Sell by bundle or unit?: Pure bundling versus mixed bundling of information goods

Wendy Hui a, Byungjoon Yoo b,⁎, Vidyanand Choudhary c, Kar Yan Tam d

a School of Information Systems, Curtin University, Australia
b Graduate School of Business, Seoul National University, 599 Gwanangno, Daehakdong, Gwanakgu, Seoul 151-916, Republic of Korea
c The Paul Merage School of Business, University of California, Irvine, United States
d Department of Information Systems, Business Statistics, and Operations Management, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong

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Pure bundling and mixed bundling are two popular pricing strategies for information goods. Pure bundling offers only the product bundle, whereas mixed bundling offers both the bundle and the individual components of the bundle. This paper builds on prior research on bundling, which usually assumes consumer heterogeneity along a single attribute of the consumer. However, an individual consumer’s demand function can be expressed as the interaction of the intercept and the slope of the demand function. We allow for consumer heterogeneity along both these dimensions. The initial willingness-to-pay (IWTP) of a consumer captures the consumer’s willingness to pay for the first unit of the product while the appetite (APP) of a consumer captures the quantity consumed when the product is free. We find that these two dimensions of heterogeneity have opposing effects. APP heterogeneity encourages the adoption of mixed bundling while IWTP heterogeneity moderates the relationship between APP heterogeneity and the preference for mixed bundling in favor of pure bundling. Our results also help explain why sellers tend to change pricing schemes over time.

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1. Introduction

The size of the information goods market including online games and digital content has increased enormously. This has generated research interest in the pricing of information goods, especially information bundling (e.g., [5,7,11,12,25]). Bundling takes advantage of the fact that variation in bundle valuation is typically smaller than variation in the valuation of individual components. However, allowing the firm to extract consumer surplus more effectively. Bakos and Brynjolfsson [3] demonstrate that when marginal cost is negligible, pure bundling is optimal as the number of goods in the bundle approaches infinity.

This paper focuses on pure bundling and mixed bundling, to determine conditions under which the firm should adopt pure bundling versus strict mixed bundling. Pure bundling offers only the pure bundle for sale, whereas mixed bundling sells both the pure bundle as well as the component goods individually. Consider the example of Lineage which is one of the largest MMORPGs (Massively Multiplayer Online Role Playing Games) in Asia with 1 million active subscriptions [16]. In 2010, Lineage generated $164 million and its sequel, Lineage II, generated $107 million in sales [18]. NCSoft, the publisher of Lineage, initially provided only subscription-based pricing ($27 per month in 2010). This is equivalent to a pure bundle where pricing is independent of actual amount of game play. Later NCSoft added a time-based pricing option (2 cents per minute) for individual players. This is equivalent to mixed bundling where consumers have a choice between the pure bundle and a la carte pricing based on amount of game play. Similarly, for PC game rooms which connect users to games and provide other services, NCSoft initially charged US$60 per IP address per month and later added the time-based pricing option (25 cents per hour). Other online game companies have also taken similar steps to introduce flexible usage-based pricing schemes for their online games [26]. Similarly, Adobe used to sell its popular Acrobat software using only perpetual licenses. Adobe has now added per-use conversion pricing for subscribers to create PDF files online. What drives firms to offer one pricing scheme or the other and sometimes switch from one to the other?

In this paper we argue that the tradeoff between mixed bundling and pure bundling can be captured by analyzing heterogeneity in consumer valuations along two dimensions. Prior literature has focused on single-dimensional consumer heterogeneity see for example [5,14,17,19,25]. We introduce the concept of consumer heterogeneity along two dimensions: (1) Initial willingness to pay (IWTP) which is the consumer’s willingness to pay for the first unit of the product or service and (2) the appetite (APP) which is the amount of consumption that leads to satiation (willingness to pay for additional consumption is zero once satiation level is reached). Both dimensions of heterogeneity are relevant and differ in their impact on the optimality of mixed vs. pure bundling. For example, BigUniverse.com, an award-winning educational service provider,
segments its customers into two groups (home users and schools), and charges them different prices for the same services. This type of third degree price discrimination differentiates consumers based on their initial willingness to pay. On the other hand Netflix.com, uses second degree price discrimination to offer a range of plans based on consumers’ appetite for the number of DVDs. At the time of writing, 2 DVDs a month plan is $4.99, the unlimited plans are $9.99 a month for 1 DVD out a-at-time, $14.99 a month for 2 DVDs out a-ta-time, and 19.99 a month for 3 DVDs out at-a-time. Since consumers vary in terms of their appetite or marginal WTP for additional DVDs, some consumers select the $4.99 plan while others select more expensive plans. Note that in the two examples consumers’ valuations may vary along both dimensions: IWTP and APP but the relative strength of IWTP vs. APP heterogeneity can drive Netflix and BigUniverse.com to adopt different pricing schemes.

Despite the fact that mixed bundling is a common pricing strategy in the digital economy and has been shown empirically to be superior to pure bundling in the pricing of journal articles (Chuang and Sirbu [8]), the literature has not adequately addressed the question of when the firm should adopt mixed bundling vs. pure bundling. Some researchers have analyzed pure bundling as a special case of mixed bundling where the component price is set high enough that no one buys using the unit sale scheme (e.g., [27, p.630]). Stremersch and Tellis [24] name this kind of mixed bundling de facto pure bundling. Note that mixed bundling in the strict sense where prices are set to entice consumers to buy individual units as well as bundles is not the same as mixed bundling where unit sale prices are set so that consumers do not use the unit sale scheme. From a theoretical and a managerial perspective, it is important to identify the conditions under which pure bundling is optimal relative to strictly mixed bundling. Given the menu costs associated with providing multiple schemes, firms do not design menus to list prices that are too high for all consumers. When pure bundling and de facto pure bundling are equally profitable, pure bundling is preferred. Hence, there are many situations where we wish to determine when pure bundling matches mixed bundling in terms of profitability, as argued by Pierce and Winter [19] and Stremersch and Tellis [24].

