DISCUSSION PAPER SERIES

Discussion paper No. 113

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January, 2014

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Cannibalization may Allow a Cost-inefficient Firm to Earn more than a Cost-efficient Firm in a Duopoly with Two Vertically Differentiated Goods*

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January 07, 2014

Abstract

We consider cannibalization in a duopoly model in which firms with different costs supply two vertically differentiated products in the same market. We find that an increase in the difference in quality between the two goods or a decrease in the marginal cost of the high-quality goods leads to cannibalization, such that the high-quality goods keep out the low-quality goods from the market. We show that, in equilibrium, cannibalization affects the product line of firms. As a result, an inefficient firm may earn more than the efficient firm. If the difference in the quality of the two goods is small enough, an increase in the production costs of the inefficient firm improves social welfare.

Keywords: Multi-product firm; Duopoly; Cannibalization; Vertical product differentiation
JEL Classification Numbers: D21, D43, L13, L15

*The authors would like to express their gratitude to Tommaso Valletti, Noriaki Matsushima, Keizo Mizuno and participants of the International Workshop on Global Competition held in Kyoto on March 3–4, 2013, for their useful comments on an earlier version of this paper. The authors also express gratitude to Kenji Fujiwara for his useful comments on an earlier draft of this paper. The second author was supported by Grant-in-Aids for Scientific Research (Nos. 23330099 and 24530255) MEXT.

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1 Introduction

In a real economy, there are oligopolistic markets in which firms produce and sell multiple products that are vertically differentiated within the same market. For example, GM sells the Chevrolet Cruze and GMC Sierra PU, and Toyota sells the Camry, Corolla Matrix, and Prius—the hybrid car—in the same segment of the car market. Hyundai also sells the Elantra and Hybrid Sonata in the same segment of the US car market. As another example, Apple sells the iPad Mini and the larger iPad in the tablet market. Similarly, Samsung sells the Galaxy Note and the Galaxy Tab, both in a smaller and larger variety.[1] Since consumers believe that the quality of the firms' technology differs, each consumer places a different value on the high-quality good of each firm. Thus, these markets are horizontally as well as vertically differentiated. In such markets, there are more cases of *cannibalization*.[2] Cannibalization occurs when a firm reduces the sales of one of its products by introducing a similar, competing product in the same market.

In this study, cannibalization is a business strategy characterized by a difference in the quality of vertically differentiated goods and cost efficiency. We also explore how cannibalization affects the profitability of firms in equilibrium.

In the existing literature on vertical product differentiation, the quality of goods that firms produce is treated as an endogenous variable. For example, in Bonanno (1986) and Motta (1993), firms initially choose a quality level and then compete in Cournot or Bertrand fashion in an oligopolistic market. Valletti (2000) considered a two-stage duopoly game in which firms first choose the quality of their goods, and then compete

[1] See "Samsung's Brand Cannibalization," http://www.indianprice.com/mobiles/articles/15-samsungs-brand-cannibalization.html.

[2] Actually, there have been many reports that the iPad Mini is cannibalizing sales of the larger iPad. See, for example, Seward (2013), "Yes, the iPad Mini is cannibalizing sales of larger iPad."

in terms of the quantity they supply. Then, he explored the effect of a minimum quality standard regulation on the Cournot equilibrium he derived. However, these studies do not consider firms that sell multiple products in the same market that are differentiated in terms of quality (vertically). In dealing with cannibalization in such a market, our model needs to allow for a multi-product firm (MPF) that differs in terms of its features or characteristics. Few previous studies address an oligopolistic market with such MPFs, although Johnson and Myatt (2003) are a notable exception.[3]

According to Johnson and Myatt (2003), firms that sell multiple quality-differentiated products frequently change their product lines when a competitor enters the market. They explain the common strategies of using "fighting brands" and "pruning" product lines. That is, they endogenized not only the quality level of each good, but also the number of goods that each firm supplied in the market.

In the positive analysis literature that refers to cannibalization, Igami and Yang (2013) recently investigated how cannibalization and preemption affect new entries and the evolution of market structure. They developed a dynamic entry model for a multi-product oligopoly based on a panel dataset of hamburger shops in Canada. According to their results, cannibalization is the main determinant of both profit and entry.

