Received 14 September 2023
Revised 13 December 2023
27 February 2024
Accepted 27 March 2024

On the benefit of developing customer profile analysis to implement personalized pricing in a supply chain

Yanhong Gan, Xingyu Gao, Wenhui Zhou and Siyuan Ke
School of Business Administration, South China University of Technology, Guangzhou, China
Yangguang Lu
AI Institute, Sany Heavy Machinery Ltd., Suzhou, China, and
Song Zhang
Large Excavator Research Institute, Sany Heavy Machinery Co., Ltd, Suzhou, China

Abstract

Purpose – The advanced technology enables retailers to develop customer profile analysis (CPA) to implement personalized pricing. However, considering the efficiency of developing CPA, the benefit to different retailers of implementing more precise personalized pricing remains unclear. Thus, this essay aimed to investigate the impact of efficiency on participants' strategies and profits in the supply chain.

Design/methodology/approach – A two-stage game model was introduced in the presence of a manufacturer who sets his wholesale price and a retailer that decides her CPA strategy. The equilibrium results were generated by backward induction.

Findings – Most retailers are willing to develop the highest CPA to implement perfect personalized pricing, but those inefficient retailers with high production costs would like to determine a middle CPA to implement bounded personalized pricing. The retailers' profits may decrease with the efficiency of developing CPA when the efficiency is middle. In this case, as the efficiency improves, the manufacturer increases the wholesale price, resulting in lower demand and thus lower profits. Moreover, define a Pareto Improvement (PI) strategy as one that benefits both manufacturers and retailers. Therefore, uniform pricing is a PI when the unit cost is high and the efficiency is low; personalized pricing is a PI when the unit cost is low and the efficiency is low or high; otherwise, there is no PI.

Originality/value – This study is the first that investigates how the retailer develops CPA to implement personalized pricing on a comprehensive spectrum, which can provide practical insights for retailers with different efficiencies.

Keywords Customer profile analysis (CPA), Pricing strategy, Personalized pricing, Uniform pricing, Game theory

Paper type Research paper

This work was funded by the Science Fund for Creative Research Groups of the National Natural Science Foundation of China (No. 72321001) and National Science Fund for Distinguished Young Scholars (No. 71925002).

Modern Supply Chain Research and Applications
Vol. 6 No. 2, 2024
pp. 86-100
Emerald Publishing Limited
2631-3871
DOI 10.1108/MSCRA-09-2023-0038

1. Introduction

Nowadays, equipped with the ability to develop customer profile analysis (CPA), firms can easily assess customers' information from their digital footprints, which has fueled interest in personalized pricing. Personalized pricing refers to a strategy in which a firm sells products or provides services at tailored prices according to customers' valuations (Du *et al.*, 2022). This pricing method has been experimented in many scenarios such as retail stores, food chains, airlines, and many other industries (Elmachtoub *et al.*, 2021). For example, in the retail industry, Target offers customers personalized coupons according to their past shopping behavior (Li and Li, 2023). In the food industry, Unimeal and Healthline collect customers' data information, i.e. dining behavior, physical fitness and health records, to customize meal plans and offer tailored price discounts (Li and Xu, 2022). Note that personalized pricing is not big data killing. Firms may offer subtly different services to customers with different valuations, which can be viewed as a way of rate fence (Chen *et al.*, 2001).

Various platforms have recently invested in CPA to implement personalized pricing. For example, Tmall has been investing a lot of money and technical resources to optimize customer profiles, and Alibaba Group has been reported to invest a huge amount in artificial intelligence and big data, with tens of billions of RMB invested in 2019 alone [1]. Groupon's Supply Intelligence team works on an AI platform that collects and analyzes information about customers [2]. Intuitively, the more one invests in CPA, the more accurate the personalized pricing is. Moreover, platforms have different efficiency in developing CPA, which means that if they choose to adopt personalized pricing, spending the same amount of money may yield different effects in improving the accuracy of customer valuation estimation. Some high-tech platforms have a strong foundation and are more efficient in developing CPA, while some emerging platforms are less efficient.

In fact, in addition to online platforms, traditional retailers can also collect customer information to adopt personalized pricing, whose efficiencies vary. In the rest of the text, we uniformly use "retailers" to represent platforms and traditional retailers. As for these retailers, they should make a trade-off between the cost of developing CPA and the revenue of a more precise personalized pricing strategy. That is, the more precise the personalized pricing, the higher the revenue from this tailored pricing, yet the more investment in CPA is needed. Therefore, we propose two questions. First, are retailers with different efficiencies always willing to pour money into developing CPA, i.e. develop the highest CPA, to implement perfect personalized pricing? If not, what are their strategies? What are the characteristics of these retailers who choose different strategies? Second, is the intuition that the more efficient at developing CPA, the more profitable it must be for retailers who implement personalized pricing correct?

Moreover, compared with uniform pricing (e.g. firms set a constant price for all customers), it is unclear whether developing CPA to implement personalized pricing can make more profits. Therefore, we propose our third question: Is there a pricing strategy that creates a win-win situation for supply chain members? When should the retailer develops CPA to implement personalized pricing and when should adopt uniform pricing?

To address the above questions, we consider a two-level supply chain consisting of a manufacturer (he) and a retailer (she), where the manufacturer determines the wholesale price and the retailer decides her CPA strategy for implementing personalized pricing. Our findings can be summarized as follows. First, high-efficiency retailers are willing to develop the highest CPA without any incentives, i.e. sparing no effort to set the customer profile error to 0 to implement perfect personalized pricing; middle-efficiency retailers are motivated to develop the highest CPA through the manufacturer lowering his wholesale price; low-efficiency retailers prefer to develop CPA at an intermediate level. Second, the intuition about the relationship between the retailer's profitability and her efficiency in developing CPA does not hold. The retailer's profits may decrease with the efficiency when the efficiency is middle.