In this paper we focus on answering the following questions: When is pure bundling better than mixed bundling? How do the two dimensions of consumer heterogeneity – IWTP and APP heterogeneity – impact the optimality of mixed bundling vs. pure bundling? We refer to the sale of individual goods as the unit sale scheme. While pure bundling has been the focus of a number of studies (e.g., [1,3,21,22]), research focusing on mixed bundling is limited. Exceptions include McAfee et al. [15], Pierce and Winter [19], Chuang and Sirbu [8], and Stremersch and Tellis [24]. These studies are reviewed in the Literature review section.

Let us take a closer look at the effects of IWTP and APP at the individual level. A consumer’s IWTP affects the consumer’s willingness to pay for the information goods in general. It may be affected by the consumer’s income level. For example, consumers in developed countries may in general have a higher IWTP for digital music than consumers in developing countries. IWTP may also be affected by the person’s interests. For example, a person who loves music from a specific artist may have high IWTP for music from that artist but low appetite since the marginal WTP for music from other artists may be very low. A consumer’s appetite (APP) for information goods affects the rate of diminishing utility for additional units of the information good. For example, a person who likes many genres of movies may be happy to see many movies, while another movie lover who is interested in a specific genre such as horror may wish to see fewer movies. A person with a high APP will receive a relatively low diminishing rate of utility from additional units of the information good and tend to have a higher level of consumption. Meanwhile, a person with a low APP will have a rapidly diminishing rate of marginal WTP for additional units and will thus consume fewer units.

We seek to extend prior research by analyzing the impact of consumer heterogeneity in IWTP and APP on the firm’s bundling decision. The degree of consumer heterogeneity for particular information goods is likely to increase over time for the following reason: When a new product is introduced to the market, it is likely to attract a small group of consumers with homogeneous characteristics (known as the “innovators” in the diffusion of innovation literature). This group of people may have a greater IWTP for new products. However, as the new product gets further along in the diffusion cycle and becomes increasingly “mainstream”, it attracts a more diverse group of users, including the early adopters, early majority, late majority and laggards. Increasing diversity in the consumer base is likely to lead to greater consumer heterogeneity in terms of both IWTP and APP, which in turn may affect the firm’s bundling and pricing decisions. Our analysis suggests that only the pure bundle scheme should be provided when there is limited APP heterogeneity among consumers. The unit sale scheme can be introduced later when the technology begins to attract a more diverse set of users who have very different APP levels. This general trend holds true in the presence of IWTP heterogeneity. However, heterogeneity in IWTP tends to moderate the relationship in favor of pure bundling. Thus our theoretical findings can help explain this pattern of changes in pricing schemes over time.

This paper is organized as follows: related literature is reviewed in Section 2. Section 3 presents the model setup. Section 4 analyzes the effects of heterogeneity in APP and IWTP on the firm’s preference for mixed bundling vs. pure bundling. Section 5 discusses the theoretical contribution and business implications of our findings. Section 6 concludes the paper and identifies future research directions.

2. Literature review

There is substantial literature on the economics of bundling. Stigler [23] is often credited with the first account of the benefits of bundling by showing how a firm’s profit can increase when it bundles together two goods which valuations are negatively correlated. Based on a series of examples, Adams and Yellen [11] graphically analyze and compare welfare implications of unit sale, pure bundling and mixed bundling of two goods. Their analytical framework has since become a basis on which a number of subsequent studies on bundling are developed. Using a Gaussian demand model, Schmalensee [22] shows that pure bundling can be profitable even when valuations of two goods across the population are positively correlated. Bakos and Brynjolfsson [3] extend this idea to the bundling of a large number of goods when marginal cost is negligible, which is a common assumption for digital goods. Other papers on pure bundling have looked at the effect of competition [10] and the complementarities and substitutabilities of individual items within the bundle [28]. This paper, however, focuses on the effect of price bundling in a monopolistic setting. Price bundling refers to the sale of two or more separate products in a package at a discount. It is different from product bundling which creates additional consumer value by bundling complementary products [24,30].

Analytical work comparing pure bundling and unit sale has identified conditions under which pure unit sale is more profitable than pure bundling, e.g., budget constraint [3] and decreasing marginal utility of information goods [11]. In this paper, we say mixed bundling to be preferable over pure bundling, the number of consumers purchasing from the pure bundle scheme and the unit sale scheme must be both strictly positive. This definition is consistent with Pierce and Winter [19] and Stremersch and Tellis [24], both suggesting that mixed bundling cannot be always better than pure bundling. However, Pierce and Winter [19] present a one-dimensional consumer heterogeneity model with two consumer types, and Stremersch and Tellis [24] illustrate their idea only with numerical examples. In this paper, we generalize the results of Pierce and Winter’s [19] and Stremersch and Tellis [24].
In most bundling and nonlinear pricing research, consumer heterogeneity is captured by a single parameter [3,14,17,19,25]. Often, the Spence–Mirrlees single crossing property (SCP) is preserved. Under SCP, the marginal utility of a good is monotone with respect to the single parameter, usually interpreted as the consumer demand for quantity (or quality). This property greatly simplifies problem-solving and often permits the research to arrive at closed form solutions. In a simulation study, Wu and Anandalingam [29] assert that the SCP assumption must be relaxed when consumers are interested in only some of the bundle components. Indeed, the type of heterogeneity that preserves SCP, as shown in this paper, may tend to highlight the superiority of mixed bundling over pure bundling and, as a result, the use of this assumption may reinforce the belief that “mixed bundling dominates pure bundling” while overshadowing an equally important question of whether the strict dominance holds in all types of market. In this paper, we show that the introduction of APP heterogeneity alone favors the mixed bundling scheme. On the other hand, the introduction of IWTP heterogeneity may tend to favor pure bundling.