For the purpose of our analysis, both the quality level and the number of differentiated goods supplied by each firm are given, unlike in preceding studies. In addition, we do not consider new entries to the market in our model. In our setting, both firms produce and supply two kinds of vertically differentiated goods in a market. This setting can provide a benchmark against which to extend our analysis to a model in which each firm strategically chooses whether to launch a new vertically differentiated product into a market in which it already competes with its rival with an existing product. In typical

[3]For the sake of simplicity, we focus on a duopoly model.

existing models of horizontal or vertical product differentiation, each firm produces only one kind of good, given exogenously, which differs from that of its rival.

Ellison (2005), another study closely related to ours, analyzed a market in which each firm sells a high-end and low-end version of the same product. Although each firm produces two differentiated goods, the two goods are sold in different markets, each with different types of consumers.[4] In contrast, our study provides a model in which both firms produce two vertically differentiated products. To explore the relationship between the difference in quality of the goods and cannibalization, we consider a duopoly with asymmetric marginal costs.

The remainder of this paper is organized as follows. In section 2, we present the model and derive a duopoly equilibrium with two vertically differentiated products in a market. Furthermore, we explore the relationship among the difference of quality of goods, cost asymmetry, and cannibalization by using comparative statistics of the equilibrium output. In section 3, we conduct a welfare analysis of the duopoly model that we analyze in section 2. Finally, section 4 concludes the paper and offers suggestions for possible future research.

2 The Model and the Derivation of an Equilibrium

Suppose that there are two firms, $(i = 1, 2)$, each producing two goods (good H and good L) that differ in terms of quality, where $1, 2$ imply firm 1 and firm 2 in the duopoly case, respectively. Let V_H and V_L denote the quality level of the two goods. Then, the maximum amount consumers are willing to pay for each good is assumed to be $V_H > V_L > 0$. Further, we assume $V_H = (1 + \mu)V_L$, where μ represents the difference

[4] His model combines vertical differentiation (two distinct qualities) and horizontal differentiation (two firms located at distinct points in a linear city).

in quality between the two goods, and we normalize the quality of the low-quality good as $V_L = 1$, for simplicity. Good $\alpha(= H, L)$ is assumed to be homogeneous for any consumer. Moreover, suppose that each firm has constant returns to scale and that $c_{iH} > c_{iL} = c_{jL} = c_L$, where $c_{i\alpha}$ is the marginal cost of firm i and α is the average cost of the good. This implies that a high-quality good incurs a higher cost of production than a low-quality good.[5] Without loss of generality, we also assume that $c_L = 0$. Under these assumptions, each firm's profit is defined in the following manner:

$$\pi_i = (p_{iH} - c_{iH})q_{iH} + p_{iL}q_{iL} \qquad i = 1, 2, \tag{1}$$

where $p_{i\alpha}$ is the price of good α sold by firm i, and $q_{i\alpha}$ is the firm's output. Each firm chooses the quantity to supply that maximizes this profit function in Cournot fashion.

Next, we describe the consumers' behavior in our model.

Following the standard specification in the literature, for example, Katz and Shapiro (1985), we assume that there is a continuum of consumers characterized by a taste parameter, θ, which is uniformly distributed between $-\infty$ and $r > 0$, with density 1. We further assume that a consumer of type $\theta \in (-\infty, r]$,for $r > 0$, obtains a net surplus from one unit of good α from firm i at price $p_{i\alpha}$. Thus, the utility (net benefit) of consumer θ who buys good α $(= H, L)$ from firm i $(= 1, 2)$ is given by

$$U_{i\alpha}(\theta) = V_\alpha\theta - p_{i\alpha} \qquad i =, 1, 2 \quad \alpha = H, L. \tag{2}$$

Each consumer decides to buy either nothing or one unit of good α from firm i to maximize his/her surplus.

[5] For the symmetric costs version of our analysis, see Kitamura ans Shinkai (2013) in details.

Before deriving the inverse demand of each good, we present three further assumptions about the consumers in our model.

