Abstract

Many wearable device products come into the market recently. As a specific application of mobile health, wearable device has garnered attentions form both practitioners and scholars. In this paper, we investigate the impact of network externality and optimal product design of wearable device in a two-dimensional product differentiation model considering a market that has a broad product variety (horizontal differentiation) and various possible quality levels (vertical differentiation). Our model shows that in the presence of product variety competition and quality competition, firms will obtain the similar benefits when they supply differentiated and undifferentiated products without considering the network externality. In addition, we find that firms’ profits will be decreased in the presence of network externality in horizontal dominance differentiation, but increased in vertical dominance differentiation. Network externality has positive impact on higher-quality product’s profit, and also has positive impact on lower-quality product’s profit only when network externality is large. Furthermore, we also find that firms should let their products incompatible when network externality is large, and they should release compatible products when network externality is small.

Keywords: Mobile Health, Wearable Devices, Horizontal Differentiation, Vertical Differentiation, Compatible, Incompatible, Network Externality.
INTRODUCTION

Information systems (IS) has specific advantages in healthcare, it can reduce national healthcare cost and improve the healthcare quality (Fichman et al. 2011). With the development of mobile technology, mobile health has emerged depending on its unique advantage on decreasing the national healthcare expenditure (Lim et al. 2011) and improving healthcare quality. Besides, with the coming of aging society (Chen & Hsiao 2012) and the improving of wireless technology (Wu et al. 2011), mobile health will attract more and more attentions in practice and academic research.

In the latest two years, many wearable device products come into the market, such as Google Glass in the field of smart glass, Geak Watch and iWatch in the direction of smart watch, Fitbit, Jawbone and 360 Kid’s Guardian in the field of smart bracelet, etc. The initial wearable device products are more like a fashionable accessory. With the development of mobile Internet and people’s attitude toward healthcare, more and more products are designed as not only fashionable products but also the mobile health products (Zheng et al. 2014). For example, people can use wearable devices to monitor blood pressure, pulse, calories and so on. Through the analysis on the data from the wearable devices, the specialist can give suggestions to people on how to live much healthier.

Some statistics shows that there is a rapid growth of the adoption of the wearable device products. Juniper Research predicts that the market value of wearable devices will be more than 1.5 billion in 2014. iResearch\(^1\) shows that the market size of wearable devices in China increases over time, from 0.42 billion in 2012 to 0.56 billion in 2013, and it will reach 1.19 billion in 2015 and 4.77 billion in 2017. Wearable device is valued more than ever before. The popularity of wearable device not only has garnered practitioners’ attention, but also attracts more and more scholars. Researchers analyze the issues about the wearable devices (mobile health) from different aspects, including consumers’ adoption (Ramanathan et al. 2013), efficiency of using mobile health (Bardhan et al. 2013), and privacy concern of mobile health (Anderson et al. 2011), etc. In practice, wearable devices consumers are heterogeneous, and they have different requirements on wearable device products. Some may concern more about fashion, some may care more about interface, and others may prefer more about functionality. Therefore, the producers need to balance the users’ demand on multiple characteristics according to their financial budgets and other competing products.

Facing the serious competition of wearable devices, how can firms win the battle? Should firms design products with more functions, or more fashionable, or more secure? How should they balance among users’ requirements, product cost and price? Taking these questions, this paper focuses on the competition between wearable devices firms. We employ a two-dimensional differentiation model (Wattal et al. 2009). We consider a market that has a broad product variety (horizontal differentiation) and various possible quality levels (vertical differentiation). Network externality is known as the more consumers of the product can lead to a higher utility when a new consumer purchases the product (Cheng et al. 2011). In short, a consumer’s utility is not only determined by the product attributes, price and quality, but also affected by other consumers who have purchased the product as well. To seek more benefits in the competition, wearable devices firms may strategically choose to release compatible or incompatible products. Thus, we will investigate the impact of network externality on the competition and firms’ optimal choices of compatibility.

Our model shows that in the presence of product variety competition and quality competition, firms will obtain similar benefits when they supply differentiated and undifferentiated products without considering the network externality. In addition, we find that firms’ profits will be decreased in the presence of network externality in horizontal dominance differentiation, but increased in vertical dominance differentiation. Network externality has positive impact on higher-quality product’s profit, but it has positive impact on lower-quality product’s profit if and only if network externality is large.

\(^1\) The statistics were accessed on 2014/02/19 at http://tech.hexun.com/2013-04-19/153346302.html.
Furthermore, we find that firms should let their products incompatible when network externality is large, and they should release compatible products when network externality is small.

The rest of this paper is organized as follows. Section 2 reviews some related literatures on economics of mobile health and two-dimensional differentiation model. In section 3, we propose our benchmark model with two-dimensional product differentiation. The impact of network externality is discussed in section 4, which is followed by conclusions and discussions in section 5.

2 LITERATURE REVIEW

The contributions of this research are related to two areas of IS literatures. First, the topic of this paper – wearable devices competition, is related to the economics of mobile health. Second, the research method of this paper is analytical modelling based on two-dimensional differentiation model.

