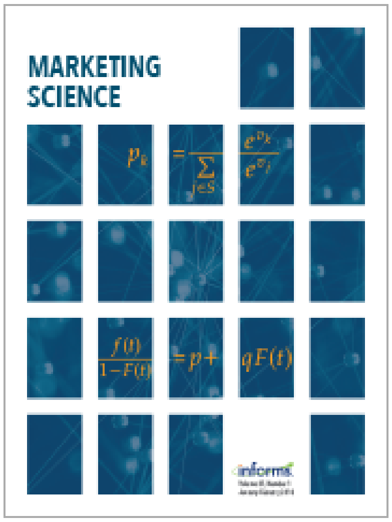


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# Service Product Design and Consumer Refund Policies

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**Abstract.** Customers often exhibit considerable uncertainty in their service valuations. In response, firms may tailor their products and allow service cancellations. We consider the joint product customization and refund policy decisions of a monopolistic firm selling to a heterogeneous customer population with imperfect signals on their valuations. Our results shed light on how customers' valuation uncertainty, characterized by the valuation heterogeneity and signal quality, drives the interaction between product line and refund policy designs. In particular, when the valuation heterogeneity is high, the firm may choose to offer a single quality level with a full refund, leading to a *variety reduction* in the product line. In contrast, when the valuation heterogeneity is low, the firm will always offer a full product line without any refund. At moderate valuation heterogeneity, both qualities and refunds are subject to more customization, and a partial refund can be optimal when the signal quality is high, even though our setup does not involve aggregate demand uncertainty, capacity limitations, competition, or channel conflicts. Interestingly, despite its appeal, generous refund terms do not increase aggregate customer surplus. Furthermore, the firm may not have incentives to reduce customers' valuation uncertainty even if doing so is costless. We verify the robustness of our results and discuss their practical implications.

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**Keywords:** product line design • cancellations • return policy • partial refunds • consumer uncertainty • services • quality

## 1. Introduction

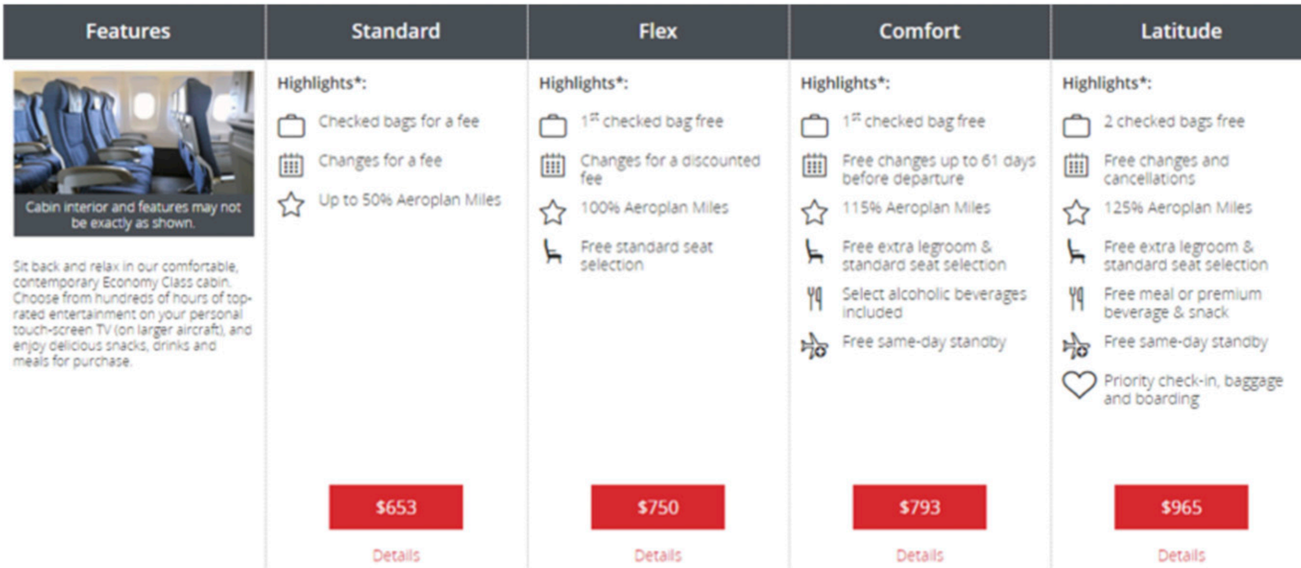
Customers often exhibit considerable uncertainty in their service valuations.[1] In response, firms may tailor their products and allow service cancellation alongside some refunds. A prime example is the airline industry. At Air Canada, for instance, the economy-class customers are offered different peripheral services, in addition to a seat on the airplane, at different rates and sometimes drastically different refund terms. As illustrated in Figure 1, an Economy Standard ticket is nonrefundable, whereas an Economy Latitude ticket is fully refundable at Air Canada. An Economy Latitude ticket also enjoys other benefits including free same-day change, complementary checked baggage, and priority check-in, all of which are not available for Economy Standard. Therefore, Air Canada *simultaneously* customizes its products and varies its refund terms for its economy-class tickets.

Product customization and refund terms can vary dramatically across industries, or even within the same firm. Indeed, for Air Canada, the product options and refund terms for business-class tickets are substantially different from those for the economy class—only a single, premium service level is offered for the business class, along with various refund-pricing options. Unlike the airline industry, however, theme parks such as Disney World offer numerous admission options and in-park services, but all are nontransferable and nonrefundable.

The joint product customization and refund design is often observed when there is a temporal separation between purchase and consumption. At the time of purchase, customers have valuation uncertainty and can only make product choices based on their perceived valuations. Once the uncertainty is resolved, customers may exercise the return (or, equivalently, cancel the service) depending on their revealed valuations. Therefore, even though both product customization and refund policies are levers for customer discrimination, the former acts ex ante, whereas the latter acts ex post.

Product design and consumer refunds have each been studied extensively in the marketing and operations literature. Much of this literature, however,

**Figure 1.** (Color online) Economy-Class Offerings for a Flight from Denver to Montreal at Air Canada



| Features | Standard | Flex | Comfort | Latitude |
|---|---|---|---|---|
| Cabin interior and features may not be exactly as shown. Sit back and relax in our comfortable, contemporary Economy Class cabin. Choose from hundreds of hours of top-rated entertainment on your personal touch-screen TV (on larger aircraft), and enjoy delicious snacks, drinks and meals for purchase. | Highlights*: Checked bags for a fee; Changes for a fee; Up to 50% Aeroplan Miles | Highlights*: 1st checked bag free; Changes for a discounted fee; 100% Aeroplan Miles; Free standard seat selection | Highlights*: 1st checked bag free; Free changes up to 61 days before departure; 115% Aeroplan Miles; Free extra legroom & standard seat selection; Select alcoholic beverages included; Free same-day standby | Highlights*: 2 checked bags free; Free changes and cancellations; 125% Aeroplan Miles; Free extra legroom & standard seat selection; Free meal or premium beverage & snack; Free same-day standby; Priority check-in, baggage and boarding |
| | $653 Details | $750 Details | $793 Details | $965 Details |

considers refund policies under a *given* product line and often assumes that a single product or quality level is offered. For the research on product line design, the main focus has been on quality customization and has not incorporated refund policies. In this paper, we aim to bridge the gap by incorporating refund terms as an important dimension of product design. Several research questions naturally arise:

1. How do product customization and customer refunds interact with each other?
2. How does customers' valuation uncertainty drive a firm's product customization and refund terms?
3. When should firms reduce customers' valuation uncertainty via information provision?

## 1.1. Summary of Main Results

We consider the following setup: A monopolistic firm serves a customer population with uncertain valuations. Customers are of either the high type or the low type, valuing product quality differently. Customers do not observe their types before the purchase but receive imperfect signals indicating their types. The firm configures its product qualities, prices, and refund policies. Consumers self-select the product to purchase based on the signal they receive. After the purchase, customers discover their true types and decide whether to return the product and obtain a refund.

In this setup, we explicitly model customers' valuation uncertainty in two dimensions. The first dimension, *valuation heterogeneity*, measures the discrepancy between the high and low valuation types. It concerns the heterogeneity among customers' *true* valuations that are revealed only ex post. The second dimension, *imperfect signal*, determines the customers' ex ante perception of their valuation types. The quality of the signal captures the intertemporal difference between customers' *perceived* and *true* valuations. We show that both dimensions are important drivers of our results.

We fully characterize the firm's optimal product line with an endogenous refund policy, which allows us to investigate the interaction between product customization and refund policies. As a baseline, we show that when refunds are not allowed, it is optimal to offer quality-differentiated products to different customer segments. However, when refunds are allowed, the firm's product line is subject to change except when customers' valuation heterogeneity is low. As valuation heterogeneity increases, the quality difference within the optimal product line shrinks and the refunds become more generous. In particular, when the valuation heterogeneity is high, it can be optimal for the seller to offer a single product with a full refund to all customers, leading to a *variety reduction* effect. In this way, the firm can engage all the high-type customers even when their valuation perception is uncertain ex ante, which cannot be achieved without ex post refunds. Therefore, the flexibility to vary refund policies allows the firm to work with a narrower span of quality levels while earning higher profit.

