A general equilibrium analysis of food industry considering the food quality

Pu-Yan NIE[1], You-Hua CHEN[2]

[1]*Institute of Industrial Economics and Institute of Resources, Environment & Sustainable Development, Jinan University, Guangzhou, P.R. China*
[2]*College of Economics and Management and Guangdong Center for Rural Economic Studies, South China Agricultural University, Guangzhou, P.R. China*

Abstract: By establishing a dynamic equilibrium model, the paper analyses the equilibrium of the food industry and the equilibrium about the food quality as well as quantity is achieved. Firstly, the study examines the effects of competitions on the price, outputs, profits and social welfare. The authors argue that competition reduces the food quality. Secondly, this paper shows that consumers benefit from the quality regulation while producers undertake a loss. Moreover, social welfare first increases then decreases with the regulation. Thirdly, the optimal quality regulation is presented and a higher quality regulation reduces competition, while the lower quality regulation promotes it. Finally, the effects of fixed costs on the equilibrium number of firms in the corresponding industry are captured.

Key words: equilibrium number, fixed costs, game theory, quality regulation

Since the food relates to the life and nutrition of the people all over the world (Sibbel 2012), there exist extensive researches about the food industry, such as the technologies related to food, including producing and manufacturing food (Bruhn and Schutz 1999; Cushen et al. 2012), the management about the food supply (Diabat et al. 2012; Bosona and Gebresenbet 2013), the economic topics with food (Pinstrup-Andersen 2009; Anderson et al. 2013) and so on.

In the industrial organization community about the food industry, many literatures focus on the firms' strategies and governmental regulations. On the one hand, some authors investigated the effects of firms' strategies on the food industry. For instance, Kong (2012) addressed the relationship between the corporate social responsibility (CSR) and food quality. Triguero et al. (2013) examined the firms' innovation strategies of the Spanish agrifood industry. Sebastiani et al. (2013) illustrated the impacts of the firms' attitudes toward consumers on the food industry and gave some suggestions to food firms. On the other hand, governmental regulation attracts more and more attention. At the same time, numerous literatures consider the governmental subsidies. For example, Anderson et al. (2013) recently reviewed the research about governmental subsidies causing distortions about the food industry. Esmaeili et al. (2013) addressed the subsidy policy in Iran while Lofgren and El-said (1999) focused on the governmental subsidy in Egypt. There also exist some papers addressing other governmental policies. Scott (2013) highlighted the effects of the migrate policy in the UK on the food industry. Gavrel et al. (2012) identified the effects of the minimum wage policy on the fast-food industry and Pacheco (2012) recently examined the effects of the minimum wages on the food industry of New Zealand.

Regarding the researching tool, there are mathematical model approaches including the game theory approaches as well as the dynamic model technology (Carriquiry and Babcock 2007; Wissmann et al. 2012), the general equilibrium technologies (Lofgren and El-said 1999; Esmaeili et al. 2013), the nature experiment (Kong 2012) and the empirical research (Sebastiani et al. 2013; Scott 2013; Triguero et al. 2013).

Notice that food safety is a serious problem in China along with other developing countries or even in some developed countries, food quality has become a

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mainstream business activity throughout of the globe. In other words, quality is very important in the food industry. So taking quality into consideration, this paper employs the equilibrium analysis to discuss the food industry by a two-stage dynamic model. Moreover, the quality regulation is analysed and the optimal quality regulation is represented. Under the quality regulation, the equilibrium number of firms is also achieved.

The rest of this paper is organized as follows: The dynamic model is established in The model. At the first stage, firms jointly determine the food quality and then they take the quantity competition at the second stage. The model analyses are given in section The model. The effects of the competition on outputs, equilibrium quality are all obtained. Then the model is extended in section Main results. On the one hand, the regulated quality is introduced and the optimal quality is achieved. On the other hand, the fixed costs to enter this industry are investigated and the effects of the fixed costs on the equilibrium number of firms are considered. Finally, the conclusions are remarked.

THE MODEL

Here we establish the general equilibrium model about the food industry. Note that the food industry is such an industry which is close to a perfect competition industry. So this paper assumes that there are N firms in the food industry and there exists no difference between the firms' products. Denote the firms to be $k \in \{1, 2, \cdots, N\}$ and N ≥ 2. The corresponding price is p and the quantity of the firm k is q_k, while $x > 0$ indicates the quality of the food in this industry.