In this case, the manufacturer increases his wholesale price as the efficiency increases, which lowers the demand and hence decreases the retailer's profits. Third, when the unit cost of the manufacturer is relatively high and the efficiency of the retailer is low or middle, uniform pricing is a Pareto Improvement (PI) strategy; when the unit cost is relatively low and the efficiency is low or high, developing CPA to implement personalized pricing is a PI strategy; otherwise, there is no PI. These findings can provide practical insights into firms' pricing strategies.

The remainder of the paper is organized as follows. Section 2 reviews the literature on personalized pricing. Section 3 provides the conceptualization and formulation of the model. Sections 4 analyzes the model and provides decision-making results. In Section 5, we compare two pricing strategies to find a win-win strategy. We summarize the thesis in Section 6. All proofs are relegated to the Online Appendix.

2. Literature review

With the development of the digital economy, data-driven personalized pricing has received wide attention from scholars. Our study is mainly related to two aspects of the literature, i.e. CPA and personalized pricing. We next comb through these two literature streams and present our innovations and importance.

First, our work relates to the economic impact of CPA. Research has proven that CPA can provide solid insights and comprehensive data support for organizations (Akter *et al.*, 2017), and data-driven decision-making can improve the operational capabilities (Gunasekaran and Ngai, 2004). Most of the current research focuses on using CPA to achieve efficient revenue management (Mikalef *et al.*, 2019; Wamba *et al.*, 2020; Hazen *et al.*, 2018). For example, Kiron *et al.* (2014) state that CPA can help companies achieve precise advertising and optimal product mix. Fan *et al.* (2015) show that CPA can enable promotion targeting and reduce corporate costs. Our paper proposes that retailers can develop CPA to implement personalized pricing to achieve more profits. Li and Li (2023) also study such a problem and they investigate how a firm makes personalized pricing decisions through CPA. However, they only consider two types of customers and there are only two different prices, which is not really personalized pricing and they do not analyze the investment decision of CPA. The deployment of CPA is a very important issue in reality, to the best of our knowledge, there is no literature yet to study how retailers develop CPA to implement tailored prices for each customer.

Second, our work contributes to the stream of literature on personalized pricing. Prior studies mainly focus on the following issues: the profitability of personalized pricing (Shaffer and Zhang, 1995), behavior-based pricing (Colombo, 2015; Ziari and Sajadieh, 2021), marketing strategy based on personalized pricing (Anderson *et al.*, 2015), customer fairness concern (Zhang *et al.*, 2022). Our research focuses on the profitability of personalized pricing. There is a series of literature showing that personalized pricing can increase profits and market penetration in a single supply chain (Acquisti and Varian, 2005; Pazgal and Soberman, 2008; Chen *et al.*, 2022), but there is also some research suggesting that personalized pricing may hurt the profitability of some supply chain members when considering competitive scenarios (Liu and Zhang, 2006; Chen *et al.*, 2020; Du *et al.*, 2022). Our paper focuses on the impact of personalized pricing on members' profits in a single two-level supply chain like Acquisti and Varian (2005), Pazgal and Soberman (2008), Chen *et al.* (2022). However, the difference is that these papers assume that firms can implement perfect personalized pricing (e.g. squeezing all customer surplus), while our paper considers that firms may implement bounded personalized pricing (e.g. there is an error between customer valuation and the tailored price) when considering the cost of developing CPA. To the best of our knowledge, almost all literature about personalized pricing considers a bang-bang comparison, i.e. totally personalized pricing vs totally uniform pricing, to analyze the profitability of personalized pricing. Conversely, our paper considers firms that enable a comprehensive spectrum of personalized pricing by developing different CPA. We discovered that a holistic perspective is essential, as a mere contrast between the two extreme cases fails to encapsulate the entire scenario. Our examination of uniform pricing versus personalized pricing diverges from prior research, as it hinges on the CPA decision.

3. The model

Consider a single channel where a manufacturer (he) sells through a retailer (she) for heterogeneous customers, whose valuations v obey a uniform distribution ranging from 0 to 1. We normalize the potential market demand to 1. The retailer with information about customers can choose to impose uniform pricing or develop CPA to adopt personalized pricing. To be specific, adopting uniform pricing indicates that the retailer sets the same price for all customers. However, if she wants to squeeze more customer surplus, she must make the extra effort, i.e. developing CPA to implement personalized pricing. Thus, there are two possible pricing structures: uniform pricing (Model U) and personalized pricing (Model P). The benchmark case, i.e. uniform pricing, is so common that we omit the details, which can be seen in the Online Appendix.

Unlike the existing perfect personalized pricing that retailers can squeeze all customer surplus, this paper considers that the retailer can impose a comprehensive spectrum of personalized pricing by determining her CPA strategy. Here, we use the error between the true customer valuation and the estimated valuation to measure CPA. That is, the smaller the error, the higher the CPA. If the error in between equals 0, CPA reaches the maximum, which also means the personalized pricing is perfect. If the error determined by the retailer is positive, the CPA is smaller and the personalized pricing is bounded.

The customer profile error is denoted as Δ, which can be explained as surplus that the retailer fails to squeeze. Therefore, personalized pricing is given by $p(v) = v - \Delta$. We denote the valuation of the marginal consumer purchasing from the retailer as $\bar{v}$ such that $p(\bar{v}) = \omega$, where ω is the wholesale price set by the manufacturer. Du *et al.* (2022) also defines the indifferent point in the same way, which indicates that as long as the retailer's profit margin is positive, i.e. $p(v) > \omega$, she tends to reduce her tailored prices to induce customers to purchase. Using the above expression displayed for $p(v)$, we determine $\bar{v} = \omega + \Delta$. Therefore, the demand is $D = 1 - \bar{v} = 1 - \omega - \Delta$.

The size of customer profile error depends on the investment in developing CPA, that is, $\beta(\Delta_0 - \Delta)^2$ β means the efficiency of developing CPA. Δ_0 is the initial customer profile error, a deviation that originates from a retailer developing CPA without carrying out extra effort. So the error set by the retailer can only be less than or equal to Δ_0. The convex investment cost has been widely used in operations areas, such as Zhang *et al.* (2021). Larger β means low efficiency in developing CPA and smaller β means high efficiency. Intuitively, if β is large, decisions about making efforts to implement more precise personalized pricing must be made carefully as excessive costs due to inefficiency may outweigh the benefits of improved accuracy.