In answering the second research question, we summarize the optimal product line design as follows:

1. When the customers' valuation heterogeneity is high, it is optimal for the firm to offer fully refundable premium-quality products to all customers.
2. When customers' valuation heterogeneity is moderate and the signal quality is low, it is optimal for the firm to offer nonrefundable good-quality service to customers who are optimistic about their valuations

and fully refundable premium-quality service to pessimistic customers.

3. When customers' valuation heterogeneity is moderate and the signal quality is high, it is optimal for the firm to offer a premium product with a partial refund to the optimistic customers and a nonrefundable low-quality product to the pessimistic customers.

4. When customers' valuation heterogeneity is low, it is optimal for the firm to adopt a no-refund policy while providing high- and low-quality products to the optimistic and pessimistic customers, respectively.

These findings suggest that the optimal product line design is jointly determined by both dimensions of the valuation uncertainty. Specifically, the product line is mainly driven by the valuation heterogeneity when it is extremely high or low (Results 1 and 4); otherwise, it critically depends on the signal quality (Results 2 and 3). These results seem to match many observations in the marketplace. For instance, business-class airfare can be rather standardized and is often fully refundable. This may be attributed to the significant valuation heterogeneity for business trips, which either is mission critical or has almost no value, depending on the business needs (Result 1). On the contrary, visitors to Disney World theme parks are offered only nonrefundable tickets because they all place a reasonably similar value on such an experience, implying low valuation heterogeneity (Results 4). Results 2 and 3 emphasize the role of the signal the customers receive. Notably, in Result 3, partial refunds can emerge as an optimal policy, even though our setup does not involve aggregate demand uncertainty, capacity limitations, competition, or channel conflicts, which are common causes identified in the existing literature for partial refunds. Instead, partial refunds in our paper result from moderate valuation heterogeneity and high signal quality, which make it more efficient to jointly customize quality ex ante and tailor refunds ex post.

For the last research question, we find that reducing customers' valuation uncertainty does not always benefit the firm; that is, a firm may not be interested in improving the signal quality or letting customers have more accurate valuations ex ante, even if it can be done at little or no cost. Indeed, when the valuation heterogeneity is high, it is advisable for the firm not to take any action at all. When the valuation heterogeneity is moderate, the firm should weaken the signal quality if it is low or strengthen it if it is high. When the valuation heterogeneity is low, the firm should weaken any existing signal. In general, information provision is preferable only when customers have higher valuation heterogeneity.

We consider two extensions of our main model. In the first one, we allow the cost of the cancelled product to be only partially recoverable. In the second one, we allow customers to upgrade if they turn out to be of the high type. We show that our key insights are robust in both extensions.

The rest of the paper is organized as follows: Section 2 surveys the most recent and relevant literature. Section 3 presents the model preliminaries and analyzes a benchmark case when refunds are not allowed. Section 4 analyzes the optimal product line design with and without standardization and discusses the implications on customer welfare. Section 5 investigates the firm's incentive to improve the signal quality. Section 6 considers two model extensions and verifies the robustness of our main results. Section 7 concludes. All technical proofs are relegated to the online appendix.

## 2. Literature

Our research intersects with two streams of literature: consumer refund policy and product line design.

There is an extensive literature on consumer refund policies, covering the various reasons that may trigger consumer returns, such as opportunism (Chu et al. 1998, Shang et al. 2017), product quality (Moorthy and Srinivasan 1995, Hsiao and Chen 2012), product mismatch (Davis et al. 1995, Guo 2009, Shulman et al. 2010), alternate options (Xie and Gerstner 2007), unattended service (Gallego et al. 2015), customer no-shows (Ringbom and Shy 2004, Ringbom and Shy 2008), and valuation uncertainty (Che 1996, Courty and Li 2000, Liu and Xiao 2008, Su 2009, Chen 2011, Shulman et al. 2011, Akcay et al. 2013, Akan et al. 2015, Shulman et al. 2015), just to list a few. Furthermore, consumer refund policies have been studied in both manufacturing and service settings. Most of the aforementioned papers focus on the manufacturing setting, with a few dedicated to service settings, such as Courty and Li (2000), Xie and Gerstner (2007), Liu and Xiao (2008), Ringbom and Shy (2008), Guo (2009), and Akan et al. (2015). Because of the high volume of papers involving consumer refund policies, we do not attempt to conduct a comprehensive literature review. Rather, we will discuss only those papers that are most relevant to ours, namely, papers that study the service settings where returns are triggered by consumers' valuation uncertainty, and those that offer insights on partial refunds.

In the service context, customer refunds are usually triggered by valuation uncertainty, as cancellation normally takes place before a service is experienced. Courty and Li (2000) introduce a price–refund menu as a way for the seller to screen customers of different valuation distributions. Akan et al. (2015) extend the problem by allowing customers to learn their valuations at different times so that the seller can screen on both the amount and timing of the refund. Liu and Xiao (2008) suggest that either the service or the refund should be offered on a more restricted basis when there is a capacity constraint; in addition, they study the impact of capacity rationing on the price–refund menu design. Chen (2011) considers a capacity-constrained seller facing both aggregate demand uncertainty and heterogeneous customer valuations, and develops an optimal selling scheme that induces truthful revelation. Even though we do not consider the capacity issue in the current paper, our results corroborate the idea that a refund may not be offered to all customers because of quality customization. Our work is also related to the recent literature on the impact of information provision regarding uncertain valuations. Shulman et al. (2015) find that information provision may increase the cancellation rate, particularly when the prepurchase valuation is moderate with regard to the price. By configuring the optimal quality–price–refund menu, our study further shows that information provision may harm the firm's profit, depending on the level of valuation uncertainty.

Another research question that has attracted considerable attention in the literature is when full or partial refunds should be offered. Davis et al. (1995) use a stylized model to demonstrate the conditions under which a full refund should be offered. Ringbom and Shy (2004) propose the use of common prices but different partial refunds in order to discriminate among customers of different no-show rates. Xie and Gerstner (2007) show that in the presence of finite capacity, a seller can benefit from a partial refund for service cancellation, as freed capacity can be used to serve other consumers. Ringbom and Shy (2008) study collusive pricing and refund policies in the service industry. They show that monopolistic and collusive service providers offer full refunds, whereas competitive service providers offer partial refunds. Guo (2009) studies the rationale behind offering partial refunds in a competitive setting and identifies capacity scarcity as a key driver for partial refunds that are adopted in equilibrium. Su (2009) studies consumer refund policies in a supply chain setting. He shows that it is optimal to offer partial refunds, which are driven by aggregate demand uncertainty. Shulman et al. (2010) also demonstrate the optimality of partial refunds in a supply chain. Their focus is whether the manufacturer or the retailer should process product returns. Shulman et al. (2011) further show that partial refunds can be more frugal in a competitive than monopolistic environment. Hsiao and Chen (2012) illustrate that there are conditions under which a refund can exceed the full price. Tran et al. (2018) study return policy design in a supply chain setting and find that a partial refund can be introduced to decrease profit variability. Partial refunds also constitute an important element of our result. We show that partial refunds can emerge as an optimal policy, even when there are no capacity limitations, aggregate demand uncertainty, risk aversion, competition, or channel conflicts, and the key drivers lie in quality customization and valuation uncertainty.

With respect to the stream of research that considers product line design, the existing literature has examined this issue under various contexts, including market segmentation (see Moorthy 1984 and references therein), distribution channels (e.g., Villas-Boas 1998, Liu and Cui 2010), advertising (e.g., Villas-Boas 2004), consumer evaluation and research costs (e.g., Villas-Boas 2009, Kuksov and Villas-Boas 2010), and preference structure (e.g., Orhun 2009, Kim et al. 2013), just to list a few. We, however, focus on how the product line design can be affected by customers' valuation uncertainty. In this regard, this paper is closely related to those considered in Guo and Zhang (2012) and Xiong and Chen (2014). Both papers consider a mixture of high- and low-type customers and study how to design the best product offerings for each type. Specifically, Guo and Zhang (2012) study the impact of consumer deliberation on optimal product design. Xiong and Chen (2014) allow consumers to choose a standard product before learning about their types, or pay a learning fee and choose afterward. However, neither of the two papers considers the option of refunds after customers discover their true types.