2.1 Economics of Mobile Health

This stream of research analyzes the phenomenon of mobile health from economic perspective. Ozdemir et al. (2011) demonstrate that there is no incentive for electronic health record (EHR) providers to share personal data, but personal health record (PHR) has incentives by developing an analytical model. Anderson et al. (2011) investigate factors that can influence users’ willingness to share PHR by using privacy boundary theory. They find that electronic health information privacy concern and trust in electronic medium have significant influence on providers’ willingness to share PHR. Huerta et al. (2013) also show that the lower total factor productivity is the main factor of hospitals’ lower adoption of EHR.

Scholars also have investigated users’ motivation of adopting mobile health. Mettler (2012) find that reasoned actions, emotional responses and habitual responses have significant influence on mobile health users’ continuous behaviour. Similarity, O’Connor et al. (2013) claim the importance of task characteristic, user characteristic and technology characteristic in the diffusion of mobile health. Ramanathan et al. (2013) find that privacy protection and invasiveness are the primary factors that influence young users’ use of mobile health to manage personal health. However, mother’s preferences on mobile health are the customization to support mood, exercise and eating patterns with little impact of privacy concern.

Another sub-stream of research about economics of mobile health is the efficiency topic. Among these researches, Menon et al. (2013) demonstrate that malpractice insurance premium will positively influence the healthcare quality, but HIS will weaken the influence. Bardhan et al. (2013) also find that HIS will positively affect the quality of healthcare and it also helps to decrease the cost. However, Huerta et al. (2013) point that electronic health record will supply lower total factor productivity. When it refers to the role of social media in HIS efficiency, Fiehman et al. (2011) and Miller et al. (2013) demonstrate that active social media will increase the user of HIS.

In our research, we pay attention to the issue of specific mobile health application – wearable device. Different away from most of literatures on mobile health, we investigate the competition in wearable device market by developing a game-theoretic model. We have considered a wearable device market with different brand products and various quality levels. Then, we also study the impact of network externality on the competition and the optimal compatibility of wearable device.

2.2 Two-dimensional Product Differentiation Model

Following the definition of Lancaster (1971) about product differentiation, horizontal differentiation reflected by the variety of product in the market and vertical differentiation shows that higher product quality is more welcomed by customers.

Hotelling (1990) and d’Aspremont et al. (1979) have supplied the basic framework of horizontal differentiation, lots of researches about horizontal differentiation is related to their models. In the linear city model, duopoly located at opposite ends of the unit line will seek the same market share and profit by setting the same price. In the spatial competition, d’Aspremont et al. (1979) shown that
no location-price equilibrium in pure strategies exists with linear space and linear fit cost, but the equilibrium will be existed with a quadratic fit cost. However, Dasgupta and Maskin (1986) proved that mixed equilibrium exists in this situation. Osborne and Pitchik (1987) and Kats (1995) have found the equilibrium and the sub-game perfect location-price equilibrium, which is different away from the work of Novshek (1980).

Jaskold Gabszewicz and Thisse (1979) and Shaked and Sutton (1982), followed by Mussa and Rosen (1978), develop duopoly competition model with vertical differentiation. Lin et al. (2012) investigate the online advertise market by developing a vertical differentiation model. The findings suggest that vertical differentiation is a beneficial strategy in online service competition. Marom and Seidmann (2011) study the price discrimination of online service provider so that their product can be vertically differentiated.

Prior literatures demonstrate that the two-dimensional differentiation model (horizontal and vertical differentiation) can capture the reality better and overcome the shortness of one-dimensional model in some way (Wattal et al. 2009). Gabszwicz and Thisse (1986) and Lambertini (1997) have stylized Hotelling model by introducing vertical differentiation in it. Dos Santos Ferreira and Thisse (1996) considered the asymmetric fit cost in Hotelling model to nest horizontal and vertical differentiation. Among the first class of researchers to prove the equilibrium existence of two-dimensional differentiation model, Caplin and Nalebuff (1991) show the existence of pure strategies equilibrium. After that, Kevin and Zach (2012) investigate competition between open source and proprietary software by developing a two-dimensional differentiation model. Telang et al. (2004) apply the two-dimensional model to analysis the competition in search engine market. Wattal et al. (2009) develop a two-dimensional differentiation model by considering a market that has product variety and various possible quality levels, which can overcome the imperfection.

This paper follows the work of Wattal et al. (2009), which has measured product fit (horizontal differentiation) and consumer’s preference on product quality (vertical differentiation) at the same time. Besides, we also investigate the impact of network externality on wearable device competition (Cheng et al. 2011). We not only study the optimal quality and price competition of firms, but also investigate the optimal product compatibility of firms in the presence of network externality.