[**Assumption 1**] There exists a consumer, $\hat{\theta}_i \in (-\infty, r], (r > 0)$, who is indifferent between the two goods of the same firm; that is,

$$U_{iH}(\hat{\theta}_i) = U_{iL}(\hat{\theta}_i) > 0, i = 1, 2. \tag{3}$$

[**Assumption 2**] There always exists a consumer, $\underline{\theta}_{iL}, i = 1, 2,$, who is indifferent between purchasing good L and purchasing nothing in the duopoly.

To derive a duopoly equilibrium, we need one other key assumption.

[**Assumption 3**] In the duopoly, for an arbitrary type-θ_α consumer,

$$U_{1\alpha}(\theta_\alpha) = U_{2\alpha}(\theta_\alpha), \alpha = H, L. \tag{4}$$

This last assumption implies that the net surplus of consumer θ_α must be the same whether buying a good produced by firm 1 or a good produced by firm 2, as long as the two firms produce the same quality of good α and have positive sales.

From these assumptions, the inverse demand functions are obtained in the following manner:

$$\begin{cases} p_H = (1+\mu)(r - Q_H) - Q_L \\ p_L = r - Q_H - Q_L. \end{cases} \tag{5}$$

To maximize profit function (1), each firm determines the quantity of its goods, q_{iH} and q_{iL}, in the following manner:

$$\max_{q_{iH}, q_{iL}} \pi_i.$$

Here, we set $c_{2H} > c_{1H} > c_{iL} = 0$, which means that firm 1 is more efficient than firm 2. The first-order conditions for profit maximization are as follows:

$$\begin{aligned}
-(1+\mu)q_{1H} + (1+\mu)(r - Q_H) - Q_L - c_{1H} - q_{1L} &= 0 \\
-(1+\mu)q_{2H} + (1+\mu)(r - Q_H) - Q_L - c_{2H} - q_{2L} &= 0 \\
-q_{1H} + r - Q_H - Q_L - q_{1L} &= 0 \\
-q_{2H} + r - Q_H - Q_L - q_{2L} &= 0.
\end{aligned}$$

Solving this system, we obtain the following Nash equilibrium quantities:

$$\begin{cases}
q_{1H}^* = \frac{r}{3} - \frac{2c_{1H} - c_{2H}}{3\mu}, \quad q_{1L}^* = \frac{2c_{1H} - c_{2H}}{3\mu} \\
q_{2H}^* = \frac{r}{3} - \frac{2c_{2H} - c_{1H}}{3\mu}, \quad q_{2L}^* = \frac{2c_{2H} - c_{1H}}{3\mu}.
\end{cases} \tag{6}$$

For q_{iH}^* and q_{iL}^* to be non-negative, we assume that

$$r \geq \frac{2c_{2H} - c_{1H}}{\mu} \quad and \quad c_{1H} \geq \frac{1}{2}c_{2H}. \tag{7}$$

Hence, the total equilibrium output Q^* becomes constant:

$$Q^* = Q_1^* + Q_2^* = Q_H^* + Q_L^* = \frac{2}{3}r. \tag{8}$$

From (5) and (6), we obtain the following equilibrium prices of the goods:

$$p_H^* = \frac{(1+\mu)r + c_{1H} + c_{2H}}{3}, \; p_L^* = \frac{r}{3}. \tag{9}$$

We also have the equilibrium profit of firm i:

$$\pi_i^* = \frac{\mu(1+\mu)r^2 - \mu(2c_{iH} - c_{jH})r + (2c_{iH} - c_{jH})^2}{9\mu}, \quad i = 1, 2\ , \quad i \neq j \qquad (10)$$

From (6), we can easily establish the following proposition.