## 3. Model Preliminaries

A service provider (henceforth referred to as the "firm") serves a market with total demand normalized to 1. The firm can serve the market with one or more products. Each product is defined by a triplet $(q, p, \beta)$ with quality $q$, price $p$, and the refund rate $\beta \in [0, 1]$. Products can differ from each other on all or a subset of these attributes. For example, two products can share the same quality but have different prices or refund rates. The cost of serving one unit of product at quality level $q$ is $q^2/2$. If the product is returned, no cost will be incurred, and an amount $\beta p$ will be refunded to the customer. This setup is meant to resonate with service settings, where cancelled service does not incur any materialized cost. However, such a setup may not be suitable for physical goods, where product cost is incurred prior to purchase and returns may involve nontrivial costs such as shipping and repackaging. Nevertheless, as will be discussed later in Section 6.1, allowing only part of the product cost $q^2/2$ to be recoverable does not impose structural changes to our main results.

### 3.1. Valuation Uncertainties

Each customer (henceforth referred to by a feminine pronoun) has a quality valuation $\theta$ and derives a product valuation $\theta q$ for a product with quality $q$

(Mussa and Rosen 1978). The parameter $\theta$ is uncertain for each customer, who can be of the high type, with quality valuation $\theta_H$, or the low type, with quality valuation $\theta_L$. Specifically,

$$\theta = \begin{cases} \theta_H \text{ with probability } \alpha, \\ \theta_L \text{ with probability } 1-\alpha, \end{cases}$$

where $0 \le \alpha \le 1$ and $\theta_L \le \theta_H$. In order to simplify our notation, we use $\bar{y}$ to denote $1-y$ for any $y \in [0,1]$ in the rest of this paper. The distribution of $\theta$ is known to both the firm and the customers, and the ratio $\theta_H/\theta_L$, henceforth referred to as the valuation heterogeneity, is an important characteristic of customers' valuation uncertainty.

Customers do not observe their valuations prior to purchase. Instead, each customer receives a private signal, "good" or "bad," indicating her true type. Subsequently, we refer to these customers as the good-signal and bad-signal customers, respectively. The quality of the signal can be measured by the probability of getting the right signal conditional on one's true type:

$$P\{\text{Good} \mid \text{High type}\} = P\{\text{Bad} \mid \text{Low type}\} = \rho,$$

where we assume $\rho \in (1/2, 1]$; thus, the signals are informative. As one's valuation type is revealed only after the purchase, the *signal quality* $\rho$ reflects the disparity between the perceived and true valuations, representing another important characteristic of customers' valuation uncertainty.

The signal and valuation types jointly divide customers into four categories based on their perceived valuation ex ante and true valuation ex post, as illustrated in Table 1.

Prior to purchase, there are two segments of customers—a fraction $\rho_G = \rho\alpha + \bar{\rho}\bar{\alpha}$ are good-signal customers, and the rest, a fraction $\rho_B = \bar{\rho}_G = \rho\bar{\alpha} + \bar{\rho}\alpha$, are bad-signal customers. Customers in each segment can apply Bayes' rule with the knowledge of valuation distribution to estimate their true types. For instance, a good-signal customer is of the high type with probability $\alpha_G$, and a bad-signal customer is of the high type with probability $\alpha_B$, where

$$\alpha_G = \frac{\rho\alpha}{\rho\alpha + \bar{\rho}\bar{\alpha}}, \quad \alpha_B = \frac{\bar{\rho}\alpha}{\bar{\rho}\alpha + \rho\bar{\alpha}}.$$

**Table 1.** Customer Categorization Based on Ex Ante and Ex Post Types

| | Prior to purchase | |
|---|---|---|
| After purchase | Good signal | Bad signal |
| High valuation | $\rho\alpha$ | $\bar{\rho}\alpha$ |
| Low valuation | $\bar{\rho}\bar{\alpha}$ | $\rho\bar{\alpha}$ |

The expected valuations for good- and bad-signal customers are $\theta_G = \alpha_G\theta_H + (1-\alpha_G)\theta_L$ and $\theta_B = \alpha_B\theta_H + (1-\alpha_B)\theta_L$, respectively. Observe that, because $\rho \in (1/2, 1]$, a good signal implies a higher chance of being a high-type customer, as well as higher expected quality valuations; that is, $\alpha_G > \alpha > \alpha_B$ and $\theta_G > \theta_B$.

After the purchase, valuation uncertainty is resolved, and customers learn their true types. The customers again fall into two segments—a fraction $\alpha$ are of the high type, and the rest, $\bar{\alpha}$, are of the low type. Customers make return decisions based on their true valuation types.

### 3.2. Customer Choice and Market Outcomes

Given that the signals are private for individual customers, the firm faces an adverse selection problem. The firm needs to design a product line with at most two products, product G, $(q_G, p_G, \beta_G)$, and product B, $(q_B, p_B, \beta_B)$, catering to the good- and bad-signal customers, respectively. When $(q_G, p_G, \beta_G) = (q_B, p_B, \beta_B)$, the two products are identical, and only one product is offered to all customers. The firm can also choose not to serve the good- or bad-signal customers; in our analysis, this can be done by assigning them a dummy product $(0, 0, 1)$.

Let $u_{si}$ denote the expected surplus for customers receiving signal $s$ and purchasing product $i$, where $s, i \in \{G, B\}$. To induce the good-signal customers to choose product G and bad-signal customers to choose product B, the firm needs to ensure that both individual rationality (IR) and incentive compatibility (IC) constraints are satisfied, that is,

$$u_{GG} \ge 0, \qquad (\text{IR}_G)$$
$$u_{BB} \ge 0, \qquad (\text{IR}_B)$$
$$u_{GG} \ge u_{GB}, \qquad (\text{IC}_G)$$
$$u_{BB} \ge u_{BG}. \qquad (\text{IC}_B)$$

The following lemma is a result of the IR constraints, noting that a customer will return the product if and only if the potential refund exceeds the true product valuation.

**Lemma 1.** *Only the low-type customers may exercise the refunds.*

Therefore, the expected surplus for customers receiving signal $s$ and purchasing product $i$ is

$$\begin{aligned} u_{si} &= \alpha_s(\theta_H q_i - p_i) + \bar{\alpha}_s \max\{\theta_L q_i - p_i, -\bar{\beta}_i p_i\} \\ &= \alpha_s\theta_H q_i + \bar{\alpha}_s \max\{\theta_L q_i, \beta_i p_i\} - p_i, \end{aligned} \qquad (1)$$

and a customer who has purchased product $i \in \{G, B\}$ will return the product if and only if (i) she turns out to be of the low type ($\theta = \theta_L$) and (ii) the refund exceeds her product valuation ($\theta_L q_i \le \beta_i p_i$). In other words, a customer will keep the product with quality $q_i$ should her valuation turn out to be high, or return the product and obtain a refund of $\beta_i p_i$ if her valuation turns out to be low. In any event, the quality $q_i$ and refund $\beta_i p_i$ jointly determine the customer's reward after the uncertainty resolves. It then follows that there are four possible market outcomes with regard to customer refunds:

RR: All low-type customers will claim the refund.

NR: Only bad-signal (purchasing product B) low-type customers will claim the refund.

RN: Only good-signal (purchasing product G) low-type customers will claim the refund.

NN: No customer will claim the refund.

In order to design the optimal product line, the firm needs to investigate the optimal product line design under each market outcome and compare the profits across the four candidate solutions.

### 3.3. Benchmark: Product Line Design Without Refund

We first analyze the benchmark case where no refund is allowed. It also corresponds to the product design under the market outcome NN. Before proceeding, we introduce the following notations and relations that will be used in the remainder of this paper:

$$\phi(\lambda, \alpha_1, \alpha_2) = \frac{\lambda\alpha_2 - \alpha_1}{\bar{\alpha}_1 - \lambda\bar{\alpha}_2}, \quad \forall\, 0 \le \alpha_1 < \alpha_2 \le 1, 0 \le \lambda \le 1,$$
$$\alpha_0 = \frac{\alpha_B - \rho\alpha}{\bar{\rho}_G} \le \alpha_B \le \alpha \le \alpha_G,$$
$$\theta_0 = \max\{\alpha_0\theta_H + \bar{\alpha}_0\theta_L, 0\} \le \theta_B \le \theta_G \le \theta_H,$$
$$\phi_0 = -\frac{\alpha_0}{1-\alpha_0}.$$

Whenever comparison arises, we refer to $\theta_0$ as "inferior," $\theta_G$ as "moderate," and $\theta_H$ as "high."

When no refund is allowed, that is, $\beta_G = \beta_B = 0$, the firm solves the following optimization problem:

$$\max_{q_G, q_B, p_G, p_B \ge 0} \quad \rho_G(p_G - q_G^2/2) + \bar{\rho}_G(p_B - q_B^2/2)$$
$$\text{s.t.} \quad (\mathrm{IR_G}), (\mathrm{IR_B}), (\mathrm{IC_G}), (\mathrm{IC_B}).$$

Note that this formulation allows both single- and dual-quality design, as well as partial or full market coverage. The results are summarized in the following lemma.

