

# ADOPTION OF BIG DATA ANALYTICS IN HEALTHCARE: THE EFFICIENCY AND PRIVACY

He Li, School of Economic Information Engineering, Southwestern University of Finance and Economics, Chengdu, China, oliver.lihe@gmail.com

Jing Wu<sup>\*</sup>, School of Economic Information Engineering, Southwestern University of Finance and Economics, Chengdu, China, kaitlynwu@swufe.edu.cn

Ling Liu, School of Economic Information Engineering, Southwestern University of Finance and Economics, Chengdu, China, lingliu@swufe.edu.cn

Qing Li, School of Economic Information Engineering, Southwestern University of Finance and Economics, Chengdu, China, liq\_t@swufe.edu.cn

## Abstract

*Big data analytics (BDA) has shown distinctive advantages on improving healthcare outcomes and reducing healthcare cost. While it also increases consumer's privacy risk. We thus focus on the question that whether health IT providers should adopt BDA to increase healthcare efficiency in the presence of privacy concerns. We focus on the healthcare wearable device market due to its natural advantages and popularity in healthcare field. Since the consumers has various preferences on the products (horizontal differentiation) with different quality levels (vertical differentiation), we adopt a two-dimensional product differentiation model to investigate the effects of BDA's efficiency-privacy tradeoff on the competition. Our results demonstrate that health IT providers should adopt BDA technology when their efficiency-privacy tradeoffs are large. Besides, when BDA cost on per unit benefit is small, or the investment has more unit benefit for itself than the rival, health IT providers also should adopt BDA. Our findings provide insights to business managers on how to optimize strategies of BDA adoption. Social planners are also guided to conduct better policies to improve health service quality by promoting BDA adoption in healthcare sector.*

*Keywords: Big Data Analytics, Healthcare, Wearable Devices, Efficiency, Privacy, Two-dimensional Product Differentiation.*

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<sup>\*</sup> Corresponding author

# 1 INTRODUCTION

In healthcare sector, big data analytics (BDA) is proved to be effective on improving healthcare outcome by recognizing individuals' healthcare conditions, identifying risks for serious health problems, and providing personalized healthcare services, etc. (Ghani et al. 2014). In addition, it also has potentials to reduce healthcare cost by recognizing healthcare resources waste, providing closer monitoring, and increasing healthcare efficiency (Kayyali et al. 2013). In the process of BDA implementation in healthcare sector, wearable device is proved to be a better data source depending on its advantages and popularity in healthcare. Wearable device can collect and transform continuous real-time healthcare data and reveal unseen scanning and sensory features (Chan et al. 2012). With the development of these technologies, a new wave of revolution is under way in healthcare sector. For instance, in the project of Parkinson's disease treatment collaborated by Intel, Amazon Web Services, and Michael J. Fox's charity, smart watches gather real-time personal health data. Then, the data is transformed to the BDA platform built by Intel, which finally deploys on a cloud infrastructure, Amazon Web Services, to allow scientists to do research.

However, the privacy issues will continue to be a major concern in this process. BDA technology generates more privacy concerns for consumers (Fabian et al. 2015) and increases privacy risks (Barocas and Nissenbaum 2014; Kshetri 2014). First, the large amount and concentration of data stored by healthcare organizations makes it more appealing for hackers. Besides, in order to provide personalized services, some tracking tools should be employed to build a detailed database of personal information, which increases consumer's privacy risks. In addition, a higher variety of information in big data makes it more difficult to protect information through the combination of structured and unstructured data from different sources. Furthermore, organizations are more likely to lack internal capacity and technologies to protect the information during the peak data collection and flow periods in BDA implementation process.

Therefore, both BDA's efficiency in healthcare and personal privacy protection are essential for consumers. However, the implementation of BDA in healthcare will bring more privacy risks with the increase of healthcare efficiency. Consumers and healthcare providers thus face the tradeoff between BDA's healthcare efficiency and privacy concern. Hence, we focus on the question that whether health IT (healthcare wearable device) providers should adopt BDA technology in the presence of efficiency-privacy tradeoff. We measure this issue in a two-dimensional differentiation framework, since there are various products (horizontal differentiation) with different quality levels (vertical differentiation) in the market. In addition, we consider the impacts of BDA on consumers as both perceived quality improvement and perceived privacy loss (Kim and Lee 2009), because BDA increases healthcare efficiency and privacy risk at the same time.