Recent research efforts on multidimensional screening shed new light on nonlinear pricing for multidimensional consumer characteristics. Armstrong [2] formulates the problem of multiproduct bundling with n goods and m-dimensional consumer preference, where m and n are arbitrary. Armstrong [2] also provides an approximate solution for the case when m = n and both m and n are large; in this case, the optimal tariff can be approximated by a two-part tariff when taste parameters are distributed independently across products. Rochet and Chone [20] introduce the sweeping technique to deal with the problem of multidimensional screening when m = n and utilities are linear in types. More recently, Basov [4] uses the Hamiltonian approach to solve the multidimensional screening problem and generalizes some of the results of Armstrong [2] and Rochet and Chone [20]. Unlike the general multidimensional screening problem, our study does not attempt to determine an optimal tariff. Instead, our objective is to determine the conditions under which de facto pure bundling occurs, i.e., when pure bundling is more profitable than strict mixed bundling.

3. The model

As discussed in Section 2, we introduce two types of heterogeneity and relax the SCP restriction, without which problems can easily become intractable. We use a quadratic utility model which has been widely used in prior literature and which enables closed form analytical solutions. Before we present the model, we would like to make three commonly used assumptions in information bundling:

Assumption 1. The marginal cost of producing an information good is zero.

Assumption 2. Disposal of information goods is free.

Assumption 3. The total number of goods produced by the firm (Q) approaches infinity.

Quadratic utility is a common assumption in the literature (e.g., [8,13]). The exact functional form is often chosen to effectively illustrate the intended message of the study. For our purpose, to control heterogeneity in bundle valuation directly by APP and IWTP heterogeneities directly, we use the following utility function:

\[ u(q) = aq - \frac{a}{2b}q^2 - t(q) \]  

where \( t(q) \) is

\[ t(q) = \begin{cases} px, & q < B/p \\ x/p, & q \geq B/p \end{cases} \]  

where \( q \) denotes quantity, \( p \) denotes unit price and \( B \) the bundle price. Assume that the total number of goods produced by the firm is \( Q \). Note that we model utility by continuous approximation, as in Chuang and Sirbu [8] and Hitt and Chen [12], although the number of information goods should be an integer. Ignoring the \( t(q) \) term, we have the willingness to pay function for \( q \) goods:

\[ w(q) = aq - \frac{a}{2b}q^2. \]  

The marginal willingness to pay function is

\[ w'(q) = a - \frac{aq}{b}q. \]  

and it represents a consumer's willingness to pay for the qth information good. Consistent with the law of diminishing marginal utility, \( w'(q) \) decreases in \( q \). The y-intercept of the linear function is \( a \), and the x-intercept is \( b \), as shown in Fig. 1. As explained in Chuang and Sirbu [8], the y-intercept can be used to control a consumer's initial willingness to pay (IWTP) for the information goods, while the x-intercept can be used to control for the consumer's potential consumption level or appetite (APP) for the information goods.

Because of Assumption 2, a consumer's bundle valuation is given by the maximum of \( w(q) \), which is equal to the area under \( w'(q) \) in the first quadrant of the Cartesian coordinate plane, i.e., \( ab/2 \). In Section 4.1, we shall set \( a = 1/2 \) and allow \( b \) to vary. Therefore, bundle valuation is given by \( b/4 \), and bundle value heterogeneity comes only from APP heterogeneity. In Section 4.2, we shall set \( b = 1/2 \) and allow \( a \) to vary. Therefore, bundle valuation is given by \( a/4 \), and bundle value heterogeneity comes only from IWTP heterogeneity. In Section 4.3, we present the most general case where both \( a \) and \( b \) vary independently. By controlling for the heterogeneity of \( a \) and \( b \), we can compare the effects of each heterogeneity on an equal basis. Table 1 summarizes the notations used in this paper.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
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<tbody>
<tr>
<td>( Q )</td>
<td>Quantity</td>
</tr>
<tr>
<td>( w(q) )</td>
<td>Willingness to pay for ( q ) goods</td>
</tr>
<tr>
<td>( u(q) )</td>
<td>Utility from consuming ( q ) goods</td>
</tr>
<tr>
<td>( t(q) )</td>
<td>Price paid for ( q ) goods</td>
</tr>
<tr>
<td>( p )</td>
<td>Unit price</td>
</tr>
<tr>
<td>( B )</td>
<td>Bundle price</td>
</tr>
<tr>
<td>( \pi )</td>
<td>Profit</td>
</tr>
<tr>
<td>( a, b )</td>
<td>Consumer types</td>
</tr>
<tr>
<td>( \alpha, \beta )</td>
<td>Variation in ( a ), variation in ( b ). ( 0 \leq \alpha \leq 0.5 ) and ( 0 \leq \beta \leq 0.5 ).</td>
</tr>
<tr>
<td>( pb )</td>
<td>Subscript, refers to pure bundling</td>
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4. Analysis