3 THE BASELINE MODEL

To measure the issue of wearable device competition, we are going to present an outline of a general model with two-dimensional differentiation (Wattal et al. 2009). In wearable device market, there are several different products with different quality levels. The various product brands will produce product variety, which is also called horizontal differentiation. The various quality levels are the vertical differentiation of competitive products. To measure such product competition where consumers have preferences on both of product fit (consumers have more preferences on the product near to her) and product quality (consumers have more preference on higher quality product), we employ a two-dimensional differentiation model where horizontal axis represents consumers’ preference on product attribute, and the vertical axis represents consumers’ preference on product quality. If we use \( x \) and \( \theta \) to represent consumer’s ideal location (her ideal wearable device product attribute) and her preference on quality, the combination of \( (x, \theta) \) in the two-dimensional place for any consumer expresses consumer’s position towards the product.

Consumer’s horizontal position on the two-dimensional space represents her ideal location of wearable device product, which describes the product attributes. We assume consumer’s horizontal location is uniformly distributed on [0,1]. Each consumer incurs a fit cost when she purchases a product. The fit cost is increased in the distance between consumer’s ideal location and the location of the given product. Consumer’s vertical position on the two-dimensional space represents her preference on product quality. We assume consumer’s preference on quality \( \theta \) is uniformly distributed on [0,1]. We also assume consumer’s reservation utility \( v \) is sufficient large that the market is fully covered. Furthermore, we assume each consumer will buy one product finally.
Considering wearable device duopoly compete in the market with each other, firm A and B locating at \( \alpha_1 \) and \( \alpha_2 \) offer products with quality \( s_A \) and \( s_B \) at price \( P_A \) and \( P_B \), respectively. We assume that \( s_A > s_B \) without loss of generality. Let \( t \) be the unit fit cost of consumer. The net utility for consumer locates at \((x, \theta)\) by purchasing from firm A and firm B are given as:

\[
\begin{align*}
 u_A &= v + \theta s_A - t \mid x - \alpha_1 \mid - P_A; \\
 u_B &= v + \theta s_B - t \mid x - \alpha_2 \mid - P_B
\end{align*}
\]

Consumer’s decision about purchasing from firm A or firm B depends on her net utility from two firms. She will choose the product that can bring her a larger utility. The indifference line is defined as the set of consumers who have the same net utilities when they purchase from two firms. Their locations satisfy \( u_A = u_B \) mathematically. Thus, the upper area from the indifference line is the market share of firm A, and the lower one is the market share of firm B. The indifference line is:

\[
\theta(x) = \frac{P_A - P_B}{s_A - s_B} + \frac{t(|x - \alpha_1| - |x - \alpha_2|)}{s_A - s_B}
\]

According to the prior researches about two-dimensional differentiation model, the Fit-Quality (F-Q) ratio (Wattal et al. 2009) was mathematically introduced as \( \mu = t/(s_A - s_B) \). Different possible values of the ratio and the market share of each situation can be seen in Figure 1. Like Figure 1(a), if \( \mu > 1 \), consumers have more preference on product fit. In this situation, each wearable device duopoly will capture consumers located near to him for all values of \( \theta \). Consumer’s preference on product fit dominates her utility when she purchases a wearable device product. We denote this situation as the horizontal dominance differentiation. However, if \( \mu < 1 \) as shown in Figure 1(b), consumers have more preference on product quality. Firms capture consumers with different preference on quality. Firm A captures consumers with higher preference on quality, and firm B captures consumers with lower preference on quality. Therefore, consumer’s preference on product quality dominates her utility. We denote this situation as vertical dominance differentiation. There are some other cases when the indifference line intersects with vertical and horizontal line somewhere in between except for the two figures, but there are no Nash equilibriums exist in these regions.

The competitive firms are beneficial from selling products. We assume the cost related to quality is a quadratic function, and the unit cost on quality is \( k \). We also assume the marginal cost is \( c \). If we let \( D_A \) and \( D_B \) represent the market share of firms, the profits for firms are given as:

\[
\pi_A = (P_A - c)D_A - ks_A^2; \quad \pi_B = (P_B - c)D_B - ks_B^2
\]

In this paper, we apply the two-stage game to seek the optimization strategies for firms (Wattal et al. 2009). In the first stage, firms choose their quality levels simultaneously. In the second stage, they choose prices according to their quality levels. We use backward induction method to solve this two-
stage game model. In our model, we assume firm’s location is exogenously given, because the locations of different products represent the long-term consumers’ choice and they often need significant investments to reposition the product. We will discuss two situations of different locations, including maximal differentiation (firms locate at the opposite ends of the x line) and minimal differentiation (all firms locate at the middle position of x line).

3.1 Maximal Differentiation

When firms are maximized differentiated horizontally, we let them locate at two opposite ends of the horizontal line, i.e. \( \alpha_1 = 0 \) and \( \alpha_2 = 1 \). An example for this case is the competition between 360 Kid’s Guardian and Fitbit. 360 Kid’s Guardian is the wearable device product that targeted to children, but Fitbit is an adults-oriented wearable device product.