**Lemma 2** (Optimal Product Line Design Without Refund). *When no refund is offered,*

(i) *the optimal product line is*

$$(q_G^{NN}, p_G^{NN}) = (\theta_G, \theta_G(\theta_G - \theta_0) + \theta_0\theta_B),$$
$$(q_B^{NN}, p_B^{NN}) = (\theta_0, \theta_0\theta_B);$$

(ii) *When $\frac{\theta_L}{\theta_H} \ge \phi_0$, the firm is better off with dual-quality design and full market coverage ($\theta_G > \theta_0 > 0$); otherwise, the firm is better off with single-quality design and partial market coverage ($\theta_G > \theta_0 = 0$).*

Lemma 2 shows that each customer segment will be assigned a distinct quality level. Good-signal customers will be served with moderate quality ($q_G^{NN} = \theta_G$), and bad-signal customers will be served with inferior quality ($q_B^{NN} = \theta_0$) or unserved when $\theta_0 = 0$. When some threshold condition is satisfied, the entire market will be covered at two distinct quality levels; otherwise, the market will be partially covered by one product. Specifically, dual-quality design is optimal for any valuation heterogeneity ($\theta_L/\theta_H$) when $\alpha_0 \ge 0$, or, equivalently, $\alpha \ge \frac{\rho^2+\rho-1}{\rho(2\rho-1)}$. As will be shown in the next section, this may not be true when refund is allowed.

## 4. Optimal Product Line Design

We now analyze the optimal product line design where refunds are allowed. The firm needs to design two products, $(q_G, p_G, \beta_G)$ and $(q_B, p_B, \beta_B)$, targeting good- and bad-signal customers, respectively. As discussed in Section 3.2, in order to find the optimal product line design, the firm compares the optimal product lines under each possible market outcome. As an example, the optimal design with the market outcome RR can be identified by solving

$$\max_{q_G, q_B, p_G, p_B, \beta_G, \beta_B \ge 0} \Pi^{RR} = \rho_G\left(p_G - \bar{\alpha}_G\beta_G p_G - \frac{\alpha_G q_G^2}{2}\right) + \bar{\rho}_G\left(p_B - \bar{\alpha}_B\beta_B p_B - \frac{\alpha_B q_B^2}{2}\right)$$

$$\text{s.t.} \quad \begin{aligned} & u_{GG} \ge 0, && (\mathrm{IR_G}) \\ & u_{BB} \ge 0, && (\mathrm{IR_B}) \\ & u_{GG} \ge u_{GB}, && (\mathrm{IC_G}) \\ & u_{BB} \ge u_{BG}, && (\mathrm{IC_B}) \\ & \beta_G p_G \ge \theta_L q_G, && (\mathrm{RR_G}) \\ & \beta_B p_B \ge \theta_L q_B, && (\mathrm{RR_B}) \\ & \beta_G \le 1, && \\ & \beta_B \le 1. && \end{aligned}$$

The firm's profit in the objective function includes initial revenues, net of refunds issued to customers, minus the service cost for customers who choose to keep the product. The IR and IC constraints ensure that the products are targeting the right set of customers, and the RR constraints ensure the RR market outcome—that all low-valuation customers, whether purchasing product G or B, will exercise the refund.

The solution under the market outcome NN was characterized in Lemma 2. The problem formulations for market outcomes NR and RN can be written in a fashion similar to that of RR above; we relegate the details to Online Appendix A. Comparing the profits across all market outcomes gives the results in Table 2. The key findings of the optimal design are summarized in the following theorem.

**Theorem 1** (Optimal Product Line Design). *When refunds are allowed, there exists $\bar{\phi}^* \geq \underline{\phi}^* \geq 0$ and $\frac{1}{2} \leq \hat{\rho} \leq 1$ such that*

*(i) if $\frac{\theta_L}{\theta_H} \leq \underline{\phi}^*$, the market outcome is RR, and the firm may offer a single, high-quality, fully refundable product ($q_G = q_B = \theta_H$, $\beta_G = \beta_B = 1$) to all customers;*

*(ii) if $\underline{\phi}^* \leq \frac{\theta_L}{\theta_H} \leq \bar{\phi}^*$ and $\rho \leq \hat{\rho}$, the market outcome is NR, and the firm should offer a moderate-quality product to good-signal customers ($q_G = \theta_G$) without any refund ($\beta_G = 0$) and a high-quality product to bad-signal customers ($q_B = \theta_H$) with a full refund ($\beta_B = 1$);*

*(iii) if $\underline{\phi}^* \leq \frac{\theta_L}{\theta_H} \leq \bar{\phi}^*$ and $\rho > \hat{\rho}$, the market outcome is RN, and the firm should offer a high-quality product to good-signal customers ($q_G = \theta_H$) with a partial refund ($0 < \beta_G < 1$) and an inferior-quality product to bad-signal customers ($q_B = \theta_0$) without any refund ($\beta_B = 0$);*

*(iv) if $\frac{\theta_L}{\theta_H} \geq \bar{\phi}^*$, the market outcome is NN, and the firm should offer a moderate-quality product to good-signal customers ($q_G = \theta_G$) and an inferior-quality product to bad-signal customers ($q_B = \theta_0$) without any refund ($\beta_G = \beta_B = 0$).*

The results clearly demonstrate how the optimal product line varies with respect to the valuation uncertainty. To begin with, we observe that when the valuation heterogeneity is high ($\theta_L/\theta_H \leq \underline{\phi}^*$), so the valuation uncertainty is high ex post, the firm should defer all customer discrimination ex post accordingly; that is, the firm can rely on a single, high-quality ($q_G^* = q_B^* = \theta_H$) product that is fully refundable ($\beta_G^* = \beta_B^* = 1$) to serve both good- and bad-signal customers. Even though there is room for refund customization (product G tolerates some price–refund trade-off, as shown in Table 2), only one quality level will be offered to all customers. This is in stark contrast to the case where refund is not allowed, where the firm may adopt a dual-quality design ($q_G^{NN} = \theta_G > q_B^{NN} = \theta_0 > 0$) under certain conditions (e.g., when $\alpha_0 \geq 0$). In fact, it can be shown that there always exists situations where the optimal design with refund entails a single, high quality level, whereas the optimal design with no refund calls for two distinct quality levels.

**Corollary 1** (Variety Reduction). *There are always $\phi_0 < \underline{\phi}^*$, and customer refund induces a variety reduction in product line design when $v_L/v_H \in (\phi_0, \underline{\phi}^*]$.*

Recall from Lemma 2 and Theorem 1 that $\phi_0$ is the threshold above which the no-refund design uses dual quality, and $\underline{\phi}^*$ is the threshold below which the customized design offers a single quality. As shown in the proof of Corollary 1, there is a nontrivial region within which customized design offers fewer quality levels than the benchmark no-refund design. We refer to this effect as variety reduction. This variety reduction effect is akin to the seminal result of Moorthy (1984), who shows that customers' incentive compatibility constraints sometimes cause the firm to combine products for different customer segments. The single-quality design entails extracting value from the high-type customers only. Because low-type customers do not value the product much, serving them will cannibalize the revenue from high-type customers. The strategy of targeting high-type customers only, however, cannot be operationalized without refund; because customers do not know their types at the time of purchase, type-based screening at the time of purchase is infeasible. Therefore, without refund, the firm is heavily dependent on imperfect, signal-based screening tools ex ante, such as quality customization, for customer discrimination. With refund, the firm can perform more effective, type-based screening ex post, by offering premium-quality service at high-type customers' maximum willingness to pay.

When the valuation heterogeneity is rather low ($\theta_L/\theta_H > \bar{\phi}^*$), and hence the valuation uncertainty is low ex post, offering refunds will encourage returns from some customers and leave these customers unserved, potentially hurting the firm's revenue. Thus, the firm will discriminate customers ex ante via

**Table 2.** Optimal Product Line

| Optimal product line | High valuation heterogeneity: $\theta_L/\theta_H \leq \underline{\phi}^*$ | Moderate valuation heterogeneity: $\underline{\phi}^* < \theta_L/\theta_H \leq \bar{\phi}^*$ | | Low valuation heterogeneity: $\theta_L/\theta_H > \bar{\phi}^*$ |
|---|---|---|---|---|
| | | Low signal quality: $\rho \leq \hat{\rho}$ | High signal quality: $\rho > \hat{\rho}$ | |
| Quality ($q_G^*, q_B^*$) | $(\theta_H, \theta_H)$ | $(\theta_G, \theta_H)$ | $(\theta_H, \theta_0)$ | $(\theta_G, \theta_0)$ |
| Price ($p_G^*, p_B^*$) | $(\alpha_G\theta_H^2 \sim \theta_H^2, \theta_H^2)$ | $(\theta_G^2, \theta_H^2)$ | $(\theta_G(\theta_H - \theta_0) + \theta_0\theta_B \sim \theta_H(\theta_H - \theta_0) + \theta_0\theta_B, \theta_0\theta_B)$ | $(\theta_G(\theta_G - \theta_0) + \theta_0\theta_B, \theta_0\theta_B)$ |
| Refund rate ($\beta_G^*, \beta_B^*$) | $\left(\frac{1}{\bar{\alpha}_G} - \frac{\alpha_G}{\bar{\alpha}_G}\frac{\theta_H^2}{p_G^*}, 1\right)$ | $(0, 1)$ | $\left(\frac{1}{\bar{\alpha}_G} - \frac{\alpha_G\theta_H^2 - (\theta_G - \theta_B)\theta_0}{\bar{\alpha}_G p_G^*}, 0\right)$ | $(0, 0)$ |
| Market outcome | RR | NR | RN | NN |

*Note.* In this table, $\underline{\phi}^* = \min\{\phi(\sqrt{\alpha_G}, \alpha_G, 1), \phi(\sqrt{\alpha_B}, \alpha_0, 1)\}$ and $\bar{\phi}^* = \max\{\phi(\sqrt{\alpha_G}, \alpha_G, 1), \phi(\sqrt{\alpha_B}, \alpha_0, 1)\}$.