This section analyzes the effects of APP heterogeneity and IWTP heterogeneity on the favorability of mixed bundling over pure bundling from the firm’s perspective. First of all, we note that when there is no variation in bundle valuation, the optimal mixed bundling strategy is a de facto pure bundling strategy. This is because in this case the optimal pure bundle scheme can extract all the consumer surplus of a consumer, whereas a unit sale scheme cannot (due to the fact that the marginal willingness to pay function is decreasing in quantity) [3]. If the firm introduces a unit sale scheme and there exists some consumers buying from the unit sale scheme, the firm’s profit is reduced as a result of consumer surplus forfeited. The question is when there is variation in bundle valuation, is mixed bundling always better than pure bundling? Furthermore, how do the two dimensions of heterogeneity impact the optimality of mixed bundling vs. pure bundling?

4.1. The effect of APP heterogeneity

In mixed bundling, the firm offers two schemes: the bundle sale scheme and the unit sale scheme. We refer to the utility model in Eq. (1). Let \( b \) follow Uniform\( (1/2 - \beta, 1/2 + \beta) \), where \( 0 \leq \beta \leq 1/2 \). Essentially, \( \beta \) controls for the heterogeneity in \( b \). In this subsection, for all consumers, we let \( a = 1/2 \). So, we focus on heterogeneity in bundle valuation that comes only from APP heterogeneity.

The willingness to pay for the \( q \)th information good is given by Eq. (4). Obviously, a consumer would not buy from the unit sale scheme if the willingness to pay for all goods produced by the firm is below the unit price \( (p) \). The consumer will only consider buying from the unit sale scheme if the good with highest willingness to pay is greater than the unit price \( (p) \). Since the highest willingness to pay is 1/2 for all consumers, the individual rationality (I.R.) constraint for the unit sale scheme is \( p \leq 1/2 \). As explained in Section 3, the willingness to pay for the bundle is \( b/4 \). The I.R. constraint for the bundle sale scheme is therefore

\[
b \geq 4B. \tag{5}\]

**Lemma 1.** If a consumer purchases from the unit sale scheme, he or she enjoys a utility of

\[
u(q^*) = \frac{1}{4}(1 - 2p)^2b \tag{6}\]

where \( q^* \) denotes the optimal quantity the consumer would purchase to maximize his or her utility from the unit sale scheme.

**Proof of Lemma 1.** The utility from purchasing from the unit sale scheme is given by

\[
u(q) = \frac{1}{2}q - \frac{1}{4B}q^2 - pq. \tag{7}\]

The consumer would purchase \( q^* \) to maximize his or her utility. Maximizing Eq. (7) with respect to \( q \) gives

\[
q^* = b(1 - 2p) \tag{8}\]

Substituting \( q^* \) back to Eq. (7) gives Eq. (6).

On the other hand, if the consumer purchases from the bundle sale scheme, his or her utility would be equal to \( u(q) = b/4 - B \). Hence, the incentive compatibility constraint (I.C.) for a consumer to choose the bundle sale scheme is given by

\[
b \geq \frac{B}{p(1 - p)}. \tag{9}\]

Since \( B/p(1 - p) > 4B \) is always satisfied because \( (1 - 2p)^2 > 0 \), the indifference curves Eqs. (5) and (9) divide the consumers into two groups: (1) those who purchase the bundle from the bundle sale scheme, and (2) those who purchase positive number of goods from the unit sale scheme, as shown in Fig. 2a. However, if it is optimal for the firm to set \( p = 1/2 \), then the mixed strategy is a de facto pure bundling strategy. Consumers would either (1) purchase the bundle from the bundle sale scheme, or (2) buy zero goods from the unit sale scheme, as shown in Fig. 2b. It turns out that this case is never optimal for the firm. In fact, the de facto pure bundling strategy is the preferred strategy only when the firm finds that \( \beta \) is rather small, which means that the consumers are quite homogeneous in their bundle valuation. In this case, as shown in Fig. 2c, the firm would price the bundle so that even the lowest consumer type would buy the bundle.

In Case 1, the firm has two sources of revenue: one from the unit sale scheme and one from the bundle sale scheme. The revenue per customer from the unit sale scheme is \( p \) multiplied by the quantity purchased, as given by Eq. (8). The revenue per customer from the bundle sale scheme is \( B \). Overall, the firm’s optimization problem is:

\[
\max \frac{1}{4B} \int_{1/2 - \beta}^{1/2 + \beta} \left( (1 - 2p)db + \int_{1/2 - \beta}^{1/2 + \beta} Bdb \right) \tag{10}\]

s.t. \( p \leq 1/2, 1/2 - \beta \leq B/(p - p^3) \leq 1/2 + \beta \).

In the objective function in Eq. (10), the factor \( 1/(2\beta) \) simply ensures that the area under the density function for \( b \) is equal to one. A boundary solution of \( p = 1/2 \) corresponds to Case 2 in Fig. 2. The boundary solution \( p = 1/2 \) and \( 4B = 1/2 - \beta \) corresponds to Case 3 in Fig. 2.
The solution to the unconstrained problem is

$$p^* = \frac{16\beta^3 - 2\sqrt{40(\beta^3 - 24\beta^3)} - 6\beta^3}{12\beta^3 + 12\beta + 3}.$$  

The constraints are satisfied when $\beta \geq 1/6$. Numerical analysis confirms that Eq. (11) is the optimal solution for $\beta \geq 1/6$. When $\beta < 1/6$, the solution is $p^* = 1/2$ and $B^* = (1 - \beta)/4$, corresponding to a de facto pure bundling strategy.