DEMAND

Given the quality of the food x, the price p and the firm k's quantity q_k, for $k \in \{1, 2, \cdots, N\}$, the inverse demand for the food industry is presented by (1)

$$p = (1 + x) - \sum_{j=1}^{N} q_j \tag{1}$$

where the market size is the exact one. Function (1) means that the inverse demand is linear about the outputs of firms along with the quality of the food. Moreover, the price increases with the quality of the food, but decreases with the total outputs. This is consistent with the reality in the food industry as well as other industries. Furthermore, for the competition attribute of the food industry, we assume that there exists no difference of the quality for the firms' products in the food industry. Therefore, it is rational to assume that all firms' quality is x.

Producers

Here we model the firms. Given the quantity q_k and the quality of the food x, firm k maximizes its profits as follows

$$\max_{q_k} \pi_k = [(1 + x) - \sum_{j=1}^{N} q_j] q_k - c(q_k, x) \tag{2}$$

In function (2), the former term $[(1 + x) - \sum_{j=1}^{N} q_j] q_k$ stands for the revenues of the firm k and the latter $c(q_k, x)$ is the costs of the firm k. To simplify, this paper always employs the quadratic cost function or $c(q_k, x) = \frac{1}{2} x q_k + \frac{1}{2} x^2$ and that is a general assumption at other studies such as D'Aspremont and Jacquemin (1988), Nie and Chen (2012), Sacco and Schmutzer (2012). Furthermore, we assume that the costs of firms are symmetric for all firms.

The timing table of this game is outlined as follows: At the first stage, the firms jointly or cooperatively determine the quality of the food. At the second stage, the firms compete at quantity.

MAIN RESULTS

Here we will discuss the base model set up at the section The Model and we analyse the model by the backward induction strategies. At the second stage, given the quality of the food x, the firms determine the outputs by (2). Therefore, we have

$$q_i = \frac{1 + 0.5x}{N + 1} \tag{3}$$

Then, we solve the model at the first stage. At the first stage, the firms jointly determine the quality following the maximized profit principle. Substituting (3) into (2), we have the following producer surplus

$$\sum_{k=1}^{N} \pi_k = N\left(\frac{1 + 0.5x}{N + 1}\right)^2 - \frac{Nx^2}{2} \tag{4}$$

Obviously, (4) is concave in x. So there exists the unique solution for (4). By the first order optimal condition of (4), we achieve

$$x^* = \frac{1}{(N+1)^2 - 0.5} \quad (5)$$

Substituted (5) into (3), we have the corresponding outputs

$$q_k^* = \frac{1 + \frac{1}{2(N+1)^2 - 1}}{N+1} = \frac{2(N+1)}{2(N+1)^2 - 1} \quad (6)$$

Therefore, the total outputs in this food industry are

$$\sum_{k=1}^{N} q_k^* = \frac{2N(N+1)}{2(N+1)^2 - 1} \quad (7)$$

The corresponding price is given by

$$p^* = 1 + \frac{2}{2(N+1)^2 - 1} - \frac{2N(N+1)}{2(N+1)^2 - 1} = \frac{2(N+1)+1}{2(N+1)^2 - 1} \quad (8)$$

The consumer surplus is

$$CS^* = \frac{1}{2}\left(\sum_{k=1}^{N} q_k^*\right)^2 = \frac{1}{2}\left[\frac{2N(N+1)}{2(N+1)^2 - 1}\right]^2 \quad (9)$$

And the profits are presented as follows

$$\pi_k^* = (q_k^*)^2 - \frac{1}{2}(x_k^*)^2$$
$$= \left[\frac{2(N+1)}{2(N+1)^2 - 1}\right]^2 - \frac{1}{2}\left[\frac{2}{2(N+1)^2 - 1}\right]^2 \quad (10)$$
$$= \frac{2}{2(N+1)^2 - 1}$$

By (5)–(9) and according to comparative static analysis approach, we immediately have the following conclusion.