**Table 3.** Customization Strategy

| Valuation uncertainty | | Product line customization | |
|---|---|---|---|
| Ex post | Ex ante | Ex post | Ex ante |
| High | | Full | None |
| Moderate | High | Full or none | Low |
| Moderate | Low | Partial or none | High |
| Low | | None | Moderate |

quality customization, and will not offer any refund. Coupled with the no-refund policy, the firm offers the lowest quality among all scenarios, that is, $\theta_G$ for good-signal customers and $\theta_0$ for bad-signal customers, because customers pay only for the expected quality and do not have a recourse when their valuations turn out to be low.

Finally, when valuation heterogeneity is moderate ($\underline{\phi}^* < \theta_L/\theta_H \leq \bar{\phi}^*$), the optimal product line depends on the signal quality, namely, the ex ante valuation uncertainty. In this case, both refund and quality are customized, and refund is allowed only for one product. When the signal is weak ($\rho \leq \hat{\rho}$), the ex ante valuation uncertainty is high. The firm should then tone down ex ante quality customization and put more weight on ex post refund customization. As shown in the third column in Table 2, customers are offered good- and premium-quality products, whereas one is nonrefundable and the other is fully refundable. When the signal is strong ($\rho > \hat{\rho}$) and the ex ante valuation uncertainty is low, however, the firm should shift more weight to ex ante quality customization. Indeed, this is the scenario where product qualities exhibit the largest gap, $\theta_H$ versus $\theta_0$, and a partial refund may arise as a result of reduced discrimination ex post. In light of the above discussion, we summarize the collection of customization strategies in Table 3 and the effects of valuation uncertainty in Corollary 2.

**Corollary 2** (Effects of Valution Uncertainty).

(i) *The firm offers higher quality levels and more liberal refund policies as the valuation heterogeneity increases.*

(ii) *Under moderate valuation heterogeneity, the bad-signal customers are offered a high-quality product and more generous refund than the good-signal customers when the signal is weak; the opposite is true when the signal is strong.*

Note that in Corollary 2(ii), when the valuation heterogeneity is moderate and the signal is strong, it is valuable for the firm to fine-tune the refund terms and offer a partial refund ($0 < \beta_G^* < 1$). Specifically, such fine-tuning of refund terms does not add value in the scenario when the valuation heterogeneity is moderate but the signal is weak ($\rho \leq \hat{\rho}$). Hence, partial refunds reflect the adjustment in ex post customer discrimination in response to a more accurate signal. This finding is summarized in Corollary 3.

**Corollary 3** (Partial Refunds). *Partial refunds* ($0 < \beta < 1$) *may arise when the valuation heterogeneity is moderate and the signal is strong* ($\rho > \hat{\rho}$).

Note that the threshold signal quality $\hat{\rho}$ changes with $\alpha$. The next proposition characterizes the values of $\hat{\rho}$ for different $\alpha$ values.

**Proposition 1** (Threshold Signal Quality). *The threshold signal quality $\hat{\rho}$ varies with $\alpha$. In particular, we have* (i) $\hat{\rho} = 0.5$ *for any* $\alpha \in (0, \frac{1}{9}]$, (ii) $0.5 < \hat{\rho} \leq 1$ *when* $\alpha \in (\frac{1}{9}, \frac{1}{2})$, *and* (iii) $\hat{\rho} = 1$ *for any* $\alpha \in [0.5, 1]$.

Together, Theorem 1 and Proposition 1 suggest that whether a partial refund should be offered is influenced by both valuation uncertainty and market composition. In a market dominated by low-type customers ($\alpha < \frac{1}{9}$), offering a full-refund policy can undermine the profitability of the firm. The firm should use partial refunds at all times ($\hat{\rho} = 0.5$). As the fraction of low-type customers drops ($\alpha$ increases), the firm can afford to offer more liberal refund policies coupled with higher quality when the signal is less accurate ($\rho < \hat{\rho} \in (0.5, 1)$). When the majority of customers are high-type customers ($\alpha \geq 0.5$), the threshold quality $\hat{\rho} = 1$, and the firm can restrict to full or no refunds without regard to the signal quality.

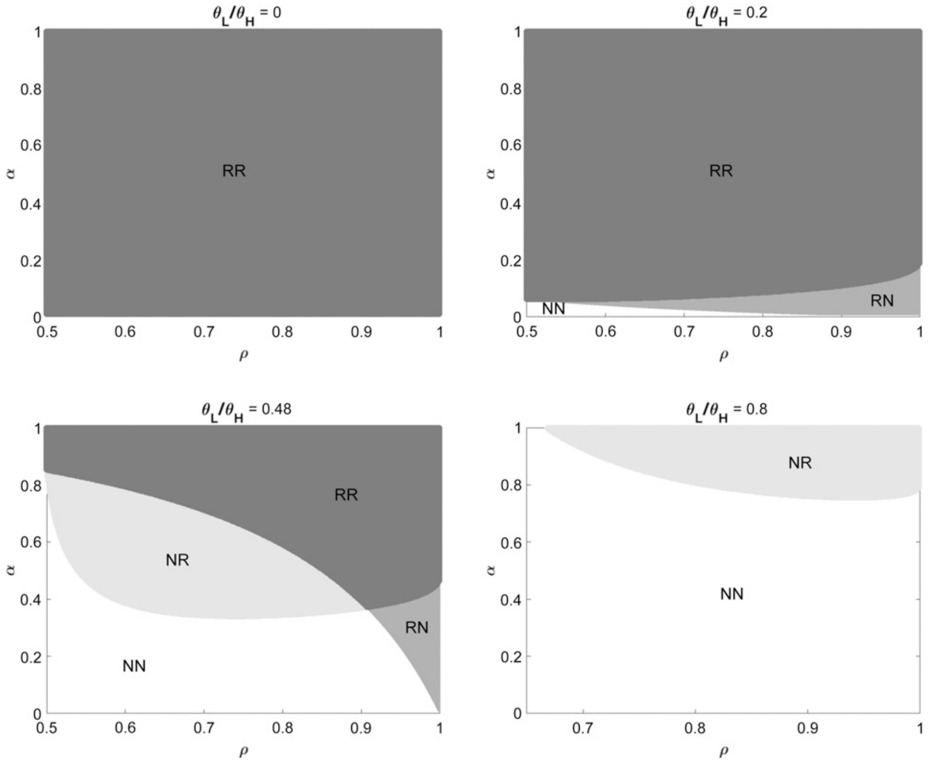
## 4.1. Numerical Examples

We conduct a numerical study to illustrate the impact of valuation uncertainties and market composition on the optimal product line. The results are shown in Figure 2. The vertical axes correspond to market composition ($\alpha$), and the horizontal axes represent signal strength ($\rho$). We consider several different valuation heterogeneities corresponding to different values of $\theta_L/\theta_H$.

The top left graph describes the scenario where the low-valuation customer will derive zero utility ($\theta_L/\theta_H = 0$); therefore, the valuation heterogeneity is high. In this scenario, the firm will make refunds available to all customers (i.e., the market outcome is RR), regardless of the market composition ($\alpha$) or signal quality ($\rho$).

As the valuation heterogeneity decreases ($\theta_L/\theta_H$ increases), it is more likely that the refund will be restricted to one of the products, but RR is still optimal as long as the fraction of high-valuation customers ($\alpha$) and the valuation heterogeneity are reasonably high. In other words, the boundary conditions for the RR outcome ($\underline{\phi}^*$) are characterized by both the fraction $\alpha$ and signal quality $\rho$. For example, to ensure that $\theta_L/\theta_H = 0.2$ falls below $\underline{\phi}^*$, the fraction $\alpha$ should exceed 0.07 for the null signal ($\rho = 0.5$) and 0.18 for near-perfect signal ($\rho$ approaching 1). For a relatively low heterogeneity level, $\theta_L/\theta_H = 0.48$, $\alpha$ should be over 0.9 (for the null signal) or 0.42 (for the near-perfect signal) for the market outcome to be RR.