**Lemma 1.** In horizontal dominance differentiation for two maximal differentiated products, the firm’s optimal quality level is \( q^{HS}_{12} = q^{HS}_{12} = \frac{1}{12k} \); the optimal price is \( p^{HS}_A = p^{HS}_B = c + t \); the market share is \( D^{HS}_A = D^{HS}_B = \frac{1}{2} \); and the optimal profit is \( \pi^{HS}_A = \pi^{HS}_B = \frac{t}{2} - \frac{1}{144k} \).

Lemma 1 suggests that in horizontal dominance differentiation, firms will offer products with the same quality level at the same price. As a result, firms can earn the same market share and profit. In this case, each firm will serve half of the market for all value of \( \theta \), i.e. \( x(0) = 1/2 \). Furthermore, wearable device firms’ quality level will only determined by unit cost on quality. The price will be positively influenced by fit cost only and marginal cost. Besides, fit cost has a positive impact on firm’s optimal profit, and unit cost on quality has a negative impact on it.

**Lemma 2.** In vertical dominance differentiation for two maximal differentiated products, the firm’s optimal quality levels is \( q^{VS}_A = q^{VS}_B = 0 \); the optimal price is \( p^{VS}_A = c + \frac{4}{27k} \), \( p^{VS}_B = c + \frac{2}{27k} \); the market share is \( D^{VS}_A = \frac{2}{3}, D^{VS}_B = \frac{1}{3} \); the optimal profit is \( \pi^{VS}_A = \frac{4}{81k}, \pi^{VS}_B = \frac{2}{81k} \).

The equilibrium condition in this case is \( 27kt < 2 \), which satisfies \( 0 < \theta_1, \theta_2 < 1 \). The higher-quality firm will serve consumers with high quality preference. Then, the firm will seek a higher market share and profit by supplying a higher quality product at a higher price. The situation for lower-quality firm is inversed. In this case, lower-quality firm will choose the lowest quality, but higher-quality firm will chose a higher quality depends on unit cost on quality. Their prices are positively affected by marginal cost. The prices and profits are all negatively influenced by unit cost on quality.

3.2 Minimal Differentiation

In this case, we investigate the competition of wearable device firms when both of them locate at the centre of the market, that is, \( \alpha_1 = \alpha_2 = 1/2 \). In practice, many firms actually sell undifferentiated products with different quality, such as books, CDs and some others. The example of wearable device competition in this case is the competition between Fitbit and Jawbone, they are all targeted to adults, and they are quality differentiated with each other.

In this case, consumer’s utility is \( u_A = v + \theta_A s_A - t x - p_A \) and \( u_B = v + \theta_B s_B - t x - p_B \). The indifference line is \( \theta(x) = (p_A - p_B)/(s_A - s_B) \). Thus, no equilibriums in horizontal dominance differentiation are possible, because the indifference line is independent of horizontal parameters. However, in vertical dominance differentiation, the indifference line is parallel with x-axis. The results in this case are the
same as maximal differentiated products competition in vertical dominance differentiation. Therefore, we will only investigate maximal differentiation in the following section.

4 THE IMPACT OF NETWORK EXTERNALITY

According to prior researches about network externality (Cheng et al. 2011), it can be divided into direct network externality and indirect network externality in different competitions. In this paper, we only investigate the impact of direct network externality on wearable device competition, because other than products like operating systems, consumers are mainly influenced by the user amounts of wearable device products.

If we denote \( \gamma(\gamma \in [0,1]) \) as the network intensity of wearable device, and \( Q \) is the number of users that have purchased or used the wearable device product, then the “network-generated” value is \( \gamma Q \). Thus, consumer’s utility will be increased when a new user adopt the same products (Cheng et al. 2011). There, \( Q \) is called network size, or effective network size of wearable device product. If a consumer purchase a product with network size of \( Q \), she will obtain utility of \( \delta(x, \theta) = (\theta + \gamma Q)s \) related to product quality.

Like the software industry, wearable device product also has the issue of compatibility. If two wearable devices are compatible, consumer’s utility will be increased by total number of users who have adopted wearable device product regardless of the brand. However, if two wearable device products are incompatible, consumer’s utility will be only increased by the number of users who have used the same product. The difference between compatible and incompatible products will lead to different network size when we examine the impact of network externality on wearable device competition. We will investigate both of incompatible and compatible wearable device products competition with network externality and the compatibility of wearable devices.

4.1 Two Products Are Incompatible

When wearable device products are incompatible, consumers’ utility will be increased by the number of the same product users when they purchase from the product. The effective network size will be equal to the demand of firms, that is, \( D_A \) and \( D_B \) respectively. Besides, \( D_A + D_B = 1 \) is also reasonable since the market is fully covered. Following the basic assumptions and model structures of the former section, we derive consumer’s utilities in this case when they purchase from two firms as Eq. (1). By letting \( u_A = u_B \) mathematically, we also obtain the indifference line as Eq. (2).

\[
\begin{align*}
u_A &= v + (\theta + \gamma D_A)s_A - tx - P_A \\
u_B &= v + (\theta + \gamma D_B)s_B - t(1 - x) - P_B \\
x(\theta) &= \frac{P_B - P_A + t + \gamma D_A s_A - \gamma D_B s_B + \theta (s_A - s_B)}{2t} 
\end{align*}
\]

