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Asymmetric competition in food industry with product substitutability

Yong-cong YANG[1], Pu-yan NIE[2]

[1]Guangdong University of Foreign Studies, Guangzhou, P.R. China
[2]School of Finance, Collaborative Innovation Center of Scientific Finance & industry, Guangdong University of Finance & Economics, Guangzhou, P.R. China

Abstract: The paper analyses the effects of asymmetric competition on food industry with product substitutability by establishing a two-stage dynamic game model. The equilibrium is captured under both the Cournot competition and Stackelberg competition. Firstly, under the Cournot competition, lower costs yield a higher quality, more outputs and higher profits. Secondly, the cost difference increases the quality difference, the market size difference and the profit difference. Thirdly, a U-shaped relationship between the product substitutability and the food quality exists. Finally, compared with the case under the Cournot competition, the food security is significantly reduced with the lower quality and less outputs in the case under the Stackelberg competition.

Keywords: food quality, game theory, non-cooperative, product substitutability

Food security closely relates to both the food quality and food quantity (Bruhn and Schutz 1999; Pinstrup-Andersen 2009; Nie and Chen 2014). Many factors determine the food security and there is much literature to address this issue. Firstly, some authors focus on the food security under natural conditions. For example, Tirado et al. (2010) remarked the relationship between climate change and food security. Hessen et al. (2002) identified the relationship between the grazer performance and food security. Secondly, some researchers capture the effects of the technology and management on the food security. For instance, Diagne et al. (2013) recently addressed the irrigate rice productivity on the food quality.

Meanwhile, some papers analyse the food security in economics. Unnevehr et al. (2010) considered the food quality with the economic method. Brewster and Goldsmith (2007) investigated the effects of the laws on food quality by comparison of the U.K. and the U.S. Nie (2014) recently considered the corporate social responsibility (CSR) in the food industry. Hoffmann (2005) described the relationship between the ownership structure and the endogenous quality choice of the food industry. Traill (1997) examined the effects of the globalization on the supply and the quality for food industries. Chaddad and Mondelli (2013) identified that the specific strategies of firms have effects on the firms' performance in the food industry.

However, the literature related to the food security seldom takes substitutability into consideration. As we know, there exists a high degree of product substitutability in the food industry, while food producers are always asymmetric. So, what are the effects of the asymmetric competition on the food security? How about the welfare implications of the competition in the food industry with product substitutability?

To address the two issues mentioned above, we further develop food security in economics and focus on the food quality and quantity by employing a two-stage game theory model. In the first stage, firms commit the food quality. At the second stage, firms compete in the food quantity. In the analyses of the food industry, we resort to the classic model of Dixit (1979), Sheshinki (1976), Matsubayashi and Yamada (2008), and, Berry and Waldfogel (2010), in which both the quality and the quantity are simultaneously considered for an industry. Moreover, we consider both the Cournot competition and Stackelberg competition, and we compare the equilibrium under the two situations.

The findings of the research reveal that, under Cournot competition, there exists a U-shaped relationship between product substitutability and food quality, while firms benefit from lower production

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cost as food quality and quantity increase. Conversely, the Stackelberg case reduces both the food quality and social welfare. That is, the Cournot competition strengthens food security but the Stackelberg competition does harm to it.

Berry and Waldfogel (2010) examined the effects of the market size on the quality and found that this relationship depends on the properties of products. They found that for the restaurant industry, in which the quality is produced largely with variable costs, the range of qualities on offer increases with the market size. In the industry of daily newspapers, where quality is produced with fixed costs, the average quality of products increases with the market size, but the market does not offer much additional variety as it grows large. In the empirical research Berry and Waldfogel (2010), the market sizes are exogenous and found that the conclusions are consistent with the endogenous product quality.

Compared with the existed conclusions in the food industry, this paper simultaneously focuses on the food quality and quantity. Moreover, this paper captures the effects of the first-move on food industry. Besides, the product substitutability is also considered and the effects of the product substitutability on the food industry are characterized.

Unlike Berry and Waldfogel (2010), this paper assumes that both quality and the market size are endogenous. Moreover, we specially consider the food industry. We establish the dynamic game model, while Dixit (1979), Gal-Or (1983), Sheshinki (1976), and, Matsubayashi and Yamada (2008) all employed the static game model. Actually, the dynamic model seems more rational.

MODEL

Taking product substitutability into account, here we establish the duopoly model related to food quality. There are two producers in this food industry, which are denoted $i \in \{1,2\}$. The unique products for the two firms are food. The firms' quality of products is correspondingly denoted $x = (x_1, x_2)$, where x_1 is the first firm's quality and x_2 denotes food quality of the second firm. Similarly, the corresponding quantity is $q = (q_1, q_2)$ along with the price $p = (p_1, p_2)$. Then, we address the functions of the utility-maximizing consumers as well as the profit-maximizing producers.