**Figure 2.** Optimal Market Outcomes (RR, RN, NR, and NN) Based on Valuation Uncertainties (Valuation Heterogeneity $\theta_L/\theta_H$ and Signal Quality $\rho$) and Market Composition (Fraction of High-Type Customers $\alpha$)




When the valuation heterogeneity drops below a certain threshold, for example, $\theta_L/\theta_H > 0.5$, RR is never optimal, and NN becomes more dominant. In all four graphs, the market outcome NN is optimal under conditions that are opposite to those inductive to RR—when the fraction of high-valuation customers ($\alpha$) and the valuation heterogeneity are both low. Specifically, when $\theta_L/\theta_H$ approaches 1, NN will always be adopted.

The bottom left graph ($\theta_L/\theta_H = 0.48$) illustrates the ranges for RN and NR when the valuation heterogeneity is moderate ($\underline{\phi}^* \le \theta_L/\theta_H \le \bar{\phi}^*$). In general, RN occupies the southeast region, whereas NR occupies the northwest. Consistent with our analytical results, refund will only be exercised by the good-signal customers (RN) if the signal is strong but high-valuation customers are rare, and only by bad-signal customers (NR) when the signal is weak but high-valuation customers are plentiful. The actual market outcome depends on the valuation heterogeneity ($\theta_L/\theta_H$). For example, consider the case with $\alpha = 0.7$ and $\rho = 0.6$. The optimal product line would yield the market outcome RR $\to$ NR $\to$ NN as $\theta_L/\theta_H$ increased from 0 to 1; but with $\alpha = 0.3$ and a more accurate signal $\rho = 0.95$, the market outcome would vary from RR $\to$ RN $\to$ NN as $\theta_L/\theta_H$ increased from 0 to 1.

We also wish to comment on the instance where the signal is perfect and customers know their true types before purchase, that is, $\rho = 1$. It can be verified that market outcomes shown on the right edge of each graph in Figure 2 will yield the same profit for the firm as NN. Thus, the firm can simply use the product line developed in Lemma 2 corresponding to the market outcome NN.

### 4.2. Standardization

We have now fully characterized the optimal product line. Next, we consider product line standardization where either a standard quality or a common refund is offered to all customers. Standardization can simplify the product line and can be useful when the cost of introducing additional products or managing a complicated refund policy is high. We also find that sometimes it can be optimal to customize either the product quality or the refund terms, but not both, even if the firm possesses such capability.

**Proposition 2** (Optimality of Standardization).

(i) *A standard refund maximizes the firm's expected profit when the signal is strong and the high-type customers does not form the majority.*

(ii) *A standard quality maximizes the firm's expected profit when the valuation heterogeneity is high.*

When the valuation heterogeneity is low or high ($\theta_L/\theta_H \ge \bar{\phi}^*$ or $\theta_L/\theta_H \le \underline{\phi}^*$, respectively), it can be derived from Theorem 1 that a common refund rate ($\beta_G = \beta_B$) is optimal. When the valuation heterogeneity is moderate ($\underline{\phi}^* \leq \theta_L/\theta_H \leq \bar{\phi}^*$) and the signal is strong ($\rho \geq \hat{\rho}$), the optimal design involves an RN market outcome with a partial refund to the good-signal customers. In this scenario, we are able to show that the optimality would be sustained even if the same partial refund were extended to the entire population, as the bad-signal customers would prefer not to exercise such a refund, and the market outcome would remain as RN; see the details in Online Appendix C. Thus, a standard refund is optimal when the signal quality $\rho$ is over the threshold $\hat{\rho}$. In addition, given that $\hat{\rho} = 1$ when $\alpha > 0.5$, as shown in Proposition 1, the optimality of standard refunds requires that the high-type customers do not form the majority of the market ($\alpha < 0.5$).

Proposition 2(ii) follows immediately from Theorem 1. As shown in Theorem 1, offering a single quality ($q_G = q_B$) is optimal if and only if the valuation heterogeneity is high ($\theta_L/\theta_H \leq \underline{\phi}^*$). Otherwise, there is always a need for quality customization. The driving force of quality standardization was discussed after Corollary 1.

In addition, we investigate the optimal design when the firm is required to offer a single quality level across all customers but may customize refunds; see details in Online Appendix B. It turns out that the firm will always apply highly differentiated refund terms (none or full) to effectively discriminate the customers ex post, because offering a standard quality makes it impossible to discriminate customers ex ante. Consequently, a partial refund will not be used together with offering a standard quality.

### 4.3. Consumer Welfare

How does customer welfare vary across customers? Would customers be better off under customized refund rates than under a standard refund rate? We summarize customers' surplus in Tables 4 and 5. Overall, customers fall into four categories depending on the signals they receive and their valuation types, denoted by GH, GL, BH and BL, where the first letter represents the signal (good or bad) and the second reflects the valuation type (high or low). The surplus for each customer category is calculated under all possible market outcomes induced by the optimal design with a standard (Proposition 6 in Online Appendix C) as well as a customized (Theorem 1) refund policy.

In general, customers who are offered a full refund will always end up with a zero surplus. Other than that, high-valuation customers receive a positive surplus, whereas low-valuation customers receive a negative surplus. Ex ante, good-signal customers expect a positive surplus $\theta_0(\theta_G - \theta_B)$, whereas bad-signal customers expect a zero surplus under both standard and customized refund policies. This suggests that customizing the refund policy does not necessarily change customers' ex ante expected surplus.

Note that the optimal product lines under the standard and customized refunds may coincide with each other, for example, when the conditions in Proposition 2 hold. To make the comparison more meaningful, we consider scenarios where the policies are distinct under the standard and customized refunds, which occur under moderate valuation heterogeneity, that is, $\theta_L/\theta_H \in [\underline{\phi}^*, \bar{\phi}^*]$. In this region, a standard refund will allow *no* refund, whereas the customized refunds will offer *distinct* refunds. From Tables 4 and 5, high-type customers are always better off under the standard refund, whereas low-type customers are better off under a customized refund. These findings are summarized in the following proposition.

**Proposition 3.**

(i) *The refund policy does not change the expected customer surplus based on signals.*

(ii) *High-type customers receive more (respectively, less) surplus under the standard (respectively, customized) refund policy, whereas the reverse applies to low-type customers.*

(iii) *The standard refund increases the variance in customer surplus, whereas the customized refund reduces the variance in the customer surplus.*

## 5. Reducing Customer Uncertainty via Information Provision

In our model, one source of valuation uncertainty originates from the imperfect signal customers receive. Refunds can be viewed as an ex post information provision device that allows customers to adjust their purchase decisions. Should customers have better knowledge of their types, however, the firm may serve them differently. We therefore would like to investigate whether the firm may benefit from any ex ante information provision by improving the

**Table 4.** Consumer Welfare Under the *Standard* Refund Policy

| Customer type | Full refund | Partial refund | No refund |
|---|---|---|---|
| GH | 0 | $\theta_H(\theta_H - \theta_G) + \theta_0(\theta_G - \theta_B)$ | $\theta_G(\theta_H - \theta_G) + \theta_0(\theta_G - \theta_B)$ |
| GL | 0 | $-\theta_H(\theta_G - \theta_L) + \theta_0(\theta_G - \theta_B) < 0$ | $-\theta_G(\theta_G - \theta_L) + \theta_0(\theta_G - \theta_B) < 0$ |
| BH | 0 | $\theta_0(\theta_H - \theta_B)$ | $\theta_0(\theta_H - \theta_B)$ |
| BL | 0 | $-\theta_0(\theta_B - \theta_L) < 0$ | $-\theta_0(\theta_B - \theta_L) < 0$ |

**Table 5.** Consumer Welfare Under the *Customized* Refund Policy (When Not Coinciding with the Standard Policy)

| Customer type | Full refund | Customized refund | No refund |
|---|---|---|---|
| GH | 0 | $\theta_G(\theta_H - \theta_G)$ | $\theta_G(\theta_H - \theta_G) + \theta_0(\theta_G - \theta_B)$ |
| GL | 0 | $-\theta_G(\theta_G - \theta_L) < 0$ | $-\theta_G(\theta_G - \theta_L) + \theta_0(\theta_G - \theta_B) < 0$ |
| BH | 0 | 0 | $\theta_0(\theta_H - \theta_B)$ |
| BL | 0 | 0 | $-\theta_0(\theta_B - \theta_L) < 0$ |

signal strength, which is the focus of this section. The findings are summarized as follows:

**Proposition 4** (Information Provision).

(i) *When the valuation heterogeneity is high, the firm has no incentive to improve the signal quality.*

(ii) *When the valuation heterogeneity is low, the firm has incentive to weaken the signal.*

(iii) *When the valuation heterogeneity is moderate, the firm may have an incentive to strengthen the signal when it is high and weaken the signal when it is low.*

To illustrate the findings, we conduct a numerical study under a similar set of parameters as in Figure 2. The firm's optimal profit as a function of the signal strength $\rho$ is plotted in Figure 3.