Therefore, we propose a two-stage game model to analyze the case. Firstly, the manufacturer charges the wholesale price ω to maximize his profit Π_M. Next, the retailer sets the customer profile error Δ to impose tailored price $p(v)$ with the objective of maximizing her profit Π_P. Specifically, if no effort is made, the initial error will be maintained and no extra cost is needed, in which scenario the personalized pricing is bounded. If the retailer wants to adopt perfect personalized pricing, the highest CPA is required, i.e. setting the error to 0.

The manufacturer's problem is given by

$$\begin{aligned} &\max_{\omega} \quad (\omega - c)(1 - \omega - \Delta), \\ &s.t. \quad\quad c \leq \omega \leq 1 - \Delta_0. \end{aligned} \tag{1}$$

The constraint on the left is to ensure that the marginal profit is non-negative, and the right one is to ensure that the demand is non-negative regardless of how the retailer decides her CPA strategy. For the manufacturer, the worst case is that the retailer does not take extra action in developing CPA, where the demand is $D = 1 - \omega - \Delta_0$, so the constraint, i.e. $\omega \leq 1 - \Delta_0$, can ensure that the demand is always non-negative.

The retailer's problem is given by

$$\begin{aligned} &\max_{\Delta} \quad \int_{\bar{v}}^{1} (p(v) - \omega)dv - \beta(\Delta_0 - \Delta)^2, \\ &s.t. \quad\quad 0 \leq \Delta \leq \Delta_0. \end{aligned} \tag{2}$$

For ease of reference, we summarize the frequently adopted notation of this paper in Table 1.

4. Model analysis

4.1 Uniform pricing

We adopt backward induction to solve the two-stage problem under uniform pricing. Lemma 1 summarizes the equilibrium outcome of this case.

Lemma 1. Under the uniform pricing, the optimal solutions and profits are given by $\omega^U = \frac{1+c}{2}$, $p^U = \frac{3+c}{4}$, $\Pi_M^U = \frac{(1-c)^2}{8}$ and $\Pi_P^U = \frac{(1-c)^2}{16}$.

Lemma 1 states the optimal solutions under the uniform pricing model, which only depends on the unit cost. When the unit cost rises, the manufacturer increases the wholesale price, and therefore the retailer increases the retail price. However, the increasing price leads to a decline in demand, which makes the manufacturer and the retailer less profitable. Next, we use it as a benchmark to compare with the personalized pricing model.

Table 1. Notations

	Meanings
Symbols	
v	Customer valuation on products, $v \sim U[0, 1]$
c	Unit production cost
β	The efficiency of developing CPA
Δ_0	Initial customer profile error
U	Customer utility
$P(v)$	Personalized prices for different customers, $P(v) = v - \Delta$
Π_M	Profit of the manufacturer
Π_P	Profit of the platform
D	Demand
Decision variables	
Δ	Customer profile error set by the platform
Ω	Wholesale price set by the manufacturer
P	Retail prices of the platform for customers in uniform pricing
Subscript	
U	Uniform pricing
P	Personalized pricing

Source(s): Table created by authors

4.2 Personalized pricing

Similarly, we solve the problem under personalized pricing using backward induction.

Lemma 2. Given ω, the retailer's optimal customer profile error Δ^P is given by

(1) *When* $0 < \beta \leq \frac{1}{2}$ *and* $c \leq \omega \leq 1 - \Delta_0$, *then* $\Delta^P = 0$.

(2) *When* $\beta > \frac{1}{2}$*: a) if* $c \leq \omega \leq 1 - 2\beta\Delta_0$, *then* $\Delta^P = 0$*; b) if* $1 - 2\beta\Delta_0 < \omega^P \leq 1 - \Delta_0$, *then* $\Delta^P = \Delta_1 = \frac{\omega - (1 - 2\beta\Delta_0)}{2\beta - 1}$.

Lemma 2 states that when the efficiency of developing CPA is high, i.e. β is relatively small, then the retailer will spare no effort to develop the highest CPA, that is, setting an optimal customer profile error $\Delta^P = 0$. Another scenario is that the efficiency of developing CPA is low, i.e. β is relatively large. In the latter case, the retailer's decision is likewise related to the wholesale price set by the manufacturer. Specifically, when the wholesale price is low, the retailer would like to set the error Δ^P to 0 to implement perfect personalized pricing. Once the wholesale price exceeds a specific threshold $1 - 2\beta\Delta_0$, the optimal customer profile error increases with the wholesale price. This is because a higher wholesale price suppresses the retailer's incentives to develop her CPA.

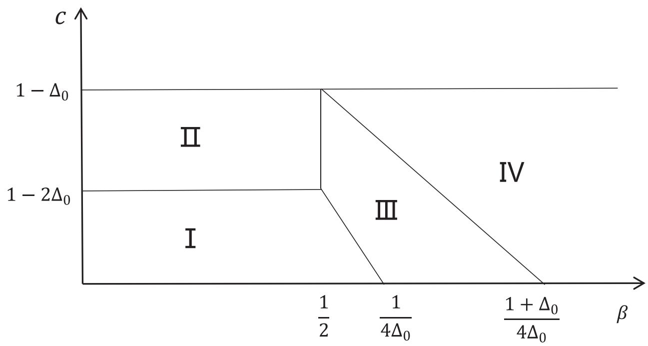
For ease of exposition, we divide the parameter space (β, c) into four mutually exclusive regions, the definition of which is provided in the following Eq.(3).