Our analysis shows the conditions when health IT providers should invest on BDA technology. Besides, this study also demonstrates the effects of BDA's efficiency-privacy tradeoff on firm's quality and price adjustments and equilibrium outcomes in different cases. This study investigates the effects of BDA's specific factor, efficiency-privacy tradeoff, on its adoption in healthcare sector, by developing a stylized two-dimensional product differentiation model. This approach provides some guidelines for future big data theoretical research. Besides, our results not only make guidelines for business managers to conduct optimal competition strategies and make proper decisions about whether to adopt BDA, but also guide social planners to make better policies so that to provide better healthcare services.

The rest of this paper is organized as follows. Section 2 reviews some related literatures. We present the baseline model in section 3, which is followed by the analysis of firm's optimal BDA adoption decisions in Section 4. The conclusions and discussions are shown in section 5.

## 2 LITERATURE REVIEW

This study is related to prior studies about health IT provider's optimal strategy from economic perspective. Among them, Ozdemir et al. (2011) study the incentives for healthcare providers to adopt

electronic health record (EHR) and the potential role of personal health record (PHR) in facilitating healthcare data sharing. They find that healthcare service providers do not have incentives to share patient's healthcare information, but an independent PHR platform will create enough incentives for healthcare providers to share healthcare data. Huang et al. (2014) investigate the optimal information security investment of HIS by stylizing an analytical network model. They show that only when the potential loss of security events reaching certain critical value, organizations would only spend a fraction of intrinsic security investment on HIS.

This study also relates to literatures about two-dimensional product differentiation model. Following the definition of Lancaster (1971) about product differentiation type, horizontal differentiation reflects the variety of product, and vertical differentiation reflects quality of product. The combination of horizontal and vertical (two-dimensional) differentiation not only captures the reality better, but also provides additional insights that could be overlooked in one-dimensional model (Wattal et al. 2009). Since Caplin and Nalebuff (1991) proved the equilibrium existence of two-dimensional differentiation model, it has been adopted in various settings. Telang et al. (2004) measure the competition in search engine market by adopting a stylized two-dimensional differentiation model. Wattal et al. (2009) model the personalization characteristics in the framework and study firm's optimal personalization and quality investment. Zhu and Zhou (2012) investigate the competition between open source and proprietary software in the framework of two-dimensional differentiation.

Another related literature stream is the privacy issues in healthcare and big data context. Researchers have studied firm's optimal strategy in the presence of consumer privacy concern. Kim and Lee (2009) employ a vertical differentiation model to study the web-based customer service quality competition in the presence of consumer privacy concern. Wattal (2007) analyzes the optimal personalization strategy such as the scope of personalization in the presence of consumer privacy concern by stylizing the horizontal differentiation model. In addition, researchers also have investigated the effects of privacy concern on consumer's intention to adopt health IT. Li et al. (2014) suggest that general privacy concern positively affects consumer's perceived privacy risk of PHR. Bansal et al. (2010) assert that health information privacy concern has significant influence on consumer's trust in the healthcare website and intention to disclose health information. Ramanathan et al. (2013) find that privacy protection and invasiveness are the primary factors that influence young users' use of mobile health. Furthermore, researchers also have discussed the impact of big data on consumer privacy and personal data security from qualitative perspective (Barocas and Nissenbaum 2014; Kshetri 2014).

In this paper, we investigate health IT provider's optimal strategy of BDA adoption by considering the tradeoff between BDA's healthcare efficiency and privacy concern. Our study contributes to prior two-dimensional product differentiation model references (Wattal et al. 2009; Zhu and Zhou 2012) by considering the effects of consumer's perceived privacy concern. In addition, this work also provides theoretical perspective on understanding the dynamics of privacy concern and BDA technology in healthcare, which is quite different from prior related studies from behavioural perspectives (Bansal et al. 2010; Li et al. 2014).