Proposition 1. The food quality decreases with the number of firms. Moreover, each firm's outputs as well as the price of food also decrease with the number of firms. Contrarily, the total outputs and the consumer surplus all increase with the number of firms.

Proof: See in the Appendix.

Remarks: In the classic equilibrium analysis, the outputs of each firm and the price of the outputs all decrease with competition, which means that the conclusion above is consistent with the existing results for the outputs. The difference is that we examine the classic results by taking the quality into account. Moreover, we achieve the relationship between the food quality and competition. Interestingly, our results illustrate that competition lowers the quality of food.

Since the quality of food relates to the life of all people and it has crucial effects on the whole society, the policy implication is that the government should restrict the entrants to maintain the food quality.

Further, we will consider the firms' profits. The total profits (or the producer surplus) in this industry are

$$PS^* = \sum_{k=1}^{N} \pi_k^* = \frac{2N}{2(N+1)^2 - 1} \quad (11)$$

The corresponding social welfare is

$$SW^* = CS^* + PS^*$$
$$= N\left(\frac{N}{2} + 1\right)\left[\frac{2(N+1)}{2(N+1)^2 - 1}\right]^2 - \frac{1}{2}\left[\frac{1}{(N+1)^2 - \frac{1}{2}}\right]^2 \quad (12)$$

By the envelopment theorem, for (9), (10) and (11), we immediately have

Proposition 2. Each firm's profits and the producer surplus all decrease with the number of firms but the social welfare increases with the number of firms.

Proof: See in Appendix

Remarks: The above proposition presents the relationship between the number of firms and the profits along with the producer surplus. The increasing effect of the number of firms on the producer surplus is larger than the decreasing effect of the consumer surplus which guarantees the result that the social welfare increases with the number of firms.

In this section, the effects of the number of firms on the food industry are captured. Some classic conclusions, including the relationship between the competition and the quantity, the consumer surplus as well as profits, are achieved. Besides, we find that competition reduces the food quality.

FURTHER DISCUSIONS

In this section, we further discuss the benchmark model in the section The Model. On the one hand, we address the effects of the regulation on the food industry. On the other hand, compared with the entry-free situation in the section The Model, we further consider the case with fixed-costs to enter.

Quality regulation

Quality regulation is common in the food industry all over the world. Based on that reality, we assume that there exists a quality regulation satisfying $x \geq x_0$, where $x_0 > 0$ is a constant representing the regulated food quality. If $x_0 \le x^*$, the equilibrium under the quality regulation is exactly the same as that in Section 3, or the quality regulation is inoperative. So here we assume that $x_0 > x^*$. By the similar approach to that in the section Main Results, we have the following equilibrium solution and the equilibrium value

$$x^{r,*} = x_0, q_k^{r,*} = \frac{2+x_0}{2(N+1)} \quad p^{r,*} = \frac{2+(2+N)x_0}{2(N+1)}. \tag{13}$$

$$\pi_k^{r,*} = \left[\frac{2+x_0}{2(N+1)}\right]^2 - \frac{1}{2}x_0^2 \quad CS^{r,*} = \frac{1}{2}\left(\frac{2N+Nx_0}{2(N+1)}\right)^2. \tag{14}$$

$$PS^{r,*} = N\left[\frac{2+x_0}{2(N+1)}\right]^2 - \frac{N}{2}x_0^2 \tag{15}$$

$$SW^{r,*} = N\left[\frac{2+x_0}{2(N+1)}\right]^2 - \frac{N}{2}x_0^2 + \frac{1}{2}\left(\frac{2N+Nx_0}{2(N+1)}\right)^2 \tag{16}$$

Compared (13)–(16) with (5)–(12), we have the following conclusions.

Proposition 3. The quality regulation improves the quality, outputs, the consumer surplus and the price, while it reduces the firms' profits and the producer surplus.

Proof. See in the Appendix.

Remarks: The above proposition characterizes the effects of the quality regulation. The consumers benefit from the quality regulation while the quality regulation damages the producers.

The quality regulation promotes the consumer surplus, but it reduces the producer surplus, oppositely. For the social welfare (or the combined consumer surplus with the producer surplus), we have the following conclusions:

Proposition 4. A lower quality regulation improves the social welfare, while a higher quality regulation reduces the social welfare. Under maximizing the social welfare, the optimal quality is

$$x^{0,*} = \frac{2(N+2)}{N(4N+7)+2}. \tag{17}$$

Proof: See in the Appendix.

