particular case of the real world. Thus, theoretical model analysis is needed to capture the panorama of reality.

The findings of this paper show that the information structure, capacity constraints and decision structure have significant influences on firms' quality decisions. The exogenous variables of pricing sensitive cost-sensitive, product substitutability, and resource consumption rate impact the equilibrium solutions. More importantly, there are interactions between the decision-making conditions and the exogenous variables. The corresponding policy implication is that quality regulation is a quite complicated matter and the supervisors should full consider the effects of information conditions, capacity constraints and decision structures in the quality regulation-making, especially for those commodities impacting residents' daily health.

There are also some limitations to this paper. First, most decision variables of the producers vary simultaneously, but most of the conclusions of this paper are obtained by isolating the changes of different variables. Second, a variable (parameter) variation will affect another, but we ignore this co-movement. The increasing resource consumption rate of the high-quality product will raise its cost sensitivity. Third, an endogenous quality assumption will make more sense. Thus, the above limitations can be investigated in further study.

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