Consumers Given $x = (x_1, x_2)$, $q = (q_1, q_2)$ and $p = (p_1, p_2)$ with $x_1 > 0$ and $x_2 > 0$, here we introduce the utility function of the representative consumer as follows

$$u(q,x) = x_1q_1 + x_2q_2 - p_1q_1 - p_2q_2 - \frac{1}{2}(q_1^2 + q_2^2) - \gamma q_2q_1 \quad (1)$$

where $\gamma \in [0, 1]$ stands for the product substitutability (Liu and Wang 2013). For $i, j = 1, 2, i \neq j$, the corresponding inverse demands are

$$p_i = x_i - q_i - \gamma q_j \quad (2)$$

(2) indicates that the price increases with the quality while decreasing with both the quantity of its products and the outputs of the rival's. The consumer surplus is

$$CS = \frac{1}{2}(q_1^2 + q_2^2) + \gamma q_2q_1 \quad (3)$$

Producers. Here we model two producers. For $i = 1, 2$, the profit functions are given

$$\pi_i = p_iq_i - c_i(q_i, x_i) \quad (4)$$

where the term p_iq_i is the revenue and $c_i(q_i, x_i)$ is the costs of the firm. This paper assumes that

$$c_i(q_i, x_i) = \frac{c_i}{2}q_ix_i + \frac{x_i^2}{2} + \frac{1-x_i}{4} - \frac{1}{4}.$$

The formulation of the cost function means that the costs depend on the food quality and outputs. Apparently, a higher quality and more quantity of food result in a higher production cost. The introduction of the quadratic term of quality guarantees that the cost function is concave. Without loss of generality, we further assume $c_2 = c_1 + \tau$, where $\tau \geq 0$, $c_1 \geq 0$ and $2 \geq c_2 \geq 1$.

The timing of the two-stage dynamic game is: At stage 1, the two food producers decide the quality. Definitely, a higher food quality increases the costs while attracting more consumers. At stage 2, the two firms simultaneously determine the food quantity based on their product quality. In this game, we assume that the food quality is a type of complete information, which is acknowledged by both the producers and the consumers, while Orosel and Zauner (2011) assumed that the good's quality is unobservable to customers. That is, the two food producers engage in the quality competition at the first stage and the quantity competition at the second stage under the condition of complete information. As a result, though they act simultaneously in the two phases, the quality strategy of either one is observable to its competitor.

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PRIMARY ANALYSIS UNDER COURNOT COMPETITION

We address the above model (1)–(3) by the backward induction. Firstly, we consider the second stage. At the second stage, (4) is concave in the quantity and we have

$$\frac{\partial \pi_i}{\partial q_i} = x_i - 2q_i - \gamma q_j - \frac{c_i}{2}x_i = 0 \tag{5}$$

Therefore, from (5) we have

$$q_i = \frac{2x_i - c_i x_i - \gamma(x_j - \frac{c_j}{2}x_j)}{4-\gamma^2} \tag{6}$$

Substituting (6) into (4), we have

$$\pi_i = [\frac{2x_i - c_i x_i - \gamma(x_j - \frac{c_j}{2}x_j)}{4-\gamma^2}]^2 - \frac{1}{2}x_i^2 + \frac{x_i}{4} \tag{7}$$

Obviously, (7) is concave in x_i and there exists the unique solution.

$$\frac{\partial \pi_i}{\partial x_i} = 2[\frac{2x_i - c_i x_i - \gamma(x_j - \frac{c_j}{2}x_j)}{4-\gamma^2}]\frac{2-c_i}{4-\gamma^2} - x_i + \frac{1}{4} = 0 \tag{8}$$

To simplify the equations, we set $\Gamma_i = \frac{2-c_i}{4-\gamma^2}$. By calculation, the equilibrium is

$$x^* = (x_1^*, x_2^*) = (\frac{1-2\Gamma_2^2 - \gamma\Gamma_1\Gamma_2}{4(1-2\Gamma_1^2)(1-2\Gamma_2^2) - 4\gamma^2\Gamma_1^2\Gamma_2^2}, \frac{1-2\Gamma_1^2 - \gamma\Gamma_1\Gamma_2}{4(1-2\Gamma_1^2)(1-2\Gamma_2^2) - 4\gamma^2\Gamma_1^2\Gamma_2^2}). \tag{9}$$

Correspondingly, by (2), (6) and (7), we immediately achieve the formulations $q^* = (q_1^*, q_2^*)$, $p^* = (p_1^*, p_2^*)$ and $\pi^* = (\pi_1^*, \pi_2^*)$.

$$q^* = (q_1^*, q_2^*) = (\frac{\Gamma_1 - 2\Gamma_1\Gamma_2^2 - \frac{\gamma}{2}\Gamma_2 + \frac{\gamma^2}{2}\Gamma_1\Gamma_2^2}{4(1-2\Gamma_1^2)(1-2\Gamma_2^2) - 4\gamma^2\Gamma_1^2\Gamma_2^2}, \frac{\Gamma_2 - 2\Gamma_2\Gamma_1^2 - \frac{\gamma}{2}\Gamma_1 + \frac{\gamma^2}{2}\Gamma_2\Gamma_1^2}{4(1-2\Gamma_1^2)(1-2\Gamma_2^2) - 4\gamma^2\Gamma_1^2\Gamma_2^2}). \tag{10}$$