### **3 THE MODEL**

We adopt a two-dimensional product differentiation model (Wattal et al. 2009) to study healthcare wearable devices competition, since there are various products (horizontal differentiation) with different quality levels (vertical differentiation) in the market. We study the competition between two types of firms: the firm produces fitness wearable device (firm 1) and the firm provides medical wearable device (firm 2). We assume that firm 1 and firm 2 offer product of quality  $s_1$  and  $s_2$  at price  $p_1$  and  $p_2$  on the location of 0 and 1 on the Hotelling (1929) line, respectively.

We also consider two dimensions of consumer preferences. Horizontally, consumers have different tastes toward various kinds of wearable devices. The healthy and the younger consumers have more possibilities to adopt a fitness wearable device, but the sick and the elder users are more likely to purchase a wearable device with medical functions. We thus assume consumers are uniformly distributed on the Hotelling (1929) line depending on their preferences. The consumer who has more

preferences on fitness (medical) functions locates near 0 (1). Consumers incur a fit cost when they purchase a product, which is increasing in the distance between their ideal locations and actual locations. We define  $t$  as the unit fit cost. Vertically, consumers have preferences on the product quality. Consumers always prefer the higher-quality product. Many factors, such as, comfortableness, function, efficiency, fashionableness, would be the important dimensions of healthcare wearable device quality. To simplify the model, we only consider the overall quality of healthcare wearable device. We use  $\theta$  to denote consumer's preference on product quality, which is assumed to be uniformly distributed over a unit line, i.e.  $\theta \in [0,1]$ . Therefore, the coordinates of  $(x, \theta)$  in the plane represents consumer's position towards the product.

Then, we model the effects of BDA on consumer's utility. On one side, BDA increases the quality of healthcare wearable device. BDA technology holds the promise of making effective usage of the larger quantities of data to support a wide range of healthcare functions, including the disease surveillance, clinical decision support systems, and individual healthcare management (Dembosky 2012). On the other side, BDA also increases consumer's perceived health information privacy risk. BDA has the tendency and potential to extract extra information beyond the regular healthcare data. Besides, the re-identification is more likely to be achieved by using BDA technology (Kshetri 2014). Thus, we assume consumer's perceived quality is increased  $\delta$  by BDA, meanwhile, the adoption of BDA in healthcare wearable device causes a consumer privacy loss  $\alpha^\dagger$ .

We also assume each consumer has a reservation utility  $v$  for the devices, and  $v$  is sufficient large so that the market is fully covered. Furthermore, we assume each consumer only buy one product finally. Hence, the consumer locates at  $(x, \theta)$  obtains the utility of  $u_i = v + \theta(s_i + \delta) - t|x - x^*| - \alpha - p_i$  and  $u_j = v + \theta s_j - t|x - x^*| - p_j$  when purchasing from the firm with and without BDA, respectively.  $s_i$  ( $s_j$ ) and  $p_i$  ( $p_j$ ) represent the quality and price of the firm with (without) BDA. Consumers will choose the product that brings them more net utilities. The indifference line is defined as the set of consumers who have the same net utilities for two products.

Firm's revenue mainly comes from selling the product. For each firm, we assume a constant marginal cost  $c$ , and a quadratic cost for quality  $k \cdot s^2$ , where  $k$  is the unit cost on quality and  $s$  is the product quality. In addition, we assume the BDA implementation cost is  $m\delta$ , where  $m$  is the unit cost on BDA efficiency. Thus, if we use  $q_i$  and  $q_j$  to denote the market share of the firm with and without BDA, their profit functions are given as  $\pi_i = (p_i - c)q_i - ks_i^2 - m\delta$  and  $\pi_j = (p_j - c)q_j - ks_j^2$ , respectively.