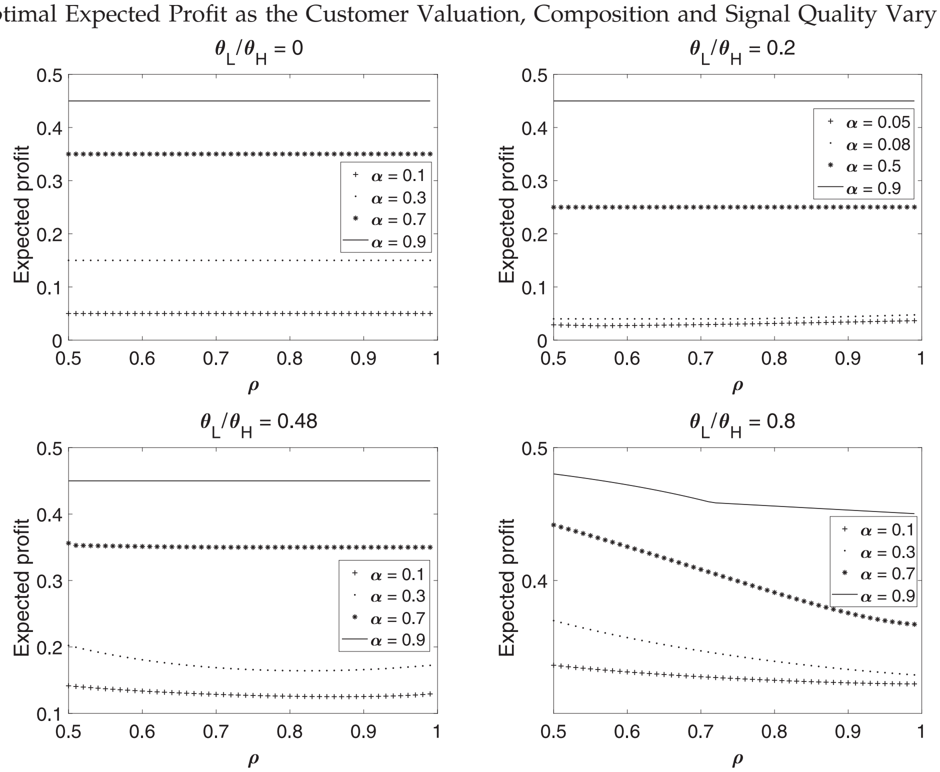
When the valuation heterogeneity is high, as in the top left graph of Figure 3 ($\theta_L/\theta_H = 0$), the firm can rely solely on the refund to extract all surplus from the high-type customers. Therefore, improving the signal adds little value to the firm.

When valuation heterogeneity is low, for example, when $\theta_L/\theta_H = 0.8$, as Theorem 1(iv) suggests, the firm inclines to use quality customization than information provision. Therefore, the firm does not gain much from information provision. In fact, the firm may wish to weaken the signal to make the customers less informed ex ante.

When the valuation heterogeneity is moderate, the benefit of ex ante information provision can go both ways. On one hand, strengthening the signal may reduce the firm's profit, particularly when the signal is weak to begin with, for example, when $\rho < 0.7$, $\theta_L/\theta_H = 0.48$, and $\alpha = 0.7$. According to the discussion under Theorem 1, this is when quality customization dominates refund. Following the same line of reasoning as the above case, information provision is not rewarding to the firm.

On the other hand, signal improvement can benefit the firm when it is already high, for example, when $\theta_L/\theta_H = 0.48$ or 0.2 and $\alpha < 0.5$. This is the case

**Figure 3.** The Optimal Expected Profit as the Customer Valuation, Composition and Signal Quality Vary



where the firm puts more weight on ex post information provision than ex ante quality customization. Therefore, the firm may benefit from signal improvement as a form of information provision.

We summarize the managerial implications of the above findings in Table 6. When the valuation heterogeneity is high, the firm can solely rely on ex post information provision devices such as customer refunds. When the valuation heterogeneity is low, the firm may abandon ex post information provision and proactively engage in activities that weaken customers' signals ex ante, for example, providing complicated catalogues or overwhelming advertisements, adding to the difficulty for customers to evaluate their valuations. When the valuation heterogeneity is moderate, the firm may adopt both ex post and ex ante information provision devices. Specifically, the firm may wish to magnify the current signal—that is, strengthen the signal if it is already strong, for example, via customer consultation or product review, or weaken the signal if it is noisy. We should point out that the above analysis did not consider the cost of information provision. In practice, the firm may need to do a benefit/cost analysis to determine whether any ex ante information provision activity is worthwhile to pursue.

## 6. Extensions

In this section, we verify the robustness of the results by exploring two extensions. Section 6.1 studies whether the insights will hold when returned products incur some cost. Section 6.2 considers the possibility of service upgrades.

### 6.1. Partially Recoverable Cost

In our analysis so far, we assume that a returned product or service cancellation would not incur any quality-related cost. This assumption is reasonable as long as no cost is incurred until service delivery. However, it is still valuable to examine whether similar results hold in a more general setting. In this section, we verify the robustness of our results by considering the scenario where only part of the quality-related cost is recoverable for a returned product.

Assume that in the event of a return, a unit of product at quality level $q$ will cost the firm $\lambda q^2/2$, where $\lambda \in [0,1]$. Our analysis so far corresponds to the special case $\lambda = 0$. In other words, $\lambda$ reflects the portion of the product cost that is *unrecoverable* upon service cancellation. The introduction of $\lambda$ has little impact on the IC and IR constraints, but calls for revising objective functions for market outcomes involving customer returns, that is, RR, RN, and NR.

For example, the optimal design under market outcome RR is given by

$$\begin{aligned}\max_{q_G,q_B,p_G,p_B,\beta_G,\beta_B\geq 0} \Pi^{RR} &= \rho_G\left(p_G - \bar{\alpha}_G\beta_G p_G - \frac{\alpha_G q_G^2}{2} - \bar{\alpha}_G\lambda\frac{q_G^2}{2}\right)\\ &\quad + \bar{\rho}_G\left(p_B - \bar{\alpha}_B\beta_B p_B - \frac{\alpha_B q_B^2}{2} - \bar{\alpha}_B\lambda\frac{q_B^2}{2}\right)\\ \text{s.t.} \quad & (IR_G), (IR_B), (IC_G), (IC_B), RR_G), (RR_B).\end{aligned}$$

Following a similar analysis as in Section 4, we derive the optimal design in the following theorem.

**Theorem 2** (Optimal Product Line Design Under Partially Recoverable Product Cost). *Under a partially recoverable product cost where $0 \leq \lambda \leq 1$,*

(i) *if $\frac{\theta_L}{\theta_H} \leq \min\{\phi(\frac{\alpha_G}{\sqrt{\alpha_G+\lambda\bar{\alpha}_G}}, \alpha_G, 1), \phi(\frac{\alpha_B}{\sqrt{\alpha_B+\lambda\bar{\alpha}_B}}, \alpha_0, 1)\}$, the market outcome is RR, and the firm may offer fully refundable products at close quality levels ($q_G = \frac{\alpha_G}{\alpha_G+\lambda\bar{\alpha}_G}\theta_H$, $q_B = \frac{\alpha_B}{\alpha_B+\lambda\bar{\alpha}_B}\theta_H$, and $\beta_G = \beta_B = 1$);*

(ii) *if $\phi(\frac{\alpha_G}{\sqrt{\alpha_G+\lambda\bar{\alpha}_G}}, \alpha_G, 1) \leq \frac{\theta_L}{\theta_H} \leq \phi(\frac{\alpha_B}{\sqrt{\alpha_B+\lambda\bar{\alpha}_B}}, \alpha_0, 1)$, the market outcome is NR, and the firm should offer a moderate-quality product to good-signal customers ($q_G = \theta_G$) without any refund ($\beta_G = 0$) and a high-quality product to bad-signal customers ($q_B = \frac{\alpha_B}{\alpha_B+\lambda\bar{\alpha}_B}\theta_H$) with a full refund ($\beta_B = 1$);*

(iii) *if $\phi(\frac{\alpha_B}{\sqrt{\alpha_B+\lambda\bar{\alpha}_B}}, \alpha_0, 1) \leq \frac{\theta_L}{\theta_H} \leq \phi(\frac{\alpha_G}{\sqrt{\alpha_G+\lambda\bar{\alpha}_G}}, \alpha_G, 1)$, the market outcome is RN, and the firm should offer a high-quality product to good-signal customers ($q_G = \frac{\alpha_G}{\alpha_G+\lambda\bar{\alpha}_G}\theta_H$) with a partial refund ($0 < \beta_G < 1$) and an inferior-quality product to bad-signal customers ($q_B = \theta_0$) without any refund ($\beta_B = 0$);*