$$\begin{aligned} p^* = (p_1^*, p_2^*) &= (\frac{(2-c_1-2\gamma^2+\frac{\gamma^2 c_1}{2})x_1^* - \frac{\gamma}{2}(2-c_2)x_2^*}{4-\gamma^2}, \frac{(2-c_2-2\gamma^2+\frac{\gamma^2 c_2}{2})x_2^* - \frac{\gamma}{2}(2-c_1)x_1^*}{4-\gamma^2}) \\ &= \frac{1}{4-\gamma^2}(\frac{(2-c_1-2\gamma^2+\frac{\gamma^2 c_1}{2})(1-2\Gamma_2^2-\gamma\Gamma_1\Gamma_2) - \frac{\gamma}{2}(2-c_2)(1-2\Gamma_1^2-\gamma\Gamma_1\Gamma_2)}{4(1-2\Gamma_1^2)(1-2\Gamma_2^2) - 4\gamma^2\Gamma_1^2\Gamma_2^2}, \\ &\quad \frac{(2-c_2-2\gamma^2+\frac{\gamma^2 c_2}{2})(1-2\Gamma_1^2-\gamma\Gamma_1\Gamma_2) - \frac{\gamma}{2}(2-c_1)(1-2\Gamma_2^2-\gamma\Gamma_1\Gamma_2)}{4(1-2\Gamma_1^2)(1-2\Gamma_2^2) - 4\gamma^2\Gamma_1^2\Gamma_2^2}). \end{aligned} \tag{11}$$

$$\pi^* = (\pi_1^*, \pi_2^*) = ((q_1^*)^2 - \frac{1}{2}(x_1^*)^2 + \frac{1}{4}x_1^*, (q_2^*)^2 - \frac{1}{2}(x_2^*)^2 + \frac{1}{4}x_2^*). \tag{12}$$

By (9)–(12), we have the following conclusions:

Proposition 1. Under the Cournot competition, the firm with a higher efficiency offers more food with a higher quality and a higher price than its rival. Moreover, the first firm's profits are also higher than those of the second.

Proof. See in Appendix.

Remarks: Under the Cournot competition, the lower marginal costs yield a higher quality and more outputs. This is consistent with the significant empirical conclusions of Thatcher and Oliver (2001) for the information industry. On one hand, according to (2), more outputs have the reducing effects on the price. On the other hand, by (2), the higher quality has the stimulating effects on the price. For the first firm, these

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stimulating effects are larger than the corresponding reducing effects. The two effects jointly determine that the firm with a higher efficiency produces food with a higher quality and quantity, while its price is also higher than that of the rival. Moreover, the cost advantage yields higher profits. Therefore, the first firm's profits are also higher than those of the second.

The equilibrium is further addressed with the comparative static analysis. By (9), we have

$$x_1^* = \frac{1-2\Gamma_2^{\,2} - \gamma\Gamma_1\Gamma_2}{4-8\Gamma_1^{\,2} - 8\Gamma_2^{\,2} + 4(4-\gamma^2)\Gamma_1^{\,2}\Gamma_2^{\,2}} = \frac{1}{4} + \frac{\Gamma_1^{\,2}[2-(4-\gamma^2)\Gamma_2^{\,2}] - \gamma\Gamma_1\Gamma_2}{4-8\Gamma_2^{\,2} - 4\Gamma_1^{\,2}[2-(4-\gamma^2)\Gamma_2^{\,2}]}.$$

Given c_2, since $\Gamma_1^{\,2}[2-(4-\gamma^2)\Gamma_2^{\,2}] - \gamma\Gamma_1\Gamma_2$ decreases with c_1 while $4-8\Gamma_2^{\,2} - 4\Gamma_1^{\,2}[2-(4-\gamma^2)\Gamma_2^{\,2}]$ increases with c_1, there is $\frac{\partial x_1^*}{\partial c_1} \le 0$. Similarly, the relationship $\frac{\partial x_2^*}{\partial c_1} \ge 0$ holds. By the similar method, given c_1, $\frac{\partial x_1^*}{\partial c_2} \ge 0$ and $\frac{\partial x_2^*}{\partial c_2} \le 0$. Denote the quality difference to be $\Delta x^* = x_1^* - x_2^*$, the market size difference to be $\Delta q^* = q_1^* - q_2^*$ and the profit difference to be $\Delta\pi^* = \pi_1^* - \pi_2^*$. From the above analysis, we have $\frac{\partial \Delta x^*}{\partial \tau} \ge 0$. Similarly, we have $\frac{\partial \Delta q^*}{\partial \tau} \ge 0$ and $\frac{\partial \Delta \pi^*}{\partial \tau} \ge 0$. This is summarized as follows:

Proposition 2. The quality difference, the market size difference and the profit difference all increase with τ.

Remarks: The higher cost difference stimulates the quality, quantity and profits of the firm with the lower cost and deters the quality, quantity and profits of the firm with the higher cost. Therefore, the quality difference, the market size difference and the profit difference all increase with τ and the above conclusions hold.

The effects of the product substitutability are further considered. We have the following conclusions

Proposition 3. Under the Cournot competition, the relationship between the product substitutability and the food quality is U-shaped. For the small product substitutability, the product substitutability reduces the outputs. For the large product substitutability, product substitutability improves the outputs.