$$\begin{cases} I = & \left\{0 < \beta \leq \frac{1}{2}, 0 \leq c \leq 1 - 2\Delta_0\right\} \cup \left\{\beta > \frac{1}{2}, 0 \leq c \leq 1 - 4\beta\Delta_0\right\}, \\ II = & \left\{0 < \beta \leq \frac{1}{2}, 1 - 2\Delta_0 < c \leq 1 - \Delta_0\right\}, \\ III = & \left\{\beta > \frac{1}{2}, 1 - 4\beta\Delta_0 < c \leq 1 - (4\beta - 1)\Delta_0\right\}, \\ IV = & \left\{\beta > \frac{1}{2}, 1 - (4\beta - 1)\Delta_0 < c \leq 1 - \Delta_0\right\}. \end{cases} \tag{3}$$

P1. Under the personalized pricing, the optimal solutions (ω^P, Δ^P) are given by

$$(\omega^P, \Delta^P) = \begin{cases} \left(\frac{1+c}{2}, 0\right), & (\beta, c) \in I \\ (1 - \Delta_0, 0), & (\beta, c) \in II \\ (1 - 2\beta\Delta_0, 0), & (\beta, c) \in III \\ \left(\frac{1 + c - \Delta_0}{2}, \frac{1 - c + (1 - 4\beta)\Delta_0}{2(1 - 2\beta)}\right), & (\beta, c) \in IV \end{cases}$$

Figure 1 shows the structure of the optimal decisions stated in Proposition 1. First, when the efficiency of developing CPA is high (β is relatively small), i.e. $(\beta, c) \in I \cup II$, the manufacturer



Source(s): Figure created by authors

Figure 1.
The optimal solutions under the personalized pricing

decides a higher wholesale price and the retailer always strongly imputes to develop CPA with an optimal customer profile error $\Delta^P = 0$, that is, the retailer always implements perfect personalized pricing. This is intuitive because the efficiency of developing CPA is high, even if the manufacturer sets a higher wholesale price, the retailer is willing to develop the highest CPA to implement perfect personalized pricing. Second, when the efficiency of developing CPA is low (β is relatively large) and the unit cost is relatively low, i.e. $(\beta, c) \in III$, the manufacturer sets a constant wholesale price just enough to motivate the retailer to develop CPA as much as possible ($\Delta^P = 0$). However, as the unit cost increases above the threshold, i.e. $(\beta, c) \in IV$, the manufacturer will increase the wholesale price to ensure that it is profitable, resulting in a reduction in the willingness of the retailer to developing CPA, so the retailer adopts bounded personalized pricing with a positive customer profile error. This is because the manufacturer is reluctant to lower wholesale prices to incentivize the retailer to adopt perfect personalized pricing when the unit cost is high and the efficiency of developing CPA is low.

Based on the above results, we gain the following insights. Most retailers are willing to develop the highest CPA to implement perfect personalized pricing. However, those inefficient retailers with high production costs would like to determine a middle CPA to implement bounded personalized pricing. This is a significant contribution to the existing perfect personalized pricing literature. In other words, it is a realistic concern of how retailers should develop their CPA to implement personalized pricing, and this paper can provide a theoretical reference for retailers to develop their CPA.

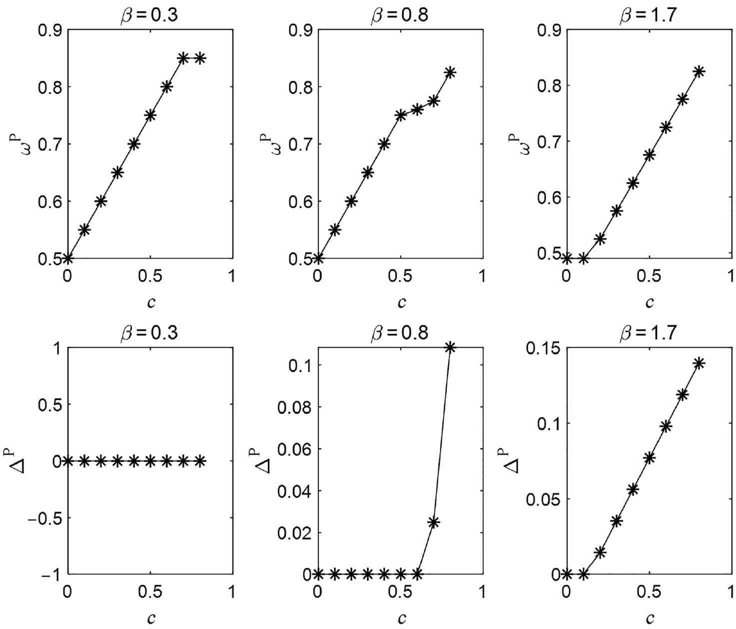
Lemma 3. The impact of c and β on optimal solutions are given by

(1) *Both ω^P and Δ^P non-decreases with c.*

(2) *ω^P first keeps irrelevant, then decreases and finally keeps irrelevant with β; Δ^P first keeps irrelevant and then increases with β.*

In order to show more clearly the impact of c and β on the equilibrium solutions, i.e. ω^P and Δ^P, we design the following numerical analysis and the results are shown in Figures 2 and 3.

Figure 2 states the impact of c on the optimal wholesale price and customer profile error. Intuitively, the manufacturer decides on a higher wholesale price as the unit cost increases as shown in the three subfigures in the first row. However, when the efficiency of developing CPA is high, the optimal customer profile error equals zero whatever the cost; when the efficiency exceeds a threshold, the optimal customer profile error increases with the unit cost.



Source(s): Figure created by authors

Figure 2. The impact of c on ω^P and Δ^P when $\Delta_0 = 0.15$

This is because high costs make the retailer less motivated to develop CPA so she will decide on a larger customer profile error.