Remarks: We argue that there exists a threshold value such that the social welfare is reduced if the regulation quality is higher than this threshold value. In other words, the social welfare first increases but then decreases with the regulation. Or, there exists an inversely U-shaped relationship between the social welfare and the quality regulation.

The policy implication of Proposition 4 is that the regulated quality should not be larger than the above threshold value. Moreover, the social optimal regulated quality is given by (17), which is useful for the decision-makers.

Our results show that the quality under competition is lower than that of the social optimal because of the relationship $x^{0,*} = \frac{2(N+2)}{N(4N+7)+2} \ge x^*$. Furthermore, the optimal quality regulation decreases with the number of producers. Under the optimal regulation, all firms earn positive profits because substituting (17) into (14) yields the following formulation

$$\pi_k^{r,*}\Big|_{x^0=x^{0,*}} = \frac{2[8(N+1)^2-(N+2)^2]}{(4N^2+7N+2)^2} > 0.$$

Under the extreme situation, we have $\lim_{N\to\infty} x^{0,*} = \lim_{N\to\infty} x^* = 0$ When there exist too many firms in this food industry (or if in this industry, there is free competition), the optimal policy is not regulation.

Here we address the effects of the quality regulation on the number of producers in the food industry. If the quality regulation is too high, some firms are forced to quit this industry under the free entry.

Equation (14) yields $\pi_k^{r,*} = \frac{1}{(N+1)^2} + \frac{x_0}{(N+1)^2} - \frac{1}{2}x_0^2[1-\frac{1}{2(N+1)^2}]$. The valid root of $\pi_k^{r,*} = \frac{1}{(N+1)^2} + \frac{x_0}{(N+1)^2} - \frac{1}{2}x_0^2[1-\frac{1}{2(N+1)^2}] = 0$ is $N = \frac{\sqrt{2}}{2} + \frac{\sqrt{2}}{x_0} - 1$. Denote the integer part of the term $N = \frac{\sqrt{2}}{2} + \frac{\sqrt{2}}{x_0} - 1$ to be $J = \text{int}(\frac{\sqrt{2}}{2} + \frac{\sqrt{2}}{x_0} - 1)$. The equilibrium number of the producers under the quality regulation is $J = \text{int}(\frac{\sqrt{2}}{2} + \frac{\sqrt{2}}{x_0} - 1)$. If $N > J$, the firms earn negative profits and some firms will quit this industry. Otherwise, the firms earn positive profits. Moreover, we have:

Proposition 5. A higher quality regulation yields less than the equilibrium number of producers, while a lower quality regulation yields the more than the equilibrium number of producers.

Proof: See in the Appendix.

Remarks: Interestingly, we proved that there is a relationship between the quality regulation and the equilibrium number of the producers in the food industry. Proposition 5 shows that the regulated quality can determine the equilibrium number of firms in the food industry.

The policy implication of the above conclusions is to launch the exact quality criterion to maintain the competition in the food industry. Too high quality regulation will cause some firms to quit in this industry.

In this subsection, we remark on the quality regulation and present the optimal quality regulation of the food industry. Moreover, the effects of the quality regulation are also characterized.

Fixed costs to enter

We also note fixed costs in some sub- food processing or the production industries such as juice production and milk processing industries. In those industries, fixed costs have major impacts on the competition. So we will expand our base model with fixed costs. When the fixed costs entering into this industry are introduced, this study addresses the equilibrium correspondingly.

Assume the fixed costs to enter this industry to be $F_0 > 0$. With the inverse demand function (1) and the food quality x, for $k \in \{1, 2, \cdots, N\}$, the firms' profit maximization problem is outlined as follows

$$\underset{q_k}{Max}\, \pi_k = [(1+x) - \sum_{j=1}^{N} q_j] q_k - c(q_k, x) - F_0 \qquad (18)$$

The equilibrium of this industry with fixed costs is the same as that in the section Main Results. For $k \in \{1, 2, \cdots, N\}$, the profits of the firms are

$$\pi_k^{F,*} = \frac{2}{2(N+1)^2 - 1} - F_0 \qquad (19)$$

By (19), taking into consideration the fixed costs to enter, the equilibrium number of the firms in this industry is the integer part of the following formulation

$$N = \sqrt{\frac{1}{2} + \frac{1}{F_0}} - 1 \qquad (20)$$

Denote

$$J = \text{int}(\sqrt{\frac{1}{2} + \frac{1}{F_0}} - 1) \qquad (21)$$

By (21), we immediately have the following conclusion and the proof is based on the above analysis.