Proof. See in Appendix.

Remarks: Under the Cournot competition, we identify the U-shaped relationship between the product substitutability and the food quality. Under the small and the large product substitutability, the relationship between product substitutability and the outputs is captured. Interestingly, the effects of the small product substitutability on the outputs are exact contrary to those under the large product substitutability. For the other product substitutability, this relationship seems uncertain.

STACKELBERG CASES

Here we further address the above topic under the Stackelberg situation. When the first firm acts as the leader and the second firm plays the follower position, we discuss it as follows. Moreover, in our Stackelberg case, the two firms launch the Stackelberg competition at the first stage to commit the food quality, while it is a Cournot competition about the food quantity at the second stage.

The first firm as the leader

In this case, we also address it by the backward induction strategy. At the second stage, two firms launch the Cournot competition in the quality and we have (6) and (7). By the first stage of the Stackelberg game, solving the second firm's problem, we obtain

$$x_2 = \frac{1-4\gamma\Gamma_1\Gamma_2 x_1}{4(1-2\Gamma_2^{\,2})} \tag{13}$$

Substituting (13) into (7) for the first firm's profits, by the first optimal conditions, we immediately have

$$\frac{\partial \pi_1}{\partial x_1} = \{[\frac{1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}}{(4-\gamma^2)(1-2\Gamma_2^{\,2})}]^2(2-c_1)^2 - 1\}x_1 + \frac{1}{4} - \frac{1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}}{4(4-\gamma^2)^2(1-2\Gamma_2^{\,2})^2}\gamma(2-c_2)(2-c_1) = 0. \tag{14}$$

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Or the equilibrium is

$$x_1^{*,s1} = \frac{[(4-\gamma^2)(1-2\Gamma_2^{\,2})]^2 - [1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_2^{\,2})]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}]^2(2-c_1)^2} \tag{15}$$

and

$$x_2^{*,s1} = \frac{1}{4(1-2\Gamma_2^{\,2})}\{1-4\gamma\Gamma_1\Gamma_2 \frac{[(4-\gamma^2)(1-2\Gamma_2^{\,2})]^2 - [1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_2^{\,2})]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}]^2(2-c_1)^2}\}. \tag{16}$$

The corresponding outputs are

$$q_1^{*,s1} = x_1^{*,s1}\Gamma_1 - \frac{\gamma x_2^{*,s1}}{2}\Gamma_2 \tag{17}$$

$$q_2^{*,s1} = x_2^{*,s1}\Gamma_2 - \frac{\gamma x_1^{*,s1}}{2}\Gamma_1 \tag{18}$$

When the first firm plays the leading position, we can examine that Propositions 1–3 also hold. Comparing (15)–(16) with (9)–(10), we have

Proposition 4. $x_1^{*,s1} \le x_1^*$ and $x_2^{*,s1} \le x_2^*$. Moreover, $q_1^{*,s1} + q_2^{*,s1} \le q_1^* + q_2^*$.

Proof. See in Appendix.

Remarks: Under the Stackelberg competition in quality, when the firm with the high efficiency acts as the leader, it owns both the cost advantage and the first move advantage. We find that the first-move advantage reduces the food quality, while the cost advantage improves the food quality. Surprisingly, the leading position reduces the food quality and the total outputs. This comes from the fact that the effects of the first move advantage are more than those of the cost advantage. Moreover, as shown in (3), the reduction of outputs reduces the consumer surplus.

The second firm as the leader

We also discuss the case, in which the second firm plays the leading position while the first firm acts as the follower at the first stage to commit the quality. At the second stage, two firms compete in the quantity.

At the second stage, the two firms launch the Cournot competition in the quality and we have (6) and (7). By the first stage of the Stackelberg game, solving the first firm's problem, we have

$$x_1 = \frac{1-4\gamma\Gamma_1\Gamma_2 x_2}{4(1-2\Gamma_1^{\,2})} \tag{19}$$

Substituting (19) into (7) for the second firm's profits, by the first optimal conditions, we achieve

$$\frac{\partial \pi_2}{\partial x_2} = \{[\frac{1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}}{(4-\gamma^2)(1-2\Gamma_1^{\,2})}]^2(2-c_2)^2 - 1\}x_2 + \frac{1}{4} - \frac{1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}}{4[(4-\gamma^2)(1-2\Gamma_1^{\,2})]^2}\gamma(2-c_2)(2-c_1) = 0. \tag{20}$$

Or the equilibrium is

$$x_2^{*,s2} = \frac{[(4-\gamma^2)(1-2\Gamma_1^{\,2})]^2 - [1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_1^{\,2})]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]^2(2-c_2)^2}, \tag{21}$$

$$x_1^{*,s2} = \frac{1}{4(1-2\Gamma_1^{\,2})}\{1-4\gamma\Gamma_1\Gamma_2 \frac{[(4-\gamma^2)(1-2\Gamma_1^{\,2})]^2 - [1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_1^{\,2})]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]^2(2-c_2)^2}\}. \tag{22}$$

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The corresponding outputs are

$$q_1^{*,s2} = x_1^{*,s2}\Gamma_1 - \frac{\gamma x_2^{*,s2}}{2}\Gamma_2, \tag{23}$$

$$q_2^{*,s2} = x_2^{*,s2}\Gamma_2 - \frac{\gamma x_1^{*,s2}}{2}\Gamma_1. \tag{24}$$

When the first firm plays the leading position, we can examine that Proposition 1–3 also hold. Comparing (21)–(22) with (9)–(10), we have

Proposition 5. $x_1^{*,s2} \le x_1^*$ and $x_2^{*,s2} \le x_2^*$. Moreover, $q_1^{*,s2} + q_2^{*,s2} \le q_1^* + q_2^*$.