Figure 3 states the impact of the efficiency of developing CPA β on the optimal wholesale price and customer profile error, which is non-intuitive. We find that the optimal wholesale price remains constant with β when the efficiency of developing CPA is high (β is relatively small) or low (β is relatively large), but decreases with β when the efficiency is middle. The optimal customer profile error remains irrelevant and then increases with β. The reasons are as follows. First, when the efficiency is high, the retailer is strongly motivated to develop the highest CPA according to Lemma 2, so the optimal customer profile error remains constant. The manufacturer does not have to pay anything to benefit from the increased demand, leading to a constant wholesale price. Second, when the efficiency is middle, for boosting sales, the manufacturer will decrease the wholesale price to motivate the retailer to develop CPA as much as possible. Last, when the efficiency is low, the manufacturer's profits from stimulating the retailer to develop CPA through price cuts are subtle, so the manufacturer prefers a constant wholesale price and the retailer will set a higher customer profile error.

P2. The impact of c and β on performance is given by

(1) *D^P and Π_M^P decrease with c.*

(2) *D^P first keeps irrelevant, then increases and finally decreases with β. Π_M^P first keeps irrelevant and then decreases with β.*

(3) *Π_P^P may jump increase when c is in some region. As β grows larger, Π_P^P first decreases, then increases and finally decreases.*

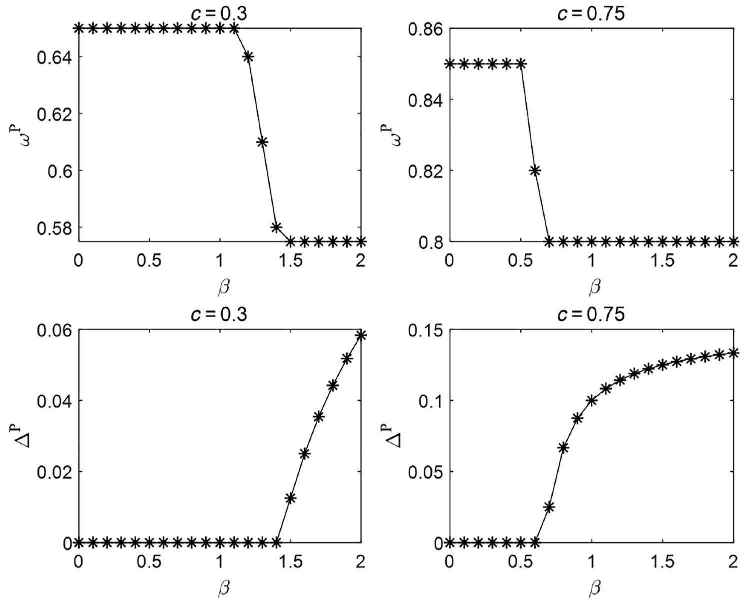


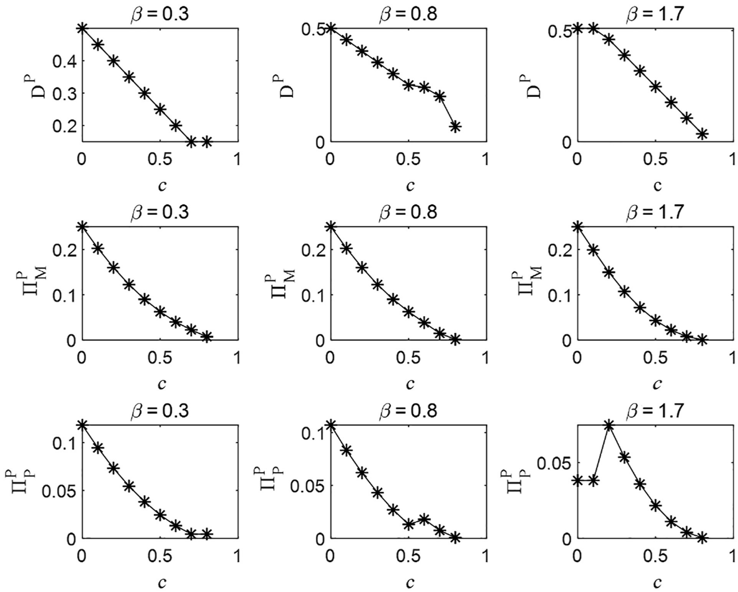
Figure 3.
The impact of β on ω^P and Δ^P when $\Delta_0 = 0.15$

Source(s): Figure created by authors

Similarly, to describe more clearly the impact of c and β on the equilibrium performance, i.e. D^P, Π_M^P and Π_P^P, we design the following numerical analysis and the results are shown in Figures 4 and 5.

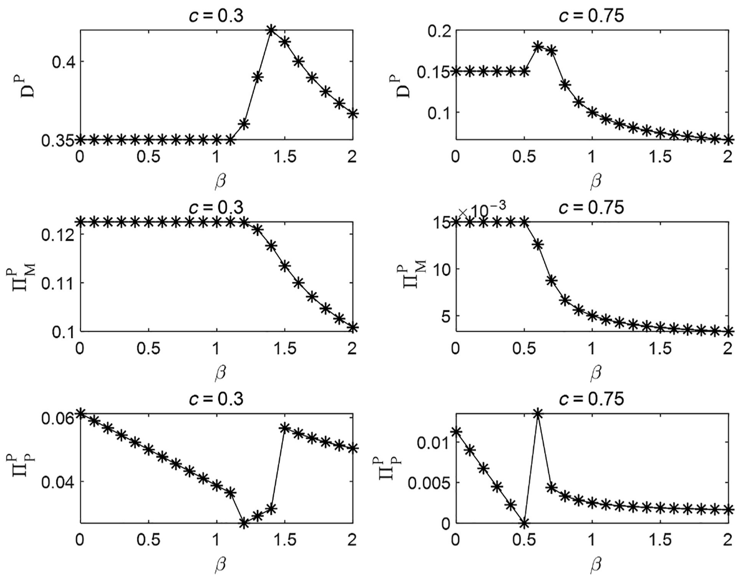
Figure 4 states the impact of c on the equilibrium demand and profits. First, D^P and Π_M^P decrease with c. The reason is as follows. As discussed in Lemma 3, the manufacturer decides a higher wholesale price and the retailer determines a larger customer profile error with the unit cost increasing, which leads to less demand. Although the manufacturer has increased his wholesale price, the increased unit cost and decreased demand still drive his profits down. As for the retailer, he sets a zero customer profile error when the unit cost is small and a positive customer profile error when the unit cost is large. An intermittent jump occurs when the unit cost is in excess of these two regions, then as the unit cost increases, a larger error biases his prices away from customer valuations, which also leads to lower profits.