**Proposition 1.** Mixed bundling yields greater profit than pure bundling when APP heterogeneity is large enough ($\beta \geq 1/6$).

For completeness and for comparison with Section 4.2, we show in Appendix A that if the firm adopts the pure bundling strategy regardless of $\beta$, the optimal bundle price and profit are, respectively,

$$p_{pb}^* = \begin{cases} 
\frac{1}{16} + \frac{1}{8} \beta & \beta \geq \frac{1}{6}, \\
\frac{1}{8} & \beta < \frac{1}{6}
\end{cases} \quad \pi_{pb}^* = \begin{cases} 
\frac{1 + 2\beta^2}{128\beta^3} & \beta \geq \frac{1}{6}, \\
\frac{1}{8} & \beta < \frac{1}{6}
\end{cases}$$  

where $\pi$ denotes profit and the subscript “pb” denotes pure bundling.

4.2. The effect of IWTP heterogeneity

Here, we let $a$ follow Uniform($1/2 - \alpha, 1/2 + \alpha$), where $0 \leq \alpha \leq 1/2$. Hence, $\alpha$ controls for the heterogeneity in $a$. In this subsection, for all consumers, we set $b = 1/2$ and so we focus on heterogeneity in bundle valuation that comes only from IWTP heterogeneity. A consumer will only consider buying from the unit sale scheme if the good with higher willingness to pay is greater than the unit price ($p$). This highest willingness to pay is given by the $y$-intercept of $w'\(t\)$ defined in Eq. (4), i.e., $a$. So, the individual rationality (IR) constraint for the unit sale scheme is $a \geq p$. As explained in Section 3, the willingness to pay for the bundle is $a/4$. The IR constraint for the bundle sale scheme is

$$a \geq 4B.$$  

**Lemma 2.** If a consumer purchases from the unit sale scheme, he or she enjoys a utility of

$$u(q) = \frac{(a-p)^2}{4a}.$$  

where $q^*$ denotes the optimal quantity the consumer would purchase to maximize his or her utility from the unit sale scheme.

**Proof of Lemma 2.** The utility from purchasing from the unit sale scheme is given by

$$u(q) = aq - aq^2 - pq.$$  

The consumer would purchase $q^*$ to maximize his or her utility. Maximizing Eq. (15) with respect to $q$ gives

$$q^* = \frac{a-p}{2a}.$$  

Substituting $q^*$ back to Eq. (16) gives Eq. (15).

On the other hand, if the consumer purchases from the bundle sale scheme, his or her utility would be equal to $u(q) = a/4 - B$. Hence, the incentive compatibility constraint (IC) for a consumer to choose the bundle sale scheme is given by

$$a - B \geq \frac{(a-p)^2}{4a}, \quad \text{or} \quad a \geq \frac{1}{3} \left[ 2B - p + 2\sqrt{B^2 - Bp + p^2} \right].$$  

It turns out that where there is only heterogeneity in IWTP, the firm will always adopt a de facto pure bundling strategy. To illustrate, we first note that $4B - p^2/(2p - 4B)$ is always true because $(p - 4B)^2 > 0$ is always true as long as $p \neq 4B$. Furthermore, if $p > 4B$, it is easy to show that $p > p^2/(2p - 4B)$. Hence, if $p > 4B$, the segmented choices by consumers are as shown in Fig. 3a. Consumers from $a = 4B$ to $a = 1/2 + \alpha$ find it affordable to buy from the bundle sale scheme. Consumers from $a = p$ to $a = 1/2 + \alpha$ find it affordable to buy from the unit sale scheme. Consumers from $a = p^2/(2p - 4B)$ to $a = 1/2 + \alpha$ prefer the bundle sale scheme over the unit sale scheme. Hence, all those who find the unit sale scheme affordable prefer the bundle sale scheme. Therefore, it is a de facto pure bundling strategy.

On the other hand, if $p < 4B$, then $p < p^2/(2p - 4B)$. Hence, if $p < 4B$ and $p > 1/2 - \alpha$, the segmented choices are as shown Fig. 3b. Consumers from $a = p$ to $a = 1/2 + \alpha$ find it affordable to buy from the bundle sale scheme. Consumers from $a = 4B$ to $a = 1/2 + \alpha$ find it affordable to buy from the unit sale scheme. Consumers from $a = p^2/(2p - 4B)$ to $a = 1/2 + \alpha$ prefer the bundle sale scheme over the unit sale scheme. Consumers from $a = 4B$ to $a = 1/2 + \alpha$ find it affordable to buy from the unit sale scheme. Consumers from $a = 4B$ to $a = 1/2 + \alpha$ find it affordable to buy from the unit sale scheme. Consumers from $a = p^2/(2p - 4B)$ to $a = 1/2 + \alpha$ prefer the bundle sale scheme over the unit sale scheme. Hence, all those who find the unit sale scheme affordable prefer the bundle sale scheme. Therefore, it is a de facto pure bundling strategy.