Proof. See in Appendix.

Remarks: Similarly, if the second firm plays the leading position, the leading position reduces the food quality and the total outputs. Therefore, the social welfare is also reduced correspondingly. Notice that the food security is mainly reflected in two aspects, namely the food quality and quantity. Therefore, the food security suffers as the food quality and production decrease.

We try to compare the equilibrium under the two cases, one is the first firm moves firstly at the beginning, and the other one is the second firm moves firstly at the beginning. The implication seems uncertain. For the second firm, by (21) and (16), we have

$$x_2^{*,s2} - x_2^{*,s1} = \frac{[(4-\gamma^2)(1-2\Gamma_1^{\,2})]^2 - [1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_1^{\,2})]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]^2(2-c_2)^2}$$

$$-\frac{1}{4(1-2\Gamma_2^{\,2})}\{1-4\gamma\Gamma_1\Gamma_2 \frac{[(4-\gamma^2)(1-2\Gamma_2^{\,2})]^2 - [1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_2^{\,2})]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}]^2(2-c_1)^2}$$

$$= \frac{[1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]^2(2-c_2)^2 - [1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_1^{\,2})]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_1^{\,2}]^2(2-c_2)^2} -$$

$$\frac{[2(2-c_2)^2 - \gamma(2-c_2)(2-c_1)][(4-\gamma^2)(1-2\Gamma_2^{\,2})]^2 - [2-(4-\gamma^2)\Gamma_2^{\,2} - \gamma^2][1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}](2-c_1)^2(2-c_2)^2}{4[(4-\gamma^2)^2 - 2(2-c_2)^2]\{[(4-\gamma^2)(1-2\Gamma_2^{\,2})]^2 - [1-\frac{1}{2}(4-\gamma^2)\Gamma_2^{\,2}]^2(2-c_1)^2\}}.$$

By the above formulation, we have $x_2^{*,s2} - x_2^{*,s1}\big|_{\gamma=0} > 0$ and $x_2^{*,s2} - x_2^{*,s1}\big|_{\gamma=1,c_1=c_2} < 0$.

CONCLUDING REMARKS

This paper addresses the asymmetric duopoly competition in the food industry. The effects of the product substitutability and the cost difference on the food quality, the quality difference and the market size difference are all captured. Interestingly, we find that the first-move reduces food quality. Compared with the case under the Cournot competition, the food security is significantly reduced in the case under the Stackelberg competition.

Unlike the empirical research of Berry and Waldfogel (2010), this paper addresses endogenously the quality and the market size. Resorted to the significant idea of Dixit (1979) and Sheshinski (1976), we first analyse both the food quality and quantity from the industrial organization approaches. Moreover, some interesting conclusions are achieved when we compare the Cournot case with the Stackelberg situation. This conclusion is helpful for the decision-makers. The policy implication is to encourage the competition in the food industry to improve the food quality. Also, the government should conduct the Cournot competition instead of the Stackelberg competition in the food industry to strengthen the food security.

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APPENDIX

Proof of Proposition 1

From $c_1 \le c_2$, we immediately achieve $x_1^* \ge x_2^*$. The relationships $c_1 \le c_2, x_1^* \ge x_2^*$ and (6) yield that $q_1^* \ge q_2^*$. From $c_1 \le c_2, x_1^* \ge x_2^*$, the relationship $p_1^* \ge p_2^*$ comes from the formulation

$$(p_1^*, p_2^*) = \left(\frac{(2-c_1-2\gamma^2+\frac{\gamma^2 c_1}{2})x_1^* - \frac{\gamma}{2}(2-c_2)x_2^*}{4-\gamma^2}, \frac{(2-c_2-2\gamma^2+\frac{\gamma^2 c_2}{2})x_2^* - \frac{\gamma}{2}(2-c_1)x_1^*}{4-\gamma^2}\right)$$

Here we show $\frac{1}{2} > x_1^*$. From (9), $c_1 \ge 1$ and $2 \ge c_2 \ge 1$, we have

$$x_1^* = \frac{1-2\Gamma_2{}^2-\gamma\Gamma_1\Gamma_2}{4(1-2\Gamma_1{}^2)(1-2\Gamma_2{}^2)-4\gamma^2\Gamma_1{}^2\Gamma_2{}^2} = \frac{1-2\Gamma_2{}^2-\gamma\Gamma_1\Gamma_2}{4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2} \le \frac{1}{4-\frac{8+8}{(4-1)^2}} < \frac{1}{2}.$$