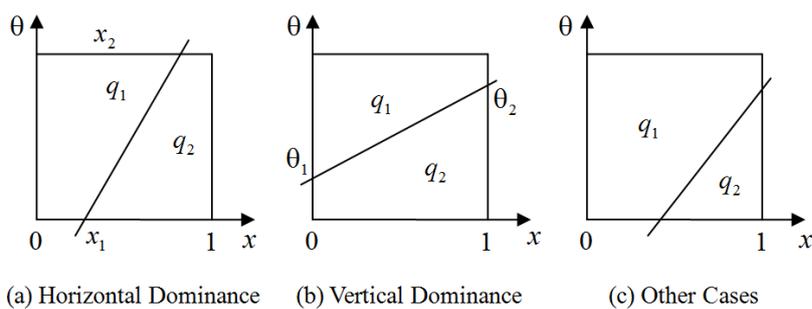


Figure 1. The Market Structure

Depending on the location of indifference line, the market can be divided into horizontal dominance and vertical dominance (Wattal et al. 2009). If the market is horizontal dominance as shown in Figure 1(a), the indifference line intersects both  $\theta = 0$  and  $\theta = 1$ , each firm captures consumers located near

<sup>†</sup> In this research-in-progress paper, we assume that all consumers have the same level of preferences on BDA efficiency and privacy loss caused by BDA. However, this assumption limits the paper in some degree, and we will consider consumer's heterogeneity toward BDA's efficiency and privacy risk in healthcare in future study.

to him for all values of  $\theta$ . Consumer's preference on product fit dominates her utility. However, in vertical dominance as shown in Figure 1(b), the indifference line intersects both  $x=0$  and  $x=1$ . One firm captures consumers with higher preference on quality, and the other firm captures consumers with lower preference on quality. Hence, consumer's preference on product quality dominates her utility. There are no Nash equilibriums lies in other regions when the indifference line intersects with vertical and horizontal line somewhere in between as shown in Figure 1(c). Therefore, we investigate both of horizontal dominance and vertical dominance. We apply a two-stage game to seek the equilibriums. In the first stage, firms simultaneously choose their quality levels. In the second stage, they simultaneously decide their prices according to the quality levels. Backward induction method is employed to solve the model.

### 3.1 No Firm Adopts Big Data Analytics

If no firm adopts BDA, the utility functions are  $u_1 = v + \theta s_1 - tx - p_1$  and  $u_2 = v + \theta s_2 - t(1-x) - p_2$ . Firms' profit functions are  $\pi_1 = (p_1 - c)q_1 - ks_1^2$  and  $\pi_2 = (p_2 - c)q_2 - ks_2^2$ . Solving the two-stage game, the equilibriums are shown in Proposition 1.

**Proposition 1.** If no firm adopts BDA strategy, the equilibriums are  $s_1^{HN} = s_2^{HN} = \frac{1}{12k}$ ;  $p_1^{HN} = p_2^{HN} = c + t$ ;  $q_1^{HN} = q_2^{HN} = \frac{1}{2}$ ;  $\pi_1^{HN} = \pi_2^{HN} = \frac{t}{2} - \frac{1}{144k}$  in horizontal dominance. The equilibriums in vertical dominance differentiation are  $s_1^{VN} = \frac{2}{9k}, s_2^{VN} = 0$ ;  $p_1^{VN} = c + \frac{4}{27k}, p_2^{VN} = c + \frac{2}{27k}$ ;  $q_1^{VN} = \frac{2}{3}, q_2^{VN} = \frac{1}{3}$ ;  $\pi_1^{VN} = \frac{4}{81k}, \pi_2^{VN} = \frac{2}{81k}$  under the condition of  $27kt < 2$ .

Proposition 1 demonstrates that if no firm adopts BDA in horizontal dominance, firms will offer products with the same quality at the same price. As a result, they earn the same market share and profits. However, in vertical dominance, the higher-quality firm will seek a higher market share and profit by supplying a higher quality product at a higher price. In this case, lower-quality firm will choose the lowest possible quality, but higher-quality firm will chose a higher quality level.