To establish a baseline for comparison with mixed bundling, we show in Appendix B that if the firm adopts the pure bundling

![Fig. 3. Segmented choices by consumers with IWTP heterogeneity. (a) Case 1: $p > 4B$. (b) Case 2: $p = 4B$. $p > 1/2 - \alpha$. (c) Case 3: $p < 4B$. $p < 1/2 - \alpha$.](image-url)
strategy regardless of \( \alpha \), the optimal bundle price and profit are, respectively,

\[
B_{pb} = \begin{cases} 
\frac{1}{16} + \frac{1}{8} \alpha & \alpha \geq \frac{1}{6} , \quad \nu_{pb} = \begin{cases} 
\frac{(1 + 2\alpha)^2}{128\alpha} & \alpha \geq \frac{1}{6} . 
\end{cases}
\end{cases}
\]

Comparing Eqs. (12) and (18), we can see that the two solutions look very similar. This is because the two problems have the same distribution for bundle valuation. The major difference is where the bundle valuation heterogeneity comes from. In Section 4.1, it comes from APP heterogeneity and in this section, it comes from IWTP heterogeneity.

Let us return to the case where the firm adopts mixed bundling. If we are in Case 2 of Fig. 3, the revenue per customer from the unit sale scheme is \( p \) multiplied by \( q^* \) as given in Eq. (16) and the revenue per customer from bundle sale scheme is \( B \). Overall, the firm’s optimization problem is:

\[
\max \frac{1}{2\alpha} \left[ \int_p^{\frac{2}{\alpha}-\alpha} \frac{p(a-p)}{2a} da + \int_{\frac{1}{16}}^{\frac{1}{8}} B \right] \\
\text{s.t.} 1/2 - \alpha \leq p \leq 4B, \frac{p^2}{2(2p - 4B)} \leq 1/2 + \alpha.
\]

If we are in Case 3 of Fig. 3, the firm’s optimization problem is:

\[
\max \frac{1}{2\alpha} \left[ \int_p^{\frac{2}{\alpha}-\alpha} \frac{p(a-p)}{2a} da + \int_{\frac{1}{16}}^{\frac{1}{8}} B \right] \\
\text{s.t.} p \leq 1/2 - \alpha, 1/2 - \alpha \leq p \leq \frac{p^2}{2(2p - 4B)}, 3 \leq 1/2 + \alpha.
\]

The solution to the unconstrained problem in Eq. (19) is \( p^* = (1 + 2\alpha)/4 \) and \( B^* = (1 + 2\alpha)/16 \), which is only admissible when \( \alpha < 1/6 \). The solution means that the three indifference curves all coincide on a single point. Hence, it is a de facto pure bundling strategy. For the problem in Eq. (20) we have a boundary solution for \( \alpha \leq 1/6 \) that suggests a de facto pure bundling strategy. For \( \alpha \geq 1/6 \), the solution is:

\[
\begin{align*}
\nu^* &= \frac{2\alpha}{1 - 2\ln(2) + 2\ln(1 + 2\alpha) - 2\ln(1 - 2\alpha)} \\
B^* &= \frac{1}{2} \left( \frac{1 + \alpha^*}{1 - 2\alpha} \right) \\
\nu^* &= \frac{\alpha}{2 - 2\ln(2) + 2\ln(1 + 2\alpha) - 2\ln(1 - 2\alpha)}.
\end{align*}
\]

However, it can be shown that \( \nu_{pb} \) in Eq. (18) is always at least as large as \( \nu^* \) above. Therefore, again, it is a de facto pure bundling strategy.

**Proposition 2.** Pure bundling yields greater profit than mixed bundling when heterogeneity in bundle valuation comes only from heterogeneity in IWTP.

In short, when consumers are sufficiently heterogeneous in their IWTP for the information goods, offering the unit sale scheme can easily cannibalize the bundle sale scheme because consumers with high IWTP who would purchase from the bundle if the bundle sale scheme was the only option might switch to the unit sale scheme to increase their consumer surplus. Fig. 4 illustrates this idea. In Fig. 4a, there are three consumers (Consumers 1 to 3) with marginal willingness to pay functions, \( w_1(q), w_2(q), \) and \( w_3(q) \), respectively. Suppose the firm decides that, in pure bundling, it would set the bundle price such that it is equal to the area under \( w_2(q) \). Then, both Consumers 2 and 3 would purchase the bundle. Suppose the firm later decides to add the unit sale scheme on top of the bundle sale scheme so that it can earn from Consumer 1 as well. In order for Consumer 1 to find the information goods affordable, the unit price \( p \) has to be lower than the y-intercept of \( w_1(q) \), as shown in Fig. 4a. However, if \( p \) is so low, Consumer 2, who enjoyed zero consumer surplus from the bundle sale scheme, would switch to the unit sale scheme and purchase \( q_2^* \) to enjoy a surplus equal to the size of the triangle enclosed by points (0, \( y_2 \)), (0, 0), and \( (q_2^*, p) \) in the Cartesian coordinate plane. Consumer 3 may or may not switch to the unit sale scheme, depending on whether the size of the triangle enclosed by points (0, \( y_3 \)), (0, \( y_2 \)), and \( (x, 0) \) is greater than the size of the triangle enclosed by points (0, \( y_2 \)), (0, 0), and \( (q_3^*, p) \), in other words, whether the consumer surplus from the bundle sale scheme is greater than the consumer surplus from the unit sale scheme. In this simple example, we can see that introduction of the unit sale scheme on top of the bundle sale scheme can potentially create substantial cannibalization effect.