Therefore, $\frac{1}{2} > x_1^*$. $\frac{1}{2} > x_1^*$ and $x_1^* \ge x_2^*$ indicate $\frac{1}{2} > x_1^* \ge x_2^*$. For the equilibrium profits, we have

$$\pi^* = (\pi_1^*, \pi_2^*) = (q_1^2 - \frac{1}{2}(x_1^*)^2 + \frac{1}{4}x_1^*, q_2^2 - \frac{1}{2}(x_2^*)^2 + \frac{1}{4}x_2^*) = (q_1^2 - \frac{1}{2}(x_1^* - \frac{1}{2})^2 + \frac{1}{8}, q_2^2 - \frac{1}{2}(x_2^* - \frac{1}{2})^2 + \frac{1}{8}).$$

$\frac{1}{2} > x_1^* \ge x_2^*$ and $q_1^* \ge q_2^*$ jointly indicate that $\pi_1^* \ge \pi_2^*$.

Proposition 1 is therefore achieved and the proof is complete.

Proof of Proposition 3

(9) indicates

$$\frac{\partial x_1^*}{\partial \gamma} = \frac{-[\frac{8\gamma\Gamma_2{}^2+(4+3\gamma^2)\Gamma_1\Gamma_2}{4-\gamma^2}][4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]}{[4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]^2} + \frac{(1-2\Gamma_2{}^2-\gamma\Gamma_1\Gamma_2)[\frac{32\gamma(\Gamma_1{}^2+\Gamma_2{}^2)}{4-\gamma^2}-24\gamma\Gamma_1{}^2\Gamma_2{}^2]}{[4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]^2}$$

$$= \frac{16\gamma\Gamma_1{}^2\Gamma_2{}^4 - \frac{4(4+3\gamma^2)\Gamma_1\Gamma_2}{4-\gamma^2} - 4(4-3\gamma^2)\Gamma_1{}^3\Gamma_2{}^3]}{[4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]^2} + \frac{8(\Gamma_1{}^2+\Gamma_2{}^2)\Gamma_1\Gamma_2 + (\frac{32\gamma\Gamma_1{}^2}{4-\gamma^2} - 24\gamma\Gamma_1{}^2\Gamma_2{}^2)}{[4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]^2}$$

$$= \frac{4}{[4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]^2(4-\gamma^2)^3}[4\gamma(4-\gamma^2)^3\Gamma_1{}^2\Gamma_2{}^4 - (4+3\gamma^2)(2-c_2)(2-c_1) -$$
$$(4-3\gamma^2)(2-c_2)^3\Gamma_1{}^3 + 2[(2-c_1)^2+(2-c_2)^2](2-c_2)\Gamma_1 + 8\gamma(2-c_1)^2 - 6\gamma(2-c_2)^2(2-c_1)\Gamma_1].$$

Apparently, $\left.\frac{\partial x_1^*}{\partial \gamma}\right|_{\gamma=0} < 0$. Moreover,

$$\left.\frac{\partial x_1^*}{\partial \gamma}\right|_{\gamma=1} = \frac{4}{27[4-\frac{8(2-c_1)^2+8(2-c_2)^2}{9}+4\frac{(2-c_2)^2(2-c_1)^2}{27}]^2}[\frac{4(2-c_2)^4(2-c_1)^2}{27} - 7(2-c_2)(2-c_1)$$
$$-\frac{(2-c_2)^3(2-c_1)^3}{27} + \frac{2[(2-c_1)^2+(2-c_2)^2](2-c_2)(2-c_1)}{3} + 8(2-c_1)^2 - 6\frac{(2-c_2)^2(2-c_1)^2}{3}]$$
$$> \frac{4}{27[4-\frac{8(2-c_1)^2+8(2-c_2)^2}{9}+4\frac{(2-c_2)^2(2-c_1)^2}{27}]^2}[\frac{4(2-c_2)^4(2-c_1)^2}{27} - \frac{(2-c_2)^3(2-c_1)^3}{27}$$
$$+(2-c_1)^2 - 2\frac{(2-c_2)^2(2-c_1)^2}{3}]$$

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$$\geq \frac{4[\frac{4(2-c_2)^4(2-c_1)^2}{27} - \frac{(2-c_2)^3(2-c_1)^3}{27} + \frac{1}{3}(2-c_1)]}{27[4-\frac{8(2-c_1)^2+8(2-c_2)^2}{9} + 4\frac{(2-c_2)^2(2-c_1)^2}{27}]^2} > 0.$$

Therefore, by the continuity, $\frac{\partial x_1^*}{\partial \gamma} < 0$ for the small product substitutability while $\frac{\partial x_1^*}{\partial \gamma} > 0$ for the large product substitutability. Furthermore, there exists the unique solution of $\frac{\partial x_1^*}{\partial \gamma} = 0$ for $\gamma \in (0,1)$. Thus, the there exists a U-shaped relationship between the food quality and the product substitutability for the first firm.

By the similar way, $\left.\frac{\partial x_2^*}{\partial \gamma}\right|_{\gamma=0} < 0$ and $\left.\frac{\partial x_2^*}{\partial \gamma}\right|_{\gamma=1} > 0$. Therefore, there exists a U-shaped relationship between the food quality and the product substitutability.