Proposition 1 *Although the efficient firm (firm* 1*) produces more of high-quality good* H *than the inefficient firm (firm* 2*), the inefficient firm sells more of the low-quality good* L *than does the efficient firm. Furthermore, if the difference in unit costs between the two firms is sufficiently small (that is, if* $2c_{1H} = c_{2H}$*), then the efficient firm does not produce the low-quality good.*

Furthermore, the equilibrium outputs of (6) lead to the following condition for cannibalization:

Corollary 1 *In the duopoly equilibrium derived above, when the difference in the quality of the two goods,* μ *or the marginal cost of high-quality good* H *of competitor —*c_{jH} *— increases (decreases), then cannibalization occurs such that high-quality (low-quality) good* H (L) *keeps low-quality (high-quality) good* L (H) *out of the market. However, if the marginal cost of high-quality good* H *of its own —*c_{iH} *—increases (decreases), then cannibalization occurs such that low-quality (high-quality) good* L (H) *keeps high-quality (low-quality) good* H (L) *out of the market.*

We illustrate the intuitive reasoning behind this corollary in relation to the recent tablet PC market. When the difference in the quality of the goods, μ, is sufficiently large, or the marginal cost of high-quality good H of its rival, c_{jH}, is high, the efficient firm, for example Apple, increases its output of the high-quality iPad. On the contrary, if its rival, the inefficient firm (for example, Samsung), can produce a high-quality tablet

at a lower cost, c_{jH} than Apple by R & D, or the difference in the quality of the goods, μ, becomes small, then Apple expands production of the lower-quality iPad Mini, which cannibalizes the larger iPad. Then, Samsung's new tablet cannibalizes sales of its existing 10.1-inch tablet. However, unless the market has goods that are extremely differentiated or extremely similar in terms of quality, cannibalization does not occur.[6]

From (10), we can show that

$$\frac{\partial \pi_i^*}{\partial \mu} = \frac{(\mu r + 2c_{iH} - c_{jH})(\mu r - (2c_{iH} - c_{jH}))}{9\mu^2} > 0, i = 1, 2.$$

Furthermore, we also check the effects of production costs on profit. From (10), we obtain

$$\begin{aligned} &\frac{\partial \pi_i^*}{\partial c_{iH}} > 0, \ \frac{\partial \pi_i^*}{\partial c_{jH}} < 0 \qquad if \quad \frac{2c_{2H} - c_{1H}}{r} \leq \mu < \frac{2(2c_{iH} - c_{jH})}{r} \\ &\frac{\partial \pi_i^*}{\partial c_{iH}} < 0, \ \frac{\partial \pi_i^*}{\partial c_{jH}} > 0 \qquad if \quad \frac{2(2c_{iH} - c_{jH})}{r} < \mu. \end{aligned}$$

Proposition 2 *When the difference in the quality of the two goods increases, the equilibrium profits of both firms increase. Furthermore, if* $(2c_{2H} - c_{1H})/r \leq \mu < \{2(2c_{iH} - c_{jH})\}/r$ $(\{2(2c_{iH} - c_{jH})\}/r < \mu)$*, an increase in the marginal cost of their own good H or a decrease in the marginal cost of the competitor's good H increases(reduces) the profit of the firm.*

[6] From the article in the web news,"Samsung's Brand Cannibalization," Samsung occasionally improves its products, which kills its existing product in the market. With the launch of the 10.1 inch Galaxy Note (Samsung's latest tablet), it would most likely cannibalize sales of the existing 10.1 inch tablet. However, Samsung does not mind, as the finest way to continue to exist in a competitive market is to eradicate your own goods. See http://www.indianprice.com/mobiles/articles/15-samsungs-brand-cannibalization.html
for more details.

This proposition is counterintuitive. When the difference in the quality between two goods is sufficiently small, each firm produces more of the low-quality good than the high-quality good, from equation (6), to avoid suffering from the positive marginal cost of producing the high-quality good. Then, an increase in the unit cost of its own good H or a decrease in the unit cost of its competitor helps this firm to produce more of the low-quality good, and reduces the quantity of the high-quality good because of cannibalization. In contrast, the rival firm sells more of the high-quality good, which has a positive marginal cost. Thus, if the difference in quality is sufficiently small, an increase in the unit cost of good H or a decrease in the unit cost of the rival firm has a positive effect on its own profit. However, if the difference in quality between the goods is sufficiently large, we have the opposite conclusion.