Proposition 6. With fixed costs $F_0 > 0$, the equilibrium number of firms is given by (21).

Remarks: (21) indicates the following facts: If $N > J$, the firms' profits are negative and some firms will quit this industry. If $N < J$, other firms have the intention to enter into this industry. The conclusions of Proposition 5 combined with that of Proposition 6 implies that fixed costs have similar effects to the quality regulation on the equilibrium number of the firms.

Moreover, the equilibrium number of firms decreases with the value of the fixed costs because of $\frac{\partial J}{\partial F} < 0$. Therefore, the fixed costs determine the equilibrium number in the food industry. As an extreme case, when the fixed costs are large enough, no firms are willing to enter this industry. The policy implication is to improve the entering threshold (or to increase the fixed costs) to restrict the number of firms in this food industry.

In this section, we discuss the quality regulation of the government and analyse the effects of the quality regulation. Moreover, the effects of the fixed costs are investigated.

CONCLUSION

The paper addresses the food industry with the equilibrium analysis approaches. The effects of the number of firms on the equilibrium are characterized under free-entry. Then, the quality regulation is considered and the social optimality quality is given. Surprisingly, there exists an inversely U-shaped relationship between the social welfare and the regulated quality. Under fixed costs, the equilibrium number of firms is presented, too.

Our conclusions characterize the food quality, competition and the quality regulation based on the equilibrium methods. As we known, it is the first time to introduce the quality in the equilibrium model to address the food industry.

Compared with the existing equilibrium model about the food industry, Esmaeili et al. (2013) and Lofgren and El-said (1999) all focused on the governmental subsidy, while this paper pays attention to the quality regulation in the food industry. Carriquiry and Babcock (2007) also investigated the food quality by the reputation model, in which both the model and the conclusions are all different from this study. Carriquiry and Babcock (2007) thought that the reputation plays an important role under the incomplete information while this paper considers the complete information.

APPENDIX

Proof of Proposition 1

By (5) and (6), we immediately achieve that the food quality as well as each firm's outputs decreases with the number of the firms. (7) indicates that

$$\sum_{k=1}^{N} q_k^* = \frac{2N(N+1)}{2(N+1)^2-1} = 1 - \frac{2(N+1)-1}{2(N+1)^2-1}$$

Therefore, both the total outputs and the consumer surplus are increased with the number of firms. From (8), we immediately have that the price of the food decreases with the number of the firms.

Conclusions are achieved and the proof is complete.

Proof of Proposition 2

By function (10), we have that each firm's profits decrease with the number of firms. And (11) indicates that the producer surplus also decreases with the number of firms for any non-negative integer N.

Here we consider the social welfare. According to (12), we have

$$SW^* = \frac{N^2}{2}[\frac{2(N+1)}{2(N+1)^2-1}]^2 + \frac{2N}{2(N+1)^2-1} = 2(N+1)^2 N^2 [\frac{1}{2(N+1)^2-1}]^2 + \frac{2N}{2(N+1)^2-1}.$$

$$\frac{\partial SW^*}{\partial N} = 4(N+1)N(2N+1)[\frac{1}{2(N+1)^2-1}]^2 - \frac{4(N+1)^2N^2}{2(N+1)^2-1}\frac{4(N+1)}{[2(N+1)^2-1]^2} - \frac{4(N-1)(N+1)+2}{[2(N+1)^2-1]^2}$$

$$= \frac{4(N+1)}{[2(N+1)^2-1]^3}\{(2N^2+1)[2(N+1)^2-1] - 4(N+1)^2N^2\} - \frac{2}{[2(N+1)^2-1]^2}$$

$$= \frac{4(N+1)}{[2(N+1)^2-1]^3}\{2(N+1)^2 - (2N^2+1)\} - \frac{2}{[2(N+1)^2-1]^2}$$

$$= \frac{4(N+1)}{[2(N+1)^2-1]^3}(4N+1) - \frac{2}{[2(N+1)^2-1]^2} > 0.$$

Conclusions are achieved and the proof is complete.