We further address the outputs. From (10), we have

$$\frac{\partial q_1^*}{\partial \gamma} = \frac{[\frac{2\gamma\Gamma_1}{4-\gamma^2} - 2\gamma\Gamma_1\Gamma_2{}^2 - \frac{(4+\gamma^2)\Gamma_2}{2(4-\gamma^2)}][4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]}{[4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]^2} +$$

$$\frac{[\Gamma_1 - \frac{(2-c_1)\Gamma_2{}^2}{2} - \frac{\gamma\Gamma_2}{2}][\frac{32\gamma(\Gamma_1{}^2+\Gamma_2{}^2)}{4-\gamma^2} - 24\gamma\Gamma_1{}^2\Gamma_2{}^2]}{[4-8(\Gamma_1{}^2+\Gamma_2{}^2)+4(4-\gamma^2)\Gamma_1{}^2\Gamma_2{}^2]^2}.$$

Obviously, $\left.\frac{\partial q_1^*}{\partial \gamma}\right|_{\gamma=0} < 0$. $\frac{\partial q_1^*}{\partial \gamma} < 0$ for the small product substitutability. Similarly, $\frac{\partial q_2^*}{\partial \gamma} < 0$ for small product substitutability.

Proposition 3 is therefore achieved and the proof is complete.

Proof of Proposition 4

From (15) and (9), we have

$$x_1^{*,s1} - x_1^* = \frac{[(4-\gamma^2)(1-2\Gamma_2{}^2)]^2 - [1-\frac{(2-c_2)^2}{2(4-\gamma^2)}]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_1{}^2)]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_2{}^2]^2(2-c_1)^2} - \frac{1}{4} - \frac{\Gamma_1{}^2[2-(2-c_2)\Gamma_2] - \gamma\Gamma_1\Gamma_2}{4-8\Gamma_2{}^2 - 4\Gamma_1{}^2[2-(2-c_2)\Gamma_2]}$$

$$= \frac{[1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2 - [1-\frac{1}{2}(2-c_2)\Gamma_2]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_1{}^2)]^2 - 4[1-\frac{1}{2}(4-\gamma^2)\Gamma_2{}^2]^2(2-c_1)^2} - \frac{\Gamma_1{}^2[2-(2-c_2)\Gamma_2] - \gamma\Gamma_1\Gamma_2}{4-8\Gamma_2{}^2 - 4\Gamma_1{}^2[2-(2-c_2)\Gamma_2]}$$

$$= \frac{\begin{gathered}\{[1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2 - [1-\frac{1}{2}(2-c_2)\Gamma_2]\gamma(2-c_2)(2-c_1)\}\{1-2\Gamma_2{}^2 - \Gamma_1{}^2[2-(2-c_2)\Gamma_2]\} \\ -\{\Gamma_1{}^2[2-(2-c_2)\Gamma_2] - \gamma\Gamma_1\Gamma_2\}\{[(4-\gamma^2)-2(2-c_2)\Gamma_2]^2 - [1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2\}\end{gathered}}{4\{[(4-\gamma^2)(1-2\Gamma_2{}^2)]^2 - [1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2\}\{1-2\Gamma_2{}^2 - \Gamma_1{}^2[2-(2-c_2)\Gamma_2]\}}$$

$$= \frac{\begin{gathered}[1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2(1-2\Gamma_2{}^2+\gamma\Gamma_1\Gamma_2) - [2\Gamma_2{}^2 - \frac{1}{2}(2-c_2)\Gamma_2]\gamma(2-c_2)(2-c_1)\}(1-2\Gamma_2{}^2) - \\ \Gamma_1{}^2[2-(2-c_2)\Gamma_2][(4-\gamma^2)(1-2\Gamma_2{}^2)]^2\end{gathered}}{4\{[(4-\gamma^2)(1-2\Gamma_2{}^2)]^2 - [1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2\}\{1-2\Gamma_2{}^2 - \Gamma_1{}^2[2-(2-c_2)\Gamma_2]\}}$$

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$$= \frac{\begin{array}{c}[1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2\gamma\Gamma_1\Gamma_2 - [2\Gamma_2{}^2-\frac{1}{2}(2-c_2)\Gamma_2]\gamma(2-c_2)(2-c_1)\}[1-2\Gamma_2{}^2] \\ -[1-\frac{1}{2}(2-c_2)\Gamma_2][1-2\Gamma_2{}^2](2-c_1)^2[1-4\Gamma_2{}^2+\frac{1}{2}(2-c_2)\Gamma_2]\end{array}}{4\{[(4-\gamma^2)(1-2\Gamma_2{}^2)]^2-[1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2\}\{1-2\Gamma_2{}^2-\Gamma_1{}^2[2-(2-c_2)\Gamma_2]\}}$$

$$= \frac{\begin{array}{c}-[2\Gamma_2{}^2-\frac{1}{2}(2-c_2)\Gamma_2]\gamma(2-c_2)(2-c_1)\}[1-2\Gamma_2{}^2]+ \\ (2-c_1)^2[1-\frac{1}{2}(2-c_2)\Gamma_2]\{(1-2\Gamma_2{}^2)\gamma^2\Gamma_2{}^2-[1-\frac{1}{2}(2-c_2)\Gamma_2](1-2\Gamma_2{}^2-\gamma\Gamma_1\Gamma_2)\}\end{array}}{4\{[(4-\gamma^2)(1-2\Gamma_2{}^2)]^2-[1-\frac{1}{2}(2-c_2)\Gamma_2]^2(2-c_1)^2\}\{1-2\Gamma_2{}^2-\Gamma_1{}^2[2-(2-c_2)\Gamma_2]\}} \le 0.$$