Finally, we confirm the difference in the profits of two firms, as follows:

$$\pi_2 - \pi_1 = \frac{(c_{2H} - c_{1H})(c_{1H} + c_{2H} - \mu r)}{3\mu} \tag{11}$$

Thus, from (7) and (11), we obtain

$$\begin{cases} \pi_1 < \pi_2 & if \ \frac{2c_{2H} - c_{1H}}{\mu} \leq r < \frac{c_{1H} + c_{2H}}{\mu} \\ \pi_1 > \pi_2 & if \ \frac{c_{1H} + c_{2H}}{\mu} < r \end{cases} . \tag{12}$$

Recall that, from proposition 1, in equilibrium, the efficient firm (Firm 1) always produces more of high-quality good H than of low-quality good L. This means that, for Firm 1, with its lower marginal cost, cannibalization occurs such that good H drives good L out of the market. On the other hand, the inefficient firm (Firm 2) produces more of good L than of good H in equilibrium. Then, for Firm 2, with its higher

marginal cost, cannibalization occurs such that good L drives good H out of the market. However, from (6), the condition $(2c_{2H} - c_{1H})/\mu \leq r < (c_{1H} + c_{2H})/\mu$ is identical to the condition $q_{1H}^* < q_{2L}^*$. That is, Firm 2 supplies more of good L than of good H, which is sold by Firm 1. Furthermore, this condition also implies that $q_{2H}^* < q_{1L}^* < q_{1H}^* < q_{2L}^*$. Therefore, the cannibalization for Firm 2 is stronger than that for Firm 1. Consequently, if r is small enough, Firm 2's profit surpasses that of Firm 1. In contrast, the inequality $(c_{1H} + c_{2H})/\mu < r$ is sufficient for the inequality $q_{1L}^* < q_{2H}^* < q_{2L}^* < q_{1H}^*$. This means that the degree of cannibalization for Firm 1 is larger than of Firm 2. In this case, Firm 1 earns more than Firm 2. In summary, in equilibrium, the firm whose goods cannibalize more goods than its rival's goods do makes the greater profit.

Proposition 3 *If consumers are distributed over the lower-valued (higher-valued) range of the ratio of total marginal cost to the difference in quality of two goods, then the inefficient firm earns more (less) profit than the efficient firm does.*

Note that $Q^* = (2r)/3$. When r is small, this implies that the total output at equilibrium is small, from (8), and the profit of the inefficient firm is larger than that of the efficient firm. Moreover, the higher the unit cost of good H of the efficient firm (Firm 1), the larger the range of r that satisfies $(2c_{2H} - c_{1H})/\mu \leq r < (c_{1H} + c_{2H})/\mu)$.

3 Welfare Analysis with Asymmetric Cost

In this section, we describe the comparative statistics of the social welfare in the equilibrium.

The social surplus in the equilibrium derived in the preceding section is given by

$$
\begin{aligned}
W^* &= \int_{\frac{r}{3}}^{\hat{\theta}^*} \theta d\theta + \int_{\hat{\theta}^*}^{r} (1+\mu)\theta d\theta - c_{1H}q_{1H}^* - c_{2H}q_{2H}^* \\
&= -\frac{\mu}{2}(\hat{\theta}^*)^2 - \frac{r^2}{18} + \frac{(1+\mu)r^2}{2} - c_{1H}q_{1H}^* - c_{2H}q_{2H}^*.
\end{aligned} \tag{13}
$$

First, we explore the effect of a change in unit cost on social welfare.

$$
\frac{\partial W^*}{\partial c_{iH}} = \frac{11c_{iH} - 7c_{jH} - 4\mu r}{9\mu} \quad i = 1, 2.
$$

Thus,

$$
\begin{cases}
\frac{\partial W^*}{\partial c_{1H}} < 0 & \\
\frac{\partial W^*}{\partial c_{2H}} > 0 & if \ \frac{2c_{2H}-c_{1H}}{r} \leq \mu < \frac{11c_{2H}-7c_{1H}}{4r} \\
\frac{\partial W^*}{\partial c_{2H}} \leq 0 & if \ \frac{11c_{2H}-7c_{1H}}{4r} \leq \mu
\end{cases} . \tag{14}
$$