Case 1: Horizontal Dominance Differentiation for Incompatible Products

Applying the backward induction method and two-stage game, optimal prices and profits when firms have chosen their quality level is shown in Eq. (3). The equilibriums of quality level, optimal price, market share and optimal profit are summarized in Lemma 3.

\[
\begin{align*}
P_A^* &= \frac{(1 - 2\gamma)s_A - (1 + 4\gamma)s_B + 6t + 6c}{6} \\
P_B^* &= \frac{(1 - 2\gamma)s_B - (1 + 4\gamma)s_A + 6t + 6c}{6} \\
\pi_A^* &= \frac{[(1 - 2\gamma)s_A - (1 + 4\gamma)s_B + 6t]^2}{36[2t - \gamma(s_A + s_B)]} - k_s_A^2 \\
\pi_B^* &= \frac{[(1 - 2\gamma)s_B - (1 + 4\gamma)s_A + 6t]^2}{36[2t - \gamma(s_A + s_B)]} - k_s_B^2
\end{align*}
\]
In horizontal dominance differentiation, firm’s optimal price is positively influenced by his own product quality and negatively impacted by rival’s product quality without network externality. Network externality will increase the impact of rival’s product quality on firm’s optimal price, but it will decrease the impact of firm’s own quality on his price. The price difference between two firms is positively affected by their quality difference, and it will be increased by network externality. As for the optimal profit of firms, rival’s product quality has negative impact on it, but the influence of their own product quality on profit is not certainly positive or negative.

**Lemma 3.** In horizontal dominance differentiation for two incompatible wearable devices, the optimal quality level is \( s_{A}^{HS} = s_{B}^{HS} = \frac{2 - \gamma}{24k} \); optimal price is \( p_{A}^{HS} = p_{B}^{HS} = c + t - \frac{\gamma(2 - \gamma)}{24k} \); the market share is still a half for firms; and optimal profit is \( \pi_{A}^{HS} = \pi_{B}^{HS} = \frac{1}{2} \frac{(2 - \gamma)(2 + 11\gamma)}{576k} \) with network externality.

Lemma 3 shows that network externality has negative impact on product quality and price of wearable device. However, it has no impact on firms’ demands. Besides, network externality has positive impact on firms’ profit when network externality is large (\( \gamma > 10/11 \)). The negative effect of network externality on profit is caused by the negative impact of network externality on optimal price.

**Case 2: Vertical Dominance Differentiation for Incompatible Products**

The optimal prices and profits of firms when they have chosen their quality level are given as Eq. (4). The equilibriums in this case are summarized in Lemma 4.

\[
\begin{align*}
 p_{A}^{*} & = \frac{(2 - \gamma)s_{A} - 2(1 + \gamma)s_{B} + 3c}{3} ; &
 p_{B}^{*} & = \frac{(1 - 2\gamma)s_{A} - (1 + \gamma)s_{B} + 3c}{3} ; \\
 \pi_{A}^{*} & = \frac{[(2 - \gamma)s_{A} - 2(1 + \gamma)s_{B}]^{2}}{3[(1 - \gamma)s_{A} - (1 + \gamma)s_{B}]} - ks_{A}^{2} ; &
 \pi_{B}^{*} & = \frac{[(1 - 2\gamma)s_{A} - (1 + \gamma)s_{B}]^{2}}{3[(1 - \gamma)s_{A} - (1 + \gamma)s_{B}]} - ks_{B}^{2} .
\end{align*}
\]

In vertical dominance differentiation, firm’s optimal price is positively affected by higher-quality firm’s quality and negative affected by the lower-quality firm’s product. The price differentiation is determined by the quality differentiation. Network externality will increase the impact of the lower quality on optimal price and decrease the impact of the higher quality on optimal price. This is interesting because firm’s price will be influenced by the lower quality more in the presence of network externality. Network externality also increases the impact of quality differentiation on price differentiation. However, the lower-quality firm’s profit is negatively determined by his quality.

**Lemma 4.** In vertical dominance differentiation for two incompatible wearable devices, firms’ optimal quality levels are \( s_{A}^{VS} = \frac{(2 - \gamma)^{2}}{18k(1 - \gamma)} \), \( s_{B}^{VS} = 0 \); optimal prices are \( p_{A}^{VS} = c + \frac{(1 - 2\gamma)(2 - \gamma)^{2}}{54k(1 - \gamma)} \), \( p_{B}^{VS} = c + \frac{(2 - \gamma)^{3}}{54k(1 - \gamma)} \); the market share of firms are \( D_{A}^{VS} = \frac{2 - \gamma}{3(1 - \gamma)} \), \( D_{B}^{VS} = \frac{1 - 2\gamma}{3(1 - \gamma)} \); and the optimal profits for firms are \( \pi_{A}^{VS} = \frac{(2 - \gamma)^{4}}{324k(1 - \gamma)^{2}} \), \( \pi_{B}^{VS} = \frac{(2 - \gamma)^{2}(1 - 2\gamma)^{2}}{162k(1 - \gamma)^{2}} \) with network externality.