### 3.2 One Firm Adopts Big Data Analytics

When firm 1 adopts BDA strategy while firm 2 does not adopt it, consumer's net utility for firm 1 and firm 2 are  $u_1 = v + \theta(s_1 + \delta) - tx - \alpha - p_1$  and  $u_2 = v + \theta s_2 - t(1-x) - p_2$ , respectively. Accordingly, firms' profit functions are  $\pi_1 = (p_1 - c)q_1 - ks_1^2 - m\delta$  and  $\pi_2 = (p_2 - c)q_2 - ks_2^2$ , respectively. Solving the two-stage game, we obtain the equilibriums in this case as shown in Proposition 2.

**Proposition 2(a).** If one firm adopts BDA in horizontal dominance, the optimal quality is  $s_1^{HO} = \frac{1}{12k} + \frac{\lambda}{2}$ ;  $s_2^{HO} = \frac{1}{12k} - \frac{\lambda}{2}$ ; the optimal price is  $p_1^{HO} = c + t + 6kt\lambda$ ;  $p_2^{HO} = c + t - 6kt\lambda$ ; the optimal demand is  $q_1^{HO} = \frac{1}{2} + 3k\lambda$ ;  $q_2^{HO} = \frac{1}{2} - 3k\lambda$ ; and the optimal profit is  $\pi_1^{HO} = \frac{t}{2} - \frac{1}{144k} + \frac{(72kt-1)}{4}(k\lambda^2 + \frac{\lambda}{3}) - m\delta$ ;  $\pi_2^{HO} = \frac{t}{2} - \frac{1}{144k} + \frac{(72kt-1)}{4}(k\lambda^2 - \frac{\lambda}{3})$ , where  $\lambda = \frac{\delta - 2\alpha}{36kt - 1}$ .

The equilibrium condition is  $[12kt(2-\sigma) - \sigma]\delta < t(36kt - 1)$  when firm 1 offers the higher-quality product. However, the condition is  $[12kt(1+\sigma) - \sigma]\delta > t(1 - 36kt)$  in the opposite case. The term of privacy sensibility ( $\sigma$ ) is introduced to represent the degree to which consumer's perceived privacy loss is associated with the unit of healthcare efficiency. Accordingly, the efficiency-privacy relationship is  $\alpha = \sigma\delta$ . We also define efficiency-privacy tradeoff indicator ( $\lambda$ ) to represent consumer's net perception for BDA. Proposition 2(a) suggests that the firm will choose a higher quality and price after adopting BDA. Response to it, the rival would decrease its quality level and price to increase the differentiation. As a result, the firm with BDA enjoys a higher market share and revenue, and the other firm would burden the market share and revenue decrease situation. In this case,

the healthcare efficiency ( $\delta$ ) increases firm's quality, price, market share, and revenue, meanwhile, decreases the rival's outcomes. In addition, the perceived privacy loss ( $\alpha$ ) has the opposite effects on the equilibriums compared with the impacts of healthcare efficiency. Furthermore, the efficiency-privacy tradeoff indicator ( $\lambda$ ) positively affects the performances of the firm with BDA and negatively influences the performances of the rival when the privacy sensitivity ( $\sigma$ ) is small.

**Proposition 2(b).** In vertical dominance, if firm 1 chooses higher quality (i.e.,  $\Delta s = s_1 + \delta - s_2 > 0$ ), the equilibrium is  $p_1^* = c + \frac{2\Delta s - \alpha}{3}$ ;  $p_2^* = c + \frac{\Delta s + \alpha}{3}$ ;  $q_1^* = \frac{2\Delta s - \alpha}{3\Delta s}$ ;  $q_2^* = \frac{\Delta s + \alpha}{3\Delta s}$ ;  $\pi_1^* = \frac{(2\Delta s - \alpha)^2}{9\Delta s} - ks_1^2 - m\delta$ ;  $\pi_2^* = \frac{(\Delta s + \alpha)^2}{9\Delta s} - ks_2^2$ ; Otherwise, the equilibrium is  $p_1^* = c - \frac{2\Delta s + \alpha}{3}$ ;  $p_2^* = c - \frac{\Delta s - \alpha}{3}$ ;  $q_1^* = \frac{2\Delta s + \alpha}{3\Delta s}$ ;  $q_2^* = \frac{\Delta s - \alpha}{3\Delta s}$ ;  $\pi_1^* = -\frac{(2\Delta s + \alpha)^2}{9\Delta s} - ks_1^2 - m\delta$ ;  $\pi_2^* = -\frac{(\Delta s - \alpha)^2}{9\Delta s} - ks_2^2$ .