Figure 5 states the impact of β on the demand and profits, which are non-monotonous. Counter-intuitively, the retailer's profits may increase with β when β is relatively middle, which can be seen in the third row of subfigures in Figure 5. This goes against the common sense that the less efficient, the less profitable. The reason is as follows. First, according to Lemma 3, the manufacturer will decide on a decreasing wholesale price to motivate the retailer to develop CPA as much as possible (e.g. $\Delta^P = 0$) in this case. On the one hand, lowering wholesale prices will increase demand. On the other hand, decreasing wholesale prices can incentivize the retailer to develop CPA, which can also increase demand. These two positive effects of increasing demand lead to an increase in the retailer's profits. However, the manufacturer's profits decreased due to a lower wholesale price. The outcomes in the other two scenarios (e.g. β is relatively small and large) are more intuitive. First, when the efficiency of developing CPA is high (β is relatively small), according to Lemma 3, the manufacturer decides on a constant wholesale price and the retailer develops CPA as much as possible, so the demand and the profit of manufacturer keep irrelevant with β, but the profit of retailer



Source(s): Figure created by authors

Figure 4.
The impact of c on D^P, Π_M^P and Π_P^P when $\Delta_0 = 0.15$



Source(s): Figure created by authors

Figure 5.
The impact of β on D^P, Π_M^P and Π_P^P when $\Delta_0 = 0.15$

decreases with β because as efficiency decreases, the cost of achieving the same customer profile accuracy ($\Delta^P = 0$) increases. Second, when the efficiency is low (β is relatively large), the manufacturer prefers a constant wholesale price and the retailer decides on a larger customer profile error, so the demand decreases with β and both profits decrease, which accords with common sense that the lower the efficiency, the lower the profits.

According to the above analysis, we know that large β suggests that it is not suitable to implement personalized pricing. The significant thing is to enhance the capability of relevant technologies, such as AI, Big Data, and Cloud Computing, to improve the efficiency of developing CPA, rather than forcing the retailer to implement personalized pricing.

5. Comparison

For ease of exposition, we divide the parameter space (β, c) into four mutually exclusive regions, the definition of which is provided in the following Eq.(4).

$$\begin{cases} A = \left\{1-\left(4-2\sqrt{2}\right)\Delta_0 < c \le \min\left\{1-2\sqrt{2-4\beta}\,\Delta_0, 1-\Delta_0\right\} \cup \max\left\{1-\dfrac{A\Delta_0}{A-1}, 1-\left(8-4\sqrt{2}\right)\beta\Delta_0\right\} < c \le 1-\Delta_0\right\}, \\ B = \left\{0 \le c \le \min\{1-2\Delta_0, 1-4\sqrt{\beta}\,\Delta_0, 1-4\beta\Delta_0\}\right\} \cup \left\{\max\left\{1-2\Delta_0, 1-2\sqrt{2-4\beta}\,\Delta_0\right\} < c \le 1-\left(4-2\sqrt{2}\right)\Delta_0\right\} \\ \quad \cup \left\{\max\{1-4\beta\Delta_0, 1-4\sqrt{\beta}\,\Delta_0\right\} \le c < \min\left\{1-\left(8-4\sqrt{2}\right)\beta\Delta_0, 1-\dfrac{A\Delta_0}{A-1}\right\}\right\}, \\ C = \left\{\max\left\{1-\left(4-2\sqrt{2}\right)\Delta_0, 1-2\sqrt{2-4\beta}\,\Delta_0\right\} \le c \le 1-\Delta_0\right\} \cup \left\{1-\left(8-4\sqrt{2}\right)\beta\Delta_0 \le c < 1-(4\beta-1)\Delta_0\right\}, \\ D = \left\{1-4\sqrt{\beta}\,\Delta_0 \le c < \min\left\{1-2\sqrt{2-4\beta}\,\Delta_0, 1-\left(4-2\sqrt{2}\right)\Delta_0\right\}\right\} \cup \left\{1-4\sqrt{\beta}\,\Delta_0 \le c < 1-4\beta\Delta_0\right\} \\ \quad \cup \left\{0 \le c < \min\{1-4\sqrt{\beta}\,\Delta_0, 1-(4\beta-1)\Delta_0\right\}\right\}. \end{cases} \tag{4}$$

P3. The comparison of profits is given by

(1) *When* $(\beta, c) \in A$, *then* $\Pi_M^U \ge \Pi_M^P$ *and* $\Pi_P^U \ge \Pi_P^P$.

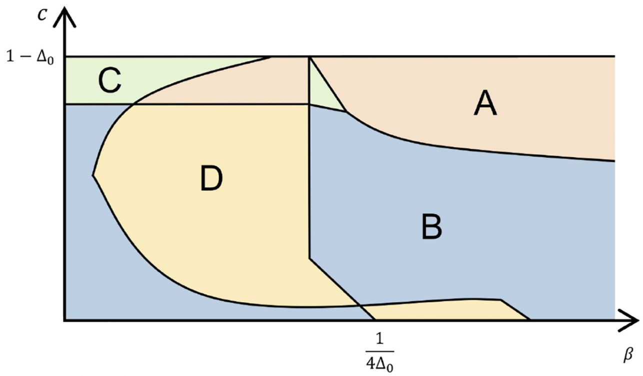
(2) *When* $(\beta, c) \in B$, *then* $\Pi_M^P \ge \Pi_M^U$ *and* $\Pi_P^P \ge \Pi_P^U$.

(3) *When* $(\beta, c) \in C$, *then* $\Pi_M^U \ge \Pi_M^P$ *and* $\Pi_P^P \ge \Pi_P^U$.