In this case, the equilibrium condition is \( 54k(1 - \gamma)^{2} < (2\gamma^{2} - 2\gamma + 1)(2 - \gamma)^{2} \), which satisfies \( 0 < \theta_{1}, \theta_{2} < 1 \). Lower-quality firm will still choose the lowest quality level in the presence of network externality. Network externality has positive impact on the higher quality and the quality differentiation is increased by the network externality. Network externality has negative impact on lower-quality firm’s price, but it has positive influence on higher-quality firm’s price if \( \gamma > 1/2 \).
Higher-quality firm’s market share is positively affected by network externality and lower-quality firm’s market share is negatively impacted by network externality. Furthermore, network externality will increase firms’ optimal profit. Network externality also positively influences higher-quality firm’s profit, but it has positive impact on lower-quality firm’s quality if and only if \( \gamma > 1/2 \).

### 4.2 Two Products Are Compatible

When the two products are compatible, consumer’s utility will be increased by the number of users who have purchased the wearable device product. The effective network size will be the total number of wearable device users, that is, \( Q = D_A + D_B = 1 \). When a consumer purchases from two firms, her utilities by purchasing from two firms are given as Eq. (5). The indifference line is given as Eq. (6).

\[
\begin{align*}
  u_A &= v + (0 + \gamma) s_A - tx - P_A \\
  u_B &= v + (0 + \gamma) s_B - t(1 - x) - P_B \\
  x(0) &= \frac{P_B - P_A + t + \gamma (s_A - s_B)}{2t} + \frac{\theta (s_A - s_B)}{2t} \quad (6)
\end{align*}
\]

**Case 3: Horizontal Dominance Differentiation for Compatible Products**

**Lemma 5.** In horizontal dominance differentiation for two compatible wearable devices, the optimal quality level is \( s_{A}^{HC} = s_{B}^{HC} = \frac{2\gamma + 1}{12k} \); the optimal price is \( P_{A}^{HC} = P_{B}^{HC} = c + t \); the market share is still a half for firms, and the optimal profit is \( \pi_{A}^{HC} = \pi_{B}^{HC} = \frac{t}{2} - \frac{(1 + 2\gamma)^2}{144k} \) with network externality.

Lemma 5 shows that network externality has positive impact on firms’ quality levels. Network externality has no impact on firm’s optimal price and market share. However, network externality will decrease firm’s optimal profit. The decrease of firm’s profit is mainly caused by the increased quality level and unchanged price and market share.

**Case 4: Vertical Dominance Differentiation for Compatible Products**

**Lemma 6.** In vertical dominance differentiation for two incompatible wearable devices, firms’ optimal quality levels are \( s_{A}^{VC} = \frac{(2 + \gamma)^2}{18k}, s_{B}^{VC} = 0 \); the optimal prices are \( P_{A}^{VC} = c + \frac{(2 + \gamma)^3}{54k}, P_{B}^{VC} = c + \frac{(1 - \gamma)(2 + \gamma)^2}{54k} \); the market share of firms are \( D_{A}^{VC} = \frac{2 + \gamma}{3}, D_{B}^{VC} = \frac{1 - \gamma}{3} \); and the optimal profits for firms are \( \pi_{A}^{VC} = \frac{(2 + \gamma)^4}{324k}, \pi_{B}^{VC} = \frac{(1 - \gamma)^3(2 + \gamma)}{162k} \) with network externality.

In this case, the equilibrium condition is \( 54kt < (1 - \gamma)(2 + \gamma)^2 \) to guarantee \( 0 < \theta_1, \theta_2 < 1 \). In vertical dominance differentiation for compatible products, lower-quality firm will still choose the lowest quality level. However, the higher-quality firm’s quality level is increased by network externality. Besides, network externality has positive impact on higher-quality firm’s price, demand and profit and negative impact on lower-quality product’s outcomes. Therefore, when two competitive products are compatible, firms should try their best to choose higher quality in the presence of network externality.
Proposition 1(a). In vertical dominance differentiation, lower-quality firm will always choose the
lowest quality level no matter the product is compatible or incompatible.

Proposition 1(b). When the two products are incompatible, network externality has negative impact
on firm’s quality in horizontal dominance differentiation, but it has positive impact on higher-quality
firm’s quality in vertical dominance differentiation.

Proposition 1(c). When the two products are compatible, network externality has positive impact on
firm’s quality level in both of horizontal and vertical dominance differentiation.

Proposition 1 demonstrates that in horizontal dominance differentiation, firms will increase their
quality level if and only if they produce compatible products with network externality. In vertical
dominance differentiation, lower-quality firm have no incentives to choose higher quality. However,
the higher-quality firm has enough incentives to choose a higher quality level in the presence of
network externality. Therefore, firms should try their best to supply higher-quality wearable device
product, and force rivals to choose lower-quality product. This threshold can explain the continuous
new products released by firms. For example, Fitbit corporate has released Fitbit Flex and Fitbit Force
sequentially. The same example of Jawbone UP2 also can be observed.