Finally, we show that a change in the quality of the difference between the two goods always has a positive effect on social welfare, as follows:

$$
\frac{\partial W^*}{\partial \mu} = \frac{3\mu^2 r^2 + 2\mu(c_{1H} + c_{2H})r - 2c_{1H}^2 - 2c_{2H}^2 + 8c_{1H}c_{2H}}{6\mu^2} \tag{15}
$$

The sign of $\partial W^*/\partial \mu$ is determined by the sign of the numerator of (15), where we define the numerator by $W_\mu^n(r)$, and $W_\mu^n(r)$ is a quadratic in r. Evaluating $W_\mu^n(r)$ at $r = (2c_{2H} - c_{1H})/\mu$, we have

$$
W_\mu^n(\frac{2c_{2H} - c_{1H}}{\mu}) = 14c_{2H}^2 - c_{1H}^2 - 2c_{1H}c_{2H} > 0,
$$

and we see that the slope of $W_{\mu}^{n}(r)$ with respect to r is

$$\left.\frac{\partial W_{\mu}^{n}(r)}{\partial r}\right|_{r=\frac{2c_{2H}-c_{1H}}{\mu}} = 6(2c_{2H}-c_{1H})^2 + 2\mu(c_{1H}+c_{2H}) > 0.$$

Then, we obtain

$$\frac{\partial W^*}{\mu} > 0. \tag{16}$$

Thus, we show that an increase in the difference between the two goods improves the social welfare.

Proposition 4 *The social surplus in equilibrium increases with*

1. *a decrease in the marginal cost of the efficient firm for the high-quality good.*
2. *a decrease (increase) in the unit cost of the inefficient firm when producing the high-quality good if the difference in quality is large (small) enough.*

Moreover, an increase in the difference between the two goods always increases the social surplus in equilibrium.

The second part of this proposition is both interesting and counterintuitive, because we may think that an increase in the production cost would lead to a decrease in social welfare. However, a case exists in which social welfare improves if there is an increase in the marginal cost of the high-quality good. The reason is that when the difference in quality is small, the increase in the marginal cost of the inefficient firm leads to a reduction in the total cost; $(\partial Total\ cost)/\partial c_{2H} < 0$. This would have a positive effect on social welfare. On the other hand, the effect on total consumer utility is always negative; $(\partial Total\ utility)/\partial c_{2H} < 0$. Thus, when the positive effect of the former dominates the

negative effect of the latter, the social surplus in equilibrium increases as the unit cost to the inefficient firm of producing good H increases and the difference in quality is sufficiently small.

4 Concluding Remarks

In this study, we considered and proposed a duopoly model of cannibalization in which two firms produce and sell two distinct products that are differentiated horizontally as well as vertically in the same market. Then, we showed that in the market equilibrium, the efficient firm produces more of the high-quality good and the inefficient firm produces more of the low-quality good.

Furthermore, we presented several comparative statistics and established that an increase in the difference in the quality of the two types of goods (i.e., a reduction in the marginal cost of producing its own high-quality good) leads to cannibalization such that the high-quality good drives the low-quality good out of the market. Similarly, a decrease in the difference in the quality of the two goods (i.e., an increase in the marginal cost of the high-quality good of the competitor) causes cannibalization such that low-quality good L drives high-quality good H out of the market. We also presented an intuitive explanation for these comparative statistics. Interestingly, when the difference in the quality of the two goods is small, an increase in the marginal cost of a firm's own good H, or a decrease in the marginal cost of the competitor's good H increases the profit of the firm. Moreover, we showed that the inefficient firm might earn more than the efficient firm.

Then, we conducted a welfare analysis and showed that an increase in the difference between the two goods and a decrease in the production costs of the high-quality good

for the efficient firm always increases social welfare. However, an increase in the marginal cost of producing the high-quality good for the inefficient firm does not always increase social welfare. In particular, if the difference in quality is sufficiently small, an increase in the unit cost of the high-quality good for the inefficient firm improves the social welfare.

Extensions to this study for future research are possible. For example, it would be useful to analyze a case in which each firm can choose its level of quality as well as the number of goods it produces. In addition, in this study, we do not consider a market with network externality, which would be worth studying if we consider a market such as the tablet PC industry described in section 2. Indeed, we are analyzing such a market in another study.

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