Different from the results in horizontal dominance, quality differentiation is more important in this case. Proposition 2(b) shows that if one firm adopts BDA in vertical dominance differentiation, both firms' prices, demands, and revenues are increased by the quality differentiation between them. Besides, quality differentiation will increase the price differentiation and decrease the demand differentiation. Furthermore, consumer's perceived privacy loss always positively affects the rival's performance and negatively impacts its own competition outcomes.

### 3.3 Both Firm Adopt Big Data Analytics

If both firms initiative BDA with the same healthcare efficiency, their products will not be differentiated in terms of BDA adoption. Thus, we assume that firms have different BDA efficiencies and privacy risks. In such case, consumer's utilities for two firms are  $u_1 = v + \theta(s_1 + \delta_1) - tx - \alpha_1 - p_1$  and  $u_2 = v + \theta(s_2 + \delta_2) - t(1-x) - \alpha_2 - p_2$ , respectively. Accordingly, firms' optimal profit functions are  $\pi_1 = (p_1 - c)q_1 - ks_1^2 - m\delta_1$  and  $\pi_2 = (p_2 - c)q_2 - ks_2^2 - m\delta_2$ . Solving the two-stage game, the equilibriums in this case are shown in Proposition 3.

**Proposition 3(a).** If both firms adopt BDA in horizontal dominance, the equilibriums are

$$s_1^{HB} = \frac{1}{12k} + \frac{\varphi}{2}; s_2^{HB} = \frac{1}{12k} - \frac{\varphi}{2}; p_1^{HB} = c + t + 6kt\varphi; p_2^{HB} = c + t - 6kt\varphi; q_1^{HB} = \frac{1}{2} + 3k\varphi; q_2^{HB} = \frac{1}{2} - 3k\varphi;$$

$$\pi_1^{HB} = \frac{t}{2} - \frac{1}{144k} + \frac{(72kt-1)}{4}(k\varphi^2 + \frac{\varphi}{3}) - m\delta_1; \pi_2^{HB} = \frac{t}{2} - \frac{1}{144k} + \frac{(72kt-1)}{4}(k\varphi^2 - \frac{\varphi}{3}) - m\delta_2.$$

$$\text{where } \varphi = \lambda_1 - \lambda_2 = \frac{(\delta_1 - 2\alpha_1) - (\delta_2 - 2\alpha_2)}{36kt - 1}.$$

In this case, when firm 1 offers higher quality after adopting BDA, the equilibrium condition is  $[12kt(2 - \sigma) - \sigma](\delta_1 - \delta_2) < t(36kt - 1)$ . Otherwise, the condition is  $[12kt(1 + \sigma) - \sigma](\delta_2 - \delta_1) < t(36kt - 1)$ . Proposition 3(a) shows that if both firms have adopted BDA in horizontal dominance, the equilibriums are affected by their BDA efforts differentiation more than each single firm's BDA investment. In addition, the firm with higher investment on BDA will be more beneficial than the rival in this case. Furthermore, the firm with higher BDA investment is also beneficial from the efficiency-privacy tradeoff differentiation, because the differentiation not only increases its competition advantages, but also increases both of horizontal and vertical differentiation.