Proposition 2(a). Network externality will decrease firms’ optimal profits in horizontal dominance
differentiation, but it will increase firms’ optimal profits in vertical dominance differentiation.

Proposition 2(b). When the two products are incompatible, network externality has positive impact on
firm’s profit when $\gamma > 10/11$ in horizontal dominance differentiation. Network externality has
positive impact on lower-quality firm’s profit when $\gamma > 1/2$ in vertical dominance differentiation and
positive impact on higher-quality firm’s profit in vertical dominance differentiation.

Proposition 2(c). When the two products are compatible, network externality has negative impact on
firm’s optimal profit in horizontal dominance differentiation. It has positive impact on high-quality
firm’s profit and negative impact on lower-quality firm’s profit in vertical dominance differentiation.

Proposition 2 suggests that wearable device firms are beneficial from network externality in vertical
dominance differentiation. The intuition explanation is that horizontal dominance differentiation
requires firms’ product variety, and consumers’ preference on quality will play less important role in
the competition. Thus, Fitbit and Jawbone are more beneficial in the presence of network externality.
Fitbit and 360 Kid’s Guardian are less beneficial from network externality.

4.3 Optimal Product Design: Compatible or Incompatible

In the industry of wearable device, making its product compatible or incompatible with competitors is
a critical issue. In this section, we are going to compare the outcomes of producing compatible
products and incompatible products. The head-to-head comparison of the outcomes (Cheng et al. 2011)
is employed in this section. We ignore the situation of one-way compatibility, which means only one
firm produce the compatible products, and the other firm will choose to release incompatible on the
other hand. The comparison results are summarized in Proposition 3 to 5.

The optimal quality level differences of different scenarios are given as Eq. (7). The quality levels of
incompatible products are lower than compatible products in horizontal dominance differentiation. In
vertical dominance differentiation, higher-quality product’s quality level is higher when the product is
incompatible if and only if $\gamma > 2(\sqrt{2} - 1)$. This threshold is summarized in Proposition 3.

$$s_A^{HS} - s_A^{HC} = s_B^{HS} - s_B^{HC} = \frac{-5\gamma}{24k} < 0; \quad s_A^{VS} - s_A^{VC} = \frac{\gamma(\gamma^2 + 4\gamma - 4)}{18k(1 - \gamma)}$$ (7)
**Proposition 3.** In horizontal dominance differentiation, producing compatible products requires higher quality. In vertical dominance differentiation, the higher-quality firm will choose higher quality on incompatible products than compatible products if and only if network externality is large. Specially, \( s_{A}^{HS} = s_{B}^{HS} > s_{A}^{HC} = s_{B}^{HC} \) and \( s_{A}^{VS} > s_{B}^{VC} \) when \( \gamma > 2(\sqrt{2} - 1) \).

The optimal price and demand differences in different cases are shown in Eq. (8). In horizontal dominance differentiation, firms will charge more if their products are compatible, i.e. \( P_{A}^{HS} > P_{B}^{HS} \) and \( P_{B}^{HS} > P_{B}^{HC} \). The market shares of firms are equal, i.e. \( D_{A}^{HS} = D_{A}^{HC} = 1/2 \). In vertical dominance differentiation, higher-quality firm will charge more if his product is compatible if network externality is large. Lower-quality firm will charge more if his product is compatible. However, higher-quality firm will catch more consumers if he produces incompatible products. Lower-quality firm will catch more consumers if he produces compatible products.

\[
\begin{align*}
P_{A}^{HS} - P_{A}^{HC} &= \frac{-\gamma(2-\gamma)}{24k} < 0; \quad P_{A}^{VS} - P_{A}^{VC} = \frac{-\gamma^{4} - 7\gamma^{3} + 3\gamma^{2} - 8\gamma + 12}{54k(1-\gamma)} > 0 \\
P_{B}^{VS} - P_{B}^{VC} &= \frac{-\gamma^{4} - 7\gamma^{3} + 3\gamma^{2} + 12\gamma - 12}{54k(1-\gamma)} < 0; \quad D_{A}^{VC} - D_{B}^{VC} = \frac{-\gamma^{2}}{3(1-\gamma)} > 0
\end{align*}
\]

**Proposition 4.** Competitive wearable device firms will set a higher price when they produce compatible products, although it will decrease their demands in vertical dominance differentiation. Specially, \( P_{i}^{HC} > P_{i}^{HS}, D_{i}^{HC} = D_{i}^{HS} \) and \( P_{i}^{VC} > P_{i}^{VS}, D_{i}^{VC} < D_{i}^{VS} \), for \( i = A, B \).