However, the cannibalization effect of an addition unit sale scheme may be smaller when consumers are not so heterogeneous in IWTP, but quite heterogeneous in APP. In Fig. 4b, there are three consumers who differ in APP. Suppose the firm decides that, in pure bundling, it would set the bundle price such that it is equal to the area under \( w_2(q) \). Then, both Consumers 2 and 3 would purchase the bundle. Suppose the firm later decides to add the unit sale scheme on top of the bundle sale scheme so that it can earn from Consumer 1 as well. In order for Consumer 1 to find the information goods affordable, the unit price \( p \) has to be lower than the y-intercept of \( w_1(q) \), as shown in Fig. 4b. Consumer 2, who enjoyed zero consumer surplus from the bundle sale scheme, would again switch to the unit sale scheme and purchase \( q_2^* \) to enjoy a surplus equal to the size of the triangle enclosed by points (0, \( y \)), (0, 0), and \( (q_2^*, p) \). This time, however,
Consumer 3 is less likely to switch to the unit sale scheme, because the size of the triangle enclosed by points $(0, y), (x_3, 0)$, and $(x_3, 0)$ seems to be substantially larger than the size of the triangle enclosed by points $(0, y), (0, p)$, and $(q^*, p)$. Thus, the cannibalization effect of the unit sale scheme is smaller in Fig. 4b than in Fig. 4a.

### 4.3. General case: Presence of both APP heterogeneity and IWTP heterogeneity

Finally, we turn to the most general case where there is variation in both APP and IWTP. Unlike in Sections 4.1 and 4.2, here, we vary both of the parameters $a$ and $b$. We assume that $a$, which controls the IWTP, follows $\text{Uniform}(1/2 - \alpha, 1/2 + \alpha)$, where $0 \leq \alpha \leq 1/2$; and $b$ which controls the APP heterogeneity, follows $\text{Uniform}(1/2 - \beta, 1/2 + \beta)$, where $0 \leq \beta \leq 1/2$.

The I.R. constraint for the unit sale scheme is

$$ a \geq p. \quad (22) $$

The I.R. constraint for the bundle sale scheme is

$$ a \geq \frac{2B}{b}. \quad (23) $$

#### Lemma 3. If a consumer purchases from the unit sale scheme, he or she enjoys a utility of

$$ u(q^*) = \frac{b(a-p)^2}{2a} \quad (24) $$

where $q^*$ denotes the optimal quantity the consumer would purchase to maximize his or her utility from the unit sale scheme.

#### Proof of Lemma 3. The utility from purchasing from the unit sale scheme is given by

$$ u(q) = aq - \frac{a}{2b}q^2 - pq. \quad (25) $$

The consumer would purchase $q^*$ to maximize his or her utility. Maximizing Eq. (25) with respect to $q$ gives

$$ q^* = \frac{b(a-p)}{a}. \quad (26) $$

Substituting $q^*$ back to Eq. (26) gives Eq. (24).

On the other hand, if the consumer purchases from the bundle sale scheme, his or her utility would be equal to $u(Q) = ab/2 - B$. Hence, the incentive compatibility constraint (I.C.) for a consumer to choose the bundle sale scheme is given by

$$ a \geq \frac{1}{2} \beta b^2. \quad (27) $$

The indifference curves Eqs. (22), (23), and (27) create many possible scenarios depending on where they cut the edges of the rectangular consumer space defined by $a$ and $b$. Furthermore, optimization with respect to two variables renders the problem intractable. Therefore, we use a combination of analytical and numerical methods to approach the problem. (The problem solving procedure is rather tedious and will be provided if asked.)

The relative performance of mixed bundling vs. pure bundling is shown in Fig. 5. As shown, when $\alpha = 0$ (i.e., zero IWTP heterogeneity), mixed bundling is preferred over pure bundling when $\beta$ (i.e., APP heterogeneity) is large enough, and, in this case, $\beta \geq 1/6$. When $\beta = 0$, pure bundling is always preferred regardless of $\alpha$. These results are consistent with those in Sections 4.1 and 4.2. In general, we observe in Fig. 5 that an increase in $\beta$ is associated with a larger area for an optimal mixed bundling strategy, while an increase in $\alpha$ is associated with a larger area for an optimal pure bundling strategy.

#### Observation 1. APP heterogeneity tends to increase the firm's preference for mixed bundling. However, this relationship is moderated by increase in IWTP heterogeneity.

### 5. Contribution and business implications

This paper is among the first to compare two commonly used bundling strategies: pure bundling and mixed bundling. In particular, this paper explores how different dimensions of heterogeneity affect the choice of bundling strategy for the firm. In general, consumer heterogeneity in appetite (APP) drives the firm towards mixed bundling. However, consumer heterogeneity in initial willingness to pay (IWTP) tends to make mixed bundling less favorable.

The addition of a unit sale scheme can be considered as an addition of multiple versions on top of the bundle sale scheme. Thus, using a model that relaxes the SCP restriction, we show that not all types of heterogeneity favor versioning. When IWTP heterogeneity is large, the cannibalization effect can become severe that versioning is not optimal. Our results add IWTP heterogeneity as a factor, in addition to menu cost [29] and cognitive cost [6,9] to explain why firms may limit the number of versions offered in the market, despite the suggestion from classical second degree price discrimination research to offer as many versions as there are consumer types [14].

Our study also highlights the importance of choosing the right degree of price discrimination. Our findings suggest that versioning is not very effective in extracting consumer surplus when consumers are heterogeneous in their IWTP. We believe that this dimension of heterogeneity is better handled by other forms of price discrimination, such as third degree price discrimination. In fact, in reality a lot of third degree price discrimination is based on the purchasing power of different groups of consumers. For example, institutions have to pay a higher price for journal subscriptions than individual readers; young children and students can enjoy cheaper movie tickets. On the other hand, when consumers are likely to be heterogeneous only in APP, versioning can be effective. For example, in fast food restaurants, versioning based on quantity discount is common.