(4) *When* $(\beta, c) \in D$, *then* $\Pi_M^P \ge \Pi_M^U$ *and* $\Pi_P^U \ge \Pi_P^P$.

Figure 6 shows the structure of the profits comparison stated in Proposition 3. The combined results of the two profit comparisons are complex and may not be well understood, so we can look at them one side at a time. As far as the manufacturer, uniform pricing is preferable when the unit cost is relatively high; personalized pricing is preferable when the unit cost is relatively low; the preferred pricing is also related to the efficiency of developing CPA when the unit cost is middle, that is, personalized pricing is preferable when the efficiency is high and uniform pricing is preferable when the efficiency is low. This is because the manufacturer can lower wholesale prices to incentivize the retailer to implement personalized pricing when the unit cost is relatively low, thereby increasing demand and his own profits. However, when the unit cost is high, the manufacturer has limited profit margins and it is unwise to reduce wholesale prices to incentivize the retailer, so he prefers uniform pricing in this case.

Regarding the retailer, the results of preferred pricing are counterintuitive. Specifically, when the unit cost is relatively high, as the efficiency of developing CPA increases, the preferred pricing is first uniform, then personalized, then uniform, and finally personalized. Another case is when the unit cost is relatively small, the preferred pricing is first



Source(s): Figure created by authors

Figure 6. The comparison of profits

personalized, then uniform, and finally personalized. This discontinuous structure is because the retailer's profit under personalized pricing is non-monotonic with the efficiency of developing CPA, according to Proposition 2 (2). That is, as the efficiency of developing CPA increases, the retailer's profit under personalized pricing first increases, then decreases, and finally increases. The reason can be seen in the text below Proposition 2 and we omit it here. However, the profit of the retailer under uniform pricing is irrelevant to the efficiency, which only depends on the unit cost. Then, by comparing profits under two pricing schemes, we gain a discontinuous structure.

Therefore, combining the preferences of both parties, we have the following four areas. First, when the unit cost is relatively high and the efficiency of developing CPA is low or middle, i.e. $(\beta, c) \in A$, uniform pricing is a Pareto improvement (PI) strategy. Second, when the unit cost is relatively high and the efficiency is high, i.e. $(\beta, c) \in C$, the manufacturer prefers uniform pricing while the retailer prefers personalized pricing. Third, when the unit cost is relatively low and the efficiency is low or high, i.e. $(\beta, c) \in B$, personalized pricing is a PI. We believe that if the unit cost is relatively small, there will be significant room for raising prices and the retailer can take full advantage of this through personalized pricing. But the intuition does not hold when the efficiency is middle, i.e. $(\beta, c) \in D$, where the manufacturer prefers personalized pricing while the retailer prefers uniform pricing. This is because the retailer always tries to decrease the customer profile error to zero, a higher β causes a decrease in profits, which suggests that the retailer would rather choose uniform pricing.

In short, the non-continuous preferred pricing regarding β requires the decision maker to carefully monitor the efficiency of developing CPA when balancing between implementing personalized pricing and adopting uniform pricing. Specifically, uniform pricing can achieve a win-win when the unit cost is relatively high and the efficiency of developing CPA is low or middle; personalized pricing can achieve a win-win when the unit cost is relatively low and the efficiency is low or high.

6. Conclusion

This paper examines the retailer's CPA strategy and the manufacturer's wholesale pricing strategy. We describe CPA by setting a customer profile error and the efficiency of developing CPA. First, we find that the retailer is not always motivated to develop the highest CPA to implement perfect personalized pricing. Specifically, when the efficiency is high, the retailer is willing to develop the highest CPA without any incentives. When the efficiency is middle, the manufacturer lowers his wholesale price to motivate the retailer to develop the highest CPA, making personalized pricing perfect. But when the efficiency is low, the manufacturer is reluctant to lower wholesale price and the retailer prefers to implement bounded personalized pricing. Second, the intuition that the more efficient the analysis, the more profitable the retailer is invalid. Moreover, the retailer's profits may decrease with the efficiency when the efficiency is middle. In this case, the manufacturer increases his wholesale price as the efficiency increases, which lowers the demand and hence decreases the retailer's profits. Third, the non-monotonicity comparing two members' profits under two pricing strategies is complicated. We find that when the unit cost is relatively high and the efficiency of developing CPA is low or middle, uniform pricing is a PI strategy; when the unit cost is relatively low and the efficiency is low or high, personalized pricing is a PI strategy; otherwise, there is no PI.

Our research generates several managerial implications. First, developing the highest CPA to implement perfect personalized pricing is not always optimal for retailer managers. When the efficiency of CPA is relatively low and the unit production cost is relatively high, managers should develop a middle CPA to implement bounded personalized pricing. Second, from the manufacturers' perspective, when the retailer loses the motivation to invest in CPA, reducing the wholesale price to motivate the retailer is the best of all other bad decisions. Third, manufacturers and retailers have different preferred pricing under different scenarios, so managers can monitor the unit cost and the efficiency of developing CPA to choose profitable pricing for both parties. For example, in the case of high unit cost and low or medium CPA development efficiency, uniform pricing can achieve a win-win situation. However, when the unit cost is relatively low and the efficiency is low or high, personalized pricing can achieve a win-win situation.

We can extend this study in several directions as future research opportunities. For example, this paper considers the retailer's CPA strategy and the manufacturer's pricing strategy under the single channel assumption. Studying the CPA decision under multi-channel sales and the interaction between channels is also feasible. To the best of our knowledge, several literature have examined personalized pricing in competitive situations, such as Liu and Zhang (2006), Chen *et al.* (2020) and Du *et al.* (2022). However, these studies only care about perfect personalized pricing in competitive situations. It is more realistic for us to study how to determine CPA strategy, which may results in bounded personalized pricing, considering that personalized pricing is not always perfect in reality. Analyzing whether new effects emerge with competition and the implications for the retailer's CPA strategy in such an extended framework, constitutes a fruitful direction for future research.