Furthermore, the hypotheses $0 < 2-c_2 \le 2-c_1 \le 1$ and $\gamma \in [0,1]$ jointly imply the relationship $1-2\Gamma_2{}^2-\gamma\Gamma_1\Gamma_2 \ge \gamma^2\Gamma_2{}^2$. Therefore, the above inequality comes from $1-\frac{1}{2}(2-c_2)\Gamma_2 \ge 1-2\Gamma_2{}^2$ and $1-2\Gamma_2{}^2-\gamma\Gamma_1\Gamma_2 \ge \gamma^2\Gamma_2{}^2$.

Similarly, we have $x_2^{*,s1} \le x_2^*$. (17)–(18) imply the relationship $q_1^{*,s1}+q_2^{*,s1} \le q_1^*+q_2^*$. Conclusions are achieved and the proof is complete.

Proof of Proposition 5

By (21) and (9), we have

$$x_2^{*,s2}-x_2^* = \frac{[(4-\gamma^2)(1-2\Gamma_1{}^2)]^2-[1-\frac{1}{2}(2-c_1)\Gamma_1]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_1{}^2)]^2-4[1-\frac{1}{2}(2-c_1)\Gamma_1]^2(2-c_2)^2} - \frac{1}{4} - \frac{\Gamma_2{}^2[2-(2-c_1)\Gamma_1]-\gamma\Gamma_1\Gamma_2}{4-8\Gamma_1{}^2-4\Gamma_2{}^2[2-(2-c_1)\Gamma_1]}$$

$$= \frac{[1-\frac{1}{2}(2-c_1)\Gamma_1]^2(2-c_2)^2-[1-\frac{1}{2}(2-c_1)\Gamma_1]\gamma(2-c_2)(2-c_1)}{4[(4-\gamma^2)(1-2\Gamma_1{}^2)]^2-4[1-\frac{1}{2}(2-c_1)\Gamma_1]^2(2-c_2)^2} - \frac{\Gamma_2{}^2[2-(2-c_1)\Gamma_1]-\gamma\Gamma_1\Gamma_2}{4-8\Gamma_1{}^2-4\Gamma_2{}^2[2-(2-c_1)\Gamma_1]}$$

$$= \frac{\begin{array}{c}\{[1-\frac{1}{2}(2-c_1)\Gamma_1]^2(2-c_2)^2-[1-\frac{1}{2}(2-c_1)\Gamma_1]\gamma(2-c_2)(2-c_1)\}\{1-2\Gamma_1{}^2-\Gamma_2{}^2[2-(2-c_1)\Gamma_1]\} \\ -\{\Gamma_2{}^2[2-(2-c_1)\Gamma_1]-\gamma\Gamma_1\Gamma_2\}\{[(4-\gamma^2)(1-2\Gamma_1{}^2)]^2-[1-\frac{1}{2}(2-c_1)\Gamma_1]^2(2-c_2)^2\}\end{array}}{\{[(4-\gamma^2)(1-2\Gamma_1{}^2)]^2-[1-\frac{1}{2}(2-c_1)\Gamma_1]^2(2-c_2)^2\}\{4-8\Gamma_1{}^2-4\Gamma_2{}^2[2-(2-c_1)\Gamma_1]\}}$$

$$= \frac{\begin{array}{c}[1-\frac{1}{2}(2-c_1)\Gamma_1]^2(2-c_2)^2(1-2\Gamma_1{}^2+\gamma\Gamma_1\Gamma_2)- \\ \Gamma_2{}^2[2-(2-c_1)\Gamma_1][(4-\gamma^2)-2\Gamma_1{}^2]^2-\frac{3}{2}\gamma(2-c_1)^2(2-c_2)(1-2\Gamma_1{}^2)\Gamma_1\end{array}}{\{[(4-\gamma^2)(1-2\Gamma_1{}^2)]^2-[1-\frac{1}{2}(2-c_1)\Gamma_1]^2(2-c_2)^2\}\{4-8\Gamma_1{}^2-4\Gamma_2{}^2[2-(2-c_1)\Gamma_1]\}} \le 0.$$

By the similar method to the proof of Proposition 4, the above inequality is achieved. Similarly, we also have $x_1^{*,s2} \le x_1^*$. For the total outputs, we also have the relationship $q_1^{*,s2}+q_2^{*,s2} \le q_1^*+q_2^*$.

Conclusions are achieved and the proof is complete.

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Contact address:

Pu-yan Nie, School of Finance, Collaborative Innovation Center of Scientific Finance & industry, Guangdong University of Finance & Economics, Guangzhou, 510320, P.R. China
e-mail: pynie2013@163.com