Proof of Proposition 3

From $x_0 > x^*$, (5)-(6) and (13) indicate $x^{r,*} > x^*, q_k^{r,*} > q_k^*$. While $q_k^{r,*} > q_k^*$ implies $CS^{r,*} > CS^*$. From $p^{r,*} = \frac{1+(1+0.5N)x_0}{N+1}$ and $p^* = \frac{1+(1+0.5N)x^*}{N+1}$, $x^{r,*} > x^*$ yields $p^{r,*} > p^*$. Thus, the quality regulation improves the quality, the outputs as well as the consumer surplus and the price.

For the profit function $\pi_k = \frac{1+0.5x}{N+1}\frac{1+0.5x}{N+1} - \frac{1}{2}x^2$, (14) and (10) imply $\left.\frac{\partial \pi_k}{\partial x}\right|_{x=x_0} > 0$ and $\left.\frac{\partial \pi_k}{\partial x}\right|_{x=x^*} = 0$. The concavity of the profit function indicates $\pi_k^{r,*} < \pi_k^*$. $\pi_k^{r,*} < \pi_k^*$ yields $PS^{r,*} > PS^*$. Therefore, the quality regulation reduces the firms' profits and the producer surplus.

Conclusions are achieved and the proof is complete.

Proof of Proposition 4

By (12) and (16), we have

$$SW^{r,*} - SW^* = N[\frac{1+0.5x_0}{N+1}\frac{1+0.5x_0}{N+1} - \frac{1}{2}x_0^2] + \frac{1}{2}(\frac{N+0.5Nx_0}{N+1})^2 - N[\frac{1+0.5x^*}{N+1}\frac{1+0.5x^*}{N+1} - \frac{1}{2}(x^*)^2] - \frac{1}{2}(\frac{N+0.5Nx^*}{N+1})^2$$

$$= 0.5N(x^*-x_0)(x^*+x_0) + \frac{1}{2(N+1)}(N+\frac{1}{2}N^2)(\frac{1+0.5x_0}{N+1} + \frac{1+0.5x^*}{N+1})(x_0 - x^*)$$

$$= 0.5N(x_0 - x^*)[\frac{1+\frac{1}{2}N}{N+1}\frac{2+0.5(x^*+x_0)}{N+1} - (x^*+x_0)]$$

$$= 0.5N(x_0 - x^*)\{\frac{2+N}{(N+1)^2} + [\frac{2+N}{2(N+1)^2} - 1](x^*+x_0)\}$$

$$= \frac{0.5N}{2(N+1)^2}(x_0 - x^*)\{\frac{(4+2N)[2(N+1)^2-1]-(4N^2+6N)}{2(N+1)^2-1} - (2N^2+3N)x_0\}$$

Therefore, $SW^{r,*} \geq SW^*$ for $x_0 \leq \frac{4+2N}{2N^2+3N} - \frac{2}{2(N+1)^2-1}$. Otherwise, $SW^{r,*} \leq SW^*$.

We further discuss the optimal regulated quality. From (16), we have that the social welfare function $SW^{r,*} = N(1+\frac{1}{2}N)(\frac{1+0.5x_0}{N+1})^2 - \frac{N}{2}x_0^2$ is strictly concave. The critical point, which is also the optimal regulated quality by government, is $x^{0,*} = \frac{2(N+2)}{N(4N+7)+2}$.

Conclusions are achieved and the proof is complete.

Proof of Proposition 5

According to the formulation of the equilibrium number of firms $J = \text{int}(\frac{\sqrt{2}}{2} + \frac{\sqrt{2}}{x_0} - 1)$ and since $\frac{dJ}{dx_0} < 0$, this conclusion is achieved directly.

Conclusions are achieved and the proof is complete.

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Contact address:

You-Hua Chen, College of Economics & Management, South China Agricultural University, Guangzhou, 510642, P.R. China
e-mail: chenyhua214@163.com