Therefore, when IWTP heterogeneity is high, even when there is not an obvious external signal (e.g., student status) for third price discrimination, it may actually be worthwhile to invest in creating an external signal, e.g., the firm might issue special membership cards to members of some nearby community centers, while selling to other consumers at relatively high prices. More relevant to e-commerce, when we book hotel services through the Internet, we
often find that we can get a better deal if we can provide a "promotional code". This is a form of third degree price discrimination because with it the firm devises a pricing strategy for each group (defined by the promotional code) without worrying about the problem of personal arbitrage (i.e. there is no need to consider the incentive compatibility constraints).

6. Conclusions and future research

Using a combination of analytical and numerical methods, we show that APP heterogeneity favors mixed bundling and that IWTP heterogeneity may reduce its profitability relative to pure bundling. This is because APP heterogeneity creates an opportunity for the firm to use versioning to sort consumers into different types; whereas IWTP heterogeneity increases the possibility of cannibalization as consumers receive more opportunity to conduct personal arbitrage. The cost to prevent personal arbitrage may become so high that it is better for the firm to simply adopt pure bundling.

Future research can extend our results in a number of ways. First, future research can focus on the degree of price discrimination as a decision variable and provide useful guidelines for real businesses in devising their pricing strategies. Second, some information goods may be less customizable than digital content such as news, images and music. In these contexts, it might not make sense to offer individual components for sale. Future research should look at how customizability affects versioning decisions. Third, the optimal versioning decision can be found by first determining the optimal number of versions, followed by the optimal version quality and price for each version. Although this problem is likely to be intractable, numerical analysis can be used to illustrate how different types of heterogeneity affect optimal versioning decisions. Finally, given the importance of marginal cost and network externalities to the information economy, future research can analyze the interaction between marginal cost, network externalities, and various types of heterogeneity.

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Appendix A. Solution to pure bundling problem in Section 4.1

When the firm adopts pure bundling, it offers only the bundle sale scheme. The I.R. constraint for a consumer to purchase the bundle is given by \( b \geq B \).

If a consumer purchases the bundle, the firm earns from him or her \( B \). Therefore the firm's profit function is given by

\[
\max_{b} \frac{1}{2B^2} f(b) \left[ 1 - (B - b)^2 \right] B
\]

s.t. \( B \geq 1/2 - \beta \).

If the firm decides to set \( B = 1/2 - \beta \), it means that the population is more or less homogeneous in \( b \) and the firm decides to turn all consumers into its customers by allowing even the lowest type in the market \( (1/2 - \beta) \) to find the bundle affordable. Note that the firm would not consider setting \( B = 1/2 - \beta \) because this would lower the profit earned from each customer without increasing the number of customers. It is easy to show that the solution is as shown in Eq. (12).

Appendix B. Solution to pure bundling problem in Section 4.2

The I.R. constraint for a consumer to purchase the bundle is given by \( a \geq B \). If a consumer purchases the bundle, the firm earns from him or her \( B \). Therefore the firm's profit function is given by

\[
\max_{b} \frac{1}{2B^2} f(b) \left[ 1 - (B - b)^2 \right] B
\]

s.t. \( B \geq 1/2 - \alpha \).

If the firm decides to set \( B = 1/2 - \alpha \), it means that the population is more or less homogeneous in \( a \) and the firm decides to turn all consumers into its customers by allowing even the lowest type in the market \( (1/2 - \alpha) \) to find the bundle affordable. It is easy to show that the solution is as shown in Eq. (18).

Appendix C. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.dss.2012.02.008.

References


Wendy Hui holds a Ph.D. in Information Systems from Hong Kong University of Science and Technology. Her current research interests include virtual world behavior, information security and research methods. She has spent two years at Zayed University, U.A.E., and three years at University of Nottingham Ningbo, China. She is a senior lecturer at Curtin University, Australia.

Byungjoon Yoo is working at Graduate school of business, Seoul National University as an associate professor. Before he joined Seoul National University, he worked at Hong Kong University of Science and Technology and Korea University. He received a Ph.D. in Information Systems from Carnegie Mellon University. His research interests are on B2B e-commerce, online auctions and pricing strategies of digital goods such as software and online game. He has published on these topics in journals such as Management Science, Journal of Management Information Systems, International Journal of Electronic Commerce, Decision Support Systems and Journal of Organizational Computing and Electronic Commerce. He has consulting experience with Korea Stock Exchange, Korea Game Development and Promotion Institute and online game vendors.

Vidyand (VC) Choudhary is an Associate Professor at the Paul Merage School of Business, University of California, Irvine (UCI). Prior to UCI, he was a faculty member at the Tepper School of Business at Carnegie Mellon University. He received his Ph.D. in Management with a focus on Information Systems from Purdue University. His research interests are in the area of economics of information systems and marketing strategy for Information Technology. His research papers have won best paper awards at the 22nd International Conference on Information Systems (ICIS) and the 10th Workshop on Information Technology and Systems (WITS). He has published in prestigious academic journals such as Management Science, Information Systems Research, and the Journal of Management Information Systems. He is currently serving as an Associate Editor at Information Systems Research.

Kar Yan Tam is Associate Provost and Chair Professor of Information Systems at the Hong Kong University of Science & Technology. His research interests include adoption of information technology, electronic commerce and web personalization. He has published extensively on these topics in major management science and information system journals. He is currently on the editorial board of a number of IS journals. Prof. Tam has extensive consulting experience with major companies including HSBC, Sun Microsystems, Symantec, and Hutchison Telecommunications.