Notes

1. https://www.alibabagroup.com/investor-relations
2. https://people.groupon.com/2018/ana-ananthakumar-product-manager-supply-intelligence-groupon-chicago/

References

Acquisti, A. and Varian, H.R. (2005), "Conditioning prices on purchase history", *Marketing Science*, Vol. 24 No. 3, pp. 367-381, doi: 10.1287/mksc.1040.0103.

Akter, S., Fosso Wamba, S. and Dewan, S. (2017), "Why pls-sem is suitable for complex modelling? An empirical illustration in big data analytics quality", *Production Planning and Control*, Vol. 28 Nos 11-12, pp. 1011-1021, doi: 10.1080/09537287.2016.1267411.

Anderson, S., Baik, A. and Larson, N. (2015), "Personalized pricing and advertising: an asymmetric equilibrium analysis", *Games and Economic Behavior*, Vol. 92, pp. 53-73, doi: 10.1016/j.geb.2015.05.006.

Chen, Y., Narasimhan, C. and Zhang, Z.J. (2001), "Individual marketing with imperfect targetability", *Marketing Science*, Vol. 20 No. 1, pp. 23-41, doi: 10.1287/mksc.20.1.23.10201.

Chen, Z., Choe, C. and Matsushima, N. (2020), "Competitive personalized pricing", *Management Science*, Vol. 66 No. 9, pp. 4003-4023, doi: 10.1287/mnsc.2019.3392.

Chen, C., Duan, Y. and Li, G. (2022), "Adoption of personalized pricing in a supply chain", *Managerial and Decision Economics*, Vol. 43 No. 7, pp. 2715-2728, doi: 10.1002/mde.3557.

Colombo, S. (2015), "Should a firm engage in behaviour-based price discrimination when facing a price discriminating rival? A game-theory analysis", *Information Economics and Policy*, Vol. 30, pp. 6-18, doi: 10.1016/j.infoecopol.2014.11.001.

Du, S., Sheng, J., Peng, J. and Zhu, Y. (2022), "Competitive implications of personalized pricing with a dominant retailer", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 161, 102690, doi: 10.1016/j.tre.2022.102690.

Elmachtoub, A.N., Gupta, V. and Hamilton, M.L. (2021), "The value of personalized pricing", *Management Science*, Vol. 67 No. 10, pp. 6055-6070, doi: 10.1287/mnsc.2020.3821.

Fan, S., Lau, R.Y. and Zhao, J.L. (2015), "Demystifying big data analytics for business intelligence through the lens of marketing mix", *Big Data Research*, Vol. 2 No. 1, pp. 28-32, doi: 10.1016/j.bdr.2015.02.006.

Gunasekaran, A. and Ngai, E.W.T. (2004), "Information systems in supply chain integration and management", *European Journal of Operational Research*, Vol. 159 No. 2, pp. 269-295, doi: 10.1016/j.ejor.2003.08.016.

Hazen, B.T., Skipper, J.B., Boone, C. and Hill, R.R. (2018), "Back in business: operations research in support of big data analytics for operations and supply chain management", *Annals of Operations Research*, Vol. 270 Nos 1-2, pp. 201-211, doi: 10.1007/s10479-016-2226-0.

Kiron, D., Prentice, P.K. and Ferguson, R.B. (2014), "The analytics mandate", *MIT Sloan Management Review*, Vol. 55 No. 4, pp. 1-25.

Li, X. and Li, K.J. (2023), "Beating the algorithm: consumer manipulation, personalized pricing, and big data management", *Manufacturing and Service Operations Management*, Vol. 25 No. 1, pp. 36-49, doi: 10.1287/msom.2022.1153.

Li, X. and Xu, Z. (2022), "Superior knowledge, price discrimination, and customer inspection", *Marketing Science*, Vol. 41 No. 6, pp. 1097-1117, doi: 10.1287/mksc.2022.1355.

Liu, Y. and Zhang, Z.J. (2006), "Research note the benefits of personalized pricing in a channel", *Marketing Science*, Vol. 25 No. 1, pp. 97-105, doi: 10.1287/mksc.1050.0120.

Mikalef, P., Boura, M., Lekakos, G. and Krogstie, J. (2019), "Big data analytics and firm performance: findings from a mixed-method approach", *Journal of Business Research*, Vol. 98, pp. 261-276, doi: 10.1016/j.jbusres.2019.01.044.

Pazgal, A. and Soberman, D. (2008), "Behavior-based discrimination: is it a winning play, and if so, when?", *Marketing Science*, Vol. 27 No. 6, pp. 977-994, doi: 10.1287/mksc.1070.0355.

Shaffer, G. and Zhang, Z.J. (1995), "Competitive coupon targeting", *Marketing Science*, Vol. 14 No. 4, pp. 395-416, doi: 10.1287/mksc.14.4.395.

Wamba, S.F., Dubey, R., Gunasekaran, A. and Akter, S. (2020), "The performance effects of big data analytics and supply chain ambidexterity: the moderating effect of environmental dynamism", *International Journal of Production Economics*, Vol. 222, 107498, doi: 10.1016/j.ijpe.2019.09.019.

Zhang, J., He, X. and Zhang, Y. (2022), "Peer-induced fairness and personalized pricing in a channel", *Journal of the Operational Research Society*, Vol. 73 No. 8, pp. 1812-1827, doi: 10.1080/01605682.2021.1940327.

Zhang, Z., Shivendu, S. and Wang, P. (2021), "Is investment in data analytics always profitable? The case of third-party-online-promotion marketplace", *Production and Operations Management*, Vol. 30 No. 7, pp. 2321-2337, doi: 10.1111/poms.13379.

Ziari, M. and Sajadieh, M.S. (2021), “A behavior-based pricing model in retail systems considering vertical and horizontal competition”, *Computers and Industrial Engineering*, Vol. 152, 107054, doi: 10.1016/j.cie.2020.107054.

Appendix
The supplementary material for this article can be found online.

Corresponding author
Wenhui Zhou can be contacted at: whzhou@scut.edu.cn