The profits differences in different scenarios are given as Eq. (9). From the expressions, we know that firms will produce incompatible products in horizontal dominance differentiation, i.e. \( \pi_{A}^{HS} - \pi_{A}^{HC} = \pi_{B}^{HS} - \pi_{B}^{HC} > 0 \) when \( 4/27 < \gamma < 1 \). Similarity, in vertical dominance differentiation competition, choosing the incompatible product is more rational for higher-quality product firm when \( \gamma > 2(\sqrt{2} - 1) \), which leads to \( \pi_{A}^{VS} > \pi_{A}^{VC} \). The incompatible product release condition for lower-quality product firm is \( \gamma > \gamma_{0} \), where \( \gamma_{0} > 1/2 \). Thus, producing incompatible products is rational with a higher network externality, or firms should release compatible products.

\[
\begin{align*}
\pi_{A}^{HS} - \pi_{A}^{HC} &= \pi_{B}^{HS} - \pi_{B}^{HC} = \frac{\gamma(27\gamma - 4)}{576k} \\
\pi_{A}^{VS} - \pi_{A}^{VC} &= \frac{\gamma(\gamma^{2} + 4\gamma - 4)[(2-\gamma)^{2} + (2 + \gamma)^{2}(1-\gamma)]}{324k(1-\gamma)^{2}} \\
\pi_{B}^{VS} - \pi_{B}^{VC} &= \frac{-\gamma(\gamma^{2} - 2\gamma + 2)(\gamma^{3} + 2\gamma^{2} - 8\gamma + 4)}{162k(1-\gamma)^{2}}
\end{align*}
\]

**Proposition 5.** Wearable device firms should let their products incompatible when network externality is large, and they should release compatible products when network externality is small. Specially, \( \pi_{A}^{HS} > \pi_{A}^{HC} = \pi_{B}^{HC} \), \( \pi_{A}^{VS} > \pi_{A}^{VC} \) and \( \pi_{B}^{VS} > \pi_{B}^{VC} \) if and only if \( \gamma > \gamma^{*} \).

In summary, the three propositions demonstrate the best strategy for wearable device firms. They also can be applied in the competition of today’s wearable device market. Fitbit and 360 Kid’s Guardian are competitive wearable device products in Chinese market. The competition between them is horizontal dominance differentiation, since they have different target users. Fitbit is targeted to adults mainly, and 360 Kid’s Guardian is faced to children on the other side. Thus, by applying the proposition, they are more likely to make their products incompatible since they have different targeted users. However, as for the competition between Fitbit and Jawbone, both of them are targeted to adults. The competition between them is mainly the quality differentiation. Thus, the competition between Fitbit and Jawbone is vertical dominance differentiation. They are more likely to make their
products compatible since they target to the same group of users and compatible products will bring more user evaluations. Furthermore, regardless of the competition between which firms, they should make compatible products when network externality is small. However, they should release incompatible products when network externality is large.

5 CONCLUSIONS & DISCUSSIONS

Healthcare industry has developed thousands of years. The challenges in today’s healthcare development have shown new features. The application of IT/IS in healthcare has created the birth of e-Health and mobile health, which has improved the development of healthcare industry a lot. To date, wearable device, as a specific application of mobile health, has attracted more and more eyes of researchers and officers. In this paper, we investigate the competition of wearable devices and the impact of network externality on the competition. Furthermore, we also study the optimal product design of wearable device, to make them compatible or incompatible with each other.

By investigating four different scenarios in the framework of two-dimensional differentiation model, we find that firms can seek similar benefits in maximal differentiation and minimal differentiation in the two-dimensional competition. The quality differentiation is the main factor that causes the price differentiation of wearable device products. Network externality will increase the quality and price differentiation. The threshold explains the price differentiation between Fitbit Force and Jawbone UP2. Network externality will decrease firms’ profit in horizontal dominance difference, but it will increase firms’ profit in vertical dominance differentiation. This result demonstrates that Fitbit and Jawbone are more beneficial from network externality when they compete with each other, and the competition between Fitbit and 360 Kid’s Guardian is less beneficial from network externality. Finally, we find that firms are better to release compatible products when the network externality is small, or they should make their products incompatible when network externality is large. Therefore, Fitbit should let their products compatible with Jawbone and incompatible with 360 Kid’s Guardian.

This research only supplies a framework of two-dimensional differentiation model with network externality. There are some possible ways to extend this research. One possible extension to this paper is to introduce the strategic behaviour into this game, such as the entry deterrence and entry accommodation strategies. The comparison of firms’ outcomes in different strategies is feasible. In our model, we have defaulted that the market is free-entry, which will lead to a continuous new entries until all firms’ optimal profits are zero. Obviously, the incumbent has enough incentives to deterrence the potential entrants if their profit will be strengthen than zero. The incumbent will also make some strategic decisions to maximize his profit. Thus, we can extend this research by considering the strategic behaviour of duopoly. The second possible way to extension this paper is to apply this model in Salop’s unit circle model to study the competition of multiple sellers, which can improve the results in duopoly competition. In unit circle model, the whole market will be a sphere in two-dimensional differentiation model. We can use numerical simulation method to solve the model. The third possible extension of this paper is to investigate firms’ optimal location choice on the line, which is also about the optimal product design of wearable device. Furthermore, we also can measure the fully covered market competition v.s. partially covered market competition in this model, which can investigate firms’ optimal strategies when they compete in the market.

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