**Proposition 3(b).** If both firms adopt BDA in vertical dominance, the equilibriums are

$$p_1^* = c + \frac{2\Delta\bar{s} - \Delta\alpha}{3}; p_2^* = c + \frac{\Delta\bar{s} + \Delta\alpha}{3}; q_1^* = \frac{2\Delta\bar{s} - \Delta\alpha}{3\Delta\bar{s}}; q_2^* = \frac{\Delta\bar{s} + \Delta\alpha}{3\Delta\bar{s}};$$

$$\pi_1^* = \frac{(2\Delta\bar{s} - \Delta\alpha)^2}{9\Delta\bar{s}} - ks_1^2 - m\delta_1; \pi_2^* = \frac{(\Delta\bar{s} + \Delta\alpha)^2}{9\Delta\bar{s}} - ks_2^2 - m\delta_2.$$

where  $\Delta\bar{s} = s_1 + \delta_1 - s_2 - \delta_2$  and  $\Delta\alpha = \alpha_1 - \alpha_2$ .

Proposition 3(b) shows that the differentiation of BDA efficiency increases the higher-quality firm's price and decreases the rival's price. But the privacy loss differentiation decreases the higher-quality firm's price and increases the lower-quality firm's price. Different from the case when one firm adopts BDA in vertical dominance, the market share is more affected by the ratio of privacy differentiation and quality differentiation (i.e.,  $\Delta\alpha / \Delta\bar{s}$ ). The ratio will decrease the higher-quality firm's market share and increase the lower-quality firm's demand.

## 4 OPTIMAL DECISION ON BDA ADOPTION

In this section, we are going to analyze firm's optimal decisions about BDA adoption by employing a game-theoretical method. We regard firm's profit when no firm adopts BDA as benchmark payoff (i.e.,  $\pi_0 = \pi^{HN}$ ). Besides, we also define two import factors, firm's unit benefit of BDA adoption ( $\gamma$ ) and the unit impact of BDA adoption on the rival ( $\varepsilon$ ), to measure the investment effects of BDA. We assume  $\gamma > \varepsilon$ , since BDA investment has more impact on firm's own outcomes. When it refers to the case when both firms adopt BDA, we measure the two factors as the function of the efficiency-privacy tradeoff differentiation. We assume firm 1 has the higher efficiency-privacy tradeoff without loss of generality. The decision matrix is given as Table 1. By analyzing the matrix, we obtain firm's optimal decisions of BDA adoption under different conditions as shown in Figure 2.

Firm 1	Firm 2	
	Not Adopt	Adopt
Not Adopt	$\begin{pmatrix} \pi_0 \\ \pi_0 \end{pmatrix}$	$\begin{pmatrix} \pi_0 + \varepsilon\lambda_2 \\ \pi_0 + \gamma\lambda_2 - m\delta_2 \end{pmatrix}$
Adopt	$\begin{pmatrix} \pi_0 + \gamma\lambda_1 - m\delta_1 \\ \pi_0 + \varepsilon\lambda_1 \end{pmatrix}$	$\begin{pmatrix} \pi_0 + \gamma(\lambda_1 - \lambda_2) - m\delta_1 \\ \pi_0 + \gamma(\lambda_2 - \lambda_1) - m\delta_2 \end{pmatrix}$

Table 1. The Decision Matrix of Big Data Adoption

**Corollary 1.** Health IT providers should adopt BDA technology when their efficiency-privacy tradeoffs ( $\lambda_1, \lambda_2$ ) are large.

Corollary 1 shows the condition when firms have incentives to invest on BDA. The implementation of BDA in healthcare increases consumer's perceived product quality by offering higher efficiency, meanwhile, firm's BDA adoption also increases consumer's perceived privacy risk because the application of BDA in healthcare may generate more consumer's personal information. Thus, firms should pay more attention to BDA's net benefit for consumer, which is denoted as the tradeoff results between efficiency and privacy concern. If consumer's perceived quality improvement is higher than the perceived privacy loss, firm's BDA adoption is effective.

**Corollary 2.** When BDA implementation cost on per unit benefit ( $m\delta/\gamma$ ) is small, or the investment has more unit benefit for itself than the rival ( $\varepsilon/\gamma$  is small), health IT providers should adopt BDA.

Corollary 2 provides two conditions when firms are more beneficial to adopt BDA. First, when per unit benefit of BDA adoption requires less investment, firms will have more incentives to adopt BDA in healthcare. Second, when the BDA investment has more effects on firm's own revenue than the rival, firms would have more possibilities to investment on the technology. This result not only guides healthcare wearable device managers to strategically decide whether adopt BDA or not, but also make some guidelines for social planners to conduct better policies to promote the adoption of BDA in healthcare sector. Social planners can make policies to reduce BDA cost, such as the increase of BDA technology research and increase the competition in BDA technology sector. Besides, they also can

take measures to promote the competition in healthcare wearable device market, so that to decrease the impact of firm's BDA investment on the rivals.

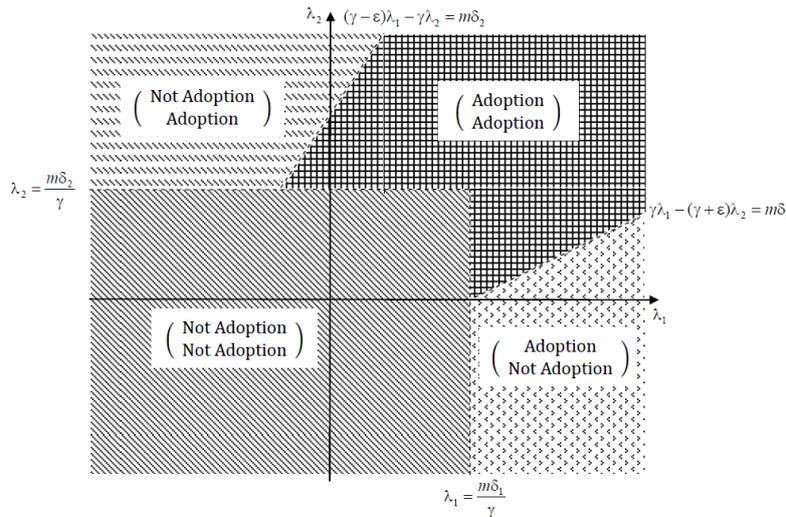


Figure 2. The Overall Equilibrium in Horizontal Dominance

## 5 CONCLUSIONS AND DISCUSSIONS

In this paper, we studied wearable device firm's optimal strategy of BDA adoption. We employ a two-dimensional differentiation framework to investigate the effects of BDA's efficiency-privacy tradeoff on firm's competition and BDA adoption decision. We regard the effects of BDA investment on consumer's perceptions as both of perceived quality improvement and privacy loss. By comparing consumer's preference on each differentiation dimension, we consider both of horizontal and vertical dominance cases. Our model indicates the conditions when firms should adopt BDA, and how firms should adjust their prices and quality levels under different conditions.

This study is among the first to apply economic theories in big data field. We investigate the effects of BDA's specific factors, healthcare efficiency and privacy risk, on its adoption in healthcare sector, by developing a stylized two-dimensional product differentiation model. Besides, BDA's benefit and cost for firms and BDA's efficiency are also considered in the model. This approach provides some guidelines for future big data theoretical research. Moreover, this research provides theoretical insights for privacy concern studies, which contrasts to prior related studies from behavioral perspectives. Furthermore, our results not only make guidelines for business managers to conduct optimal competition strategies and make proper decisions on their product design, but also guide social planners to make policies to promote big data adoption and provide better healthcare services.

Although our two-dimensional product differentiation model with privacy concern captures the reality better, there are still some limitations in this work. First, we only investigate the fully covered market situation by assuming consumer's reservation utility is sufficient large. However, the consumers located far from the firm's actual location are likely to receive negative utilities in some cases, such as the price is too high. Thus, we can extend the model to study firms' optimal competition strategies and outcomes under both of fully covered and partially covered market in the next step. Besides, we only consider the cases when firms simultaneously choose their quality levels and prices. But firms are more likely to sequentially enter into the healthcare market. Therefore, another possible extension of this work is to consider firm's strategic behaviours by modelling a sequential entry case.

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