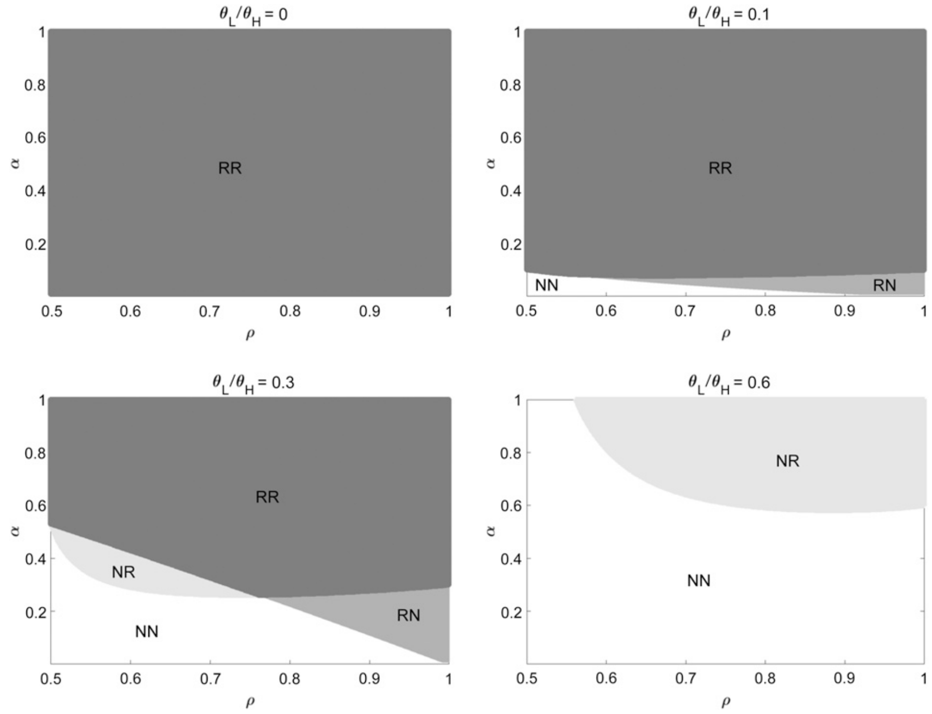
(iv) *if $\frac{\theta_L}{\theta_H} \geq \max\{\phi(\frac{\alpha_G}{\sqrt{\alpha_G+\lambda\bar{\alpha}_G}}, \alpha_G, 1), \phi(\frac{\alpha_B}{\sqrt{\alpha_B+\lambda\bar{\alpha}_B}}, \alpha_0, 1)\}$, the market outcome is NN, and the firm should offer a moderate-quality product to good-signal customers ($q_G = \theta_G$) and an inferior-quality product to bad-signal customers ($q_B = \theta_0$) without any refund ($\beta_G = \beta_B = 0$).*

Theorem 2 shows that the structure of the results does not change when part or all of the product cost is unrecoverable. At $\lambda = 0.2$, Figure 4 demonstrates strong similarity to Figure 2, where $\lambda = 0$. It also shows that as the valuation heterogeneity increases ($\theta_L/\theta_H$

**Table 6.** Firm's Information Provision Strategy

| | High valuation heterogeneity | Moderate valuation heterogeneity | Low valuation heterogeneity |
|---|---|---|---|
| Ex ante | No action | Strengthen strong signal, weaken ambiguous signal | Weaken all signals |
| Ex post | Full refunds | Customized refunds | No refund |

**Figure 4.** Optimal Market Outcome with Partially Recoverable Product Cost ($\lambda$ = 0.2)




decreases), the firm relies more on the refund than quality customization to maximize its profit. Specifically, the quality difference between the two products shrinks when the valuation heterogeneity is high. The variety reduction effect identified in Corollary 1 continues to hold if we define variety as the span, rather than the number, of quality levels.

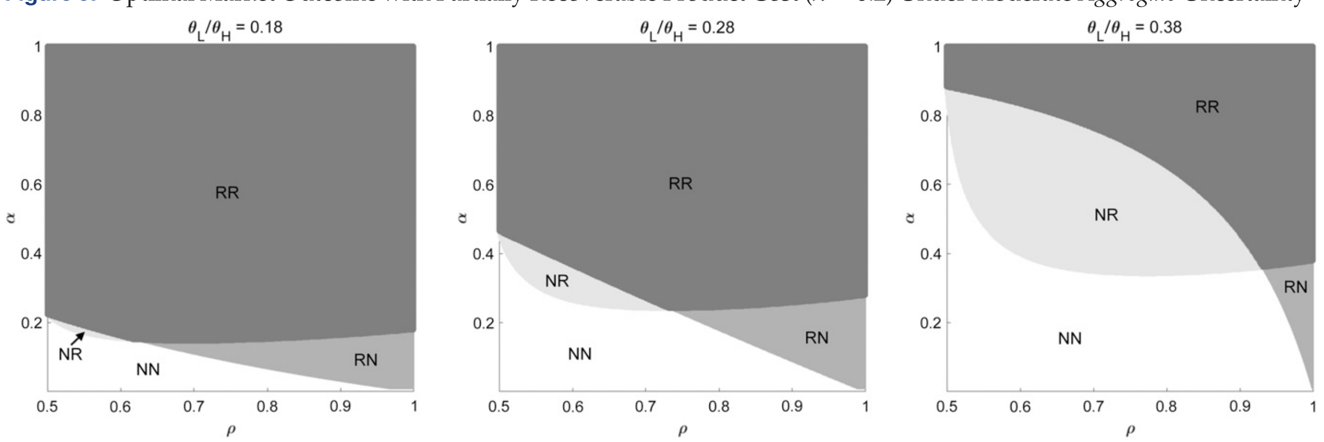
The effect of signal strength is also similar to what was identified in Theorem 1. Although doing the same analytical characterization on signal quality $\rho$ is challenging for general $\lambda$, Figure 5 confirms that NR dominates when the signal is weak (small $\rho$), and RN dominates when the signal is strong (large $\rho$).

Corollary 4 provides additional insights on how the cost of refunds may affect the optimal product line design.

**Corollary 4.** *The firm tends to offer more quality customization and less generous refunds as the unrecoverable portion of the product cost, $\lambda$, increases.*

Corollary 4 identifies the nonrecoverable cost as a factor that affects the trade-off between ex ante (quality customization) and ex post (customer refunds) customer discrimination. As a result, a firm should carefully examine the nature of its customer base as well as its cost structure when deciding on its quality and refund terms. That is, in service

**Figure 5.** Optimal Market Outcome with Partially Recoverable Product Cost ($\lambda$ = 0.2) Under Moderate *Aggregate* Uncertainty



domains where cancellation yields little quality-related sunk cost, a firm should focus more on refund design and less on quality customization; for industries where returns may cause substantial, irreversible quality-related costs, for example, tailored services and make-to-order products, the firm should offer more differentiated quality levels and be less generous on refund terms.

## 6.2. Service Upgrade

A refund policy gives low-type customers the recourse to withdraw from a current service after learning about their true valuation. A natural question to ask is whether similar recourse should be extended to high-type customers as well, and to what extent it may impact the refund policy design.

In this subsection, we explore the possibility that a customer may upgrade the service after discovering her true valuation; that is, a customer can switch to an alternate product ex post and pay the difference in prices plus a certain upgrade fee ($f$) if the quality of the alternate product is higher. Intuitively, the scope of upgrade should be limited to high-type customers only; otherwise, all customers would upgrade ex post and no one would rationally purchase the low-quality product to begin with, making the problem trivial to study.

The expected surplus for customers receiving signal $s$ and purchasing product $i$ is

$$u_{si} = \begin{cases} \alpha_s(\theta_H q_i - p_i) + \bar{\alpha}_s \max\{\theta_L q_i - p_i, -\bar{\beta}_i p_i\}, & \\ \qquad\qquad\qquad\qquad\qquad\qquad \text{when } q_i > q_j, \\ \alpha_s \max\{\theta_H q_i - p_i - f, \theta_H q_j - p_j\} & \\ \quad + \bar{\alpha}_s \max\{\theta_L q_i - p_i, -\bar{\beta}_i p_i\}, \qquad \text{when } q_i \le q_j, \end{cases} \tag{2}$$

where $\{s, i, j\} \in \{G, B\}$ and $i \neq j$. Depending on which product has higher quality, the upgrade decision will apply one way or the other: when $q_G \geq q_B$, high-type customers who have purchased product B will *upgrade* to product G, and those who have purchased product G can only *stay* with the same product, and vice versa.

Similar to the discussion in Section 3.2, there are still four market outcomes with regard to product returns. Together with possible upgrades, there are eight scenarios to consider. We use a superscript U to denote the upgrading outcome. For example, $RN^U$ means that bad-signal customers who purchased a nonrefundable product will upgrade.

We summarize our findings as follows:

**Theorem 3.** *There exists a $\phi^U \geq 0$ such that*

(i) *when* $\frac{\theta_L}{\theta_H} \leq \phi^U$, $RN^U$ *is the optimal design, where* $q_G = \theta_H, q_B = 0$, $\beta_G \leq 1$, *and* $\beta_B = 0$;

(ii) *when* $\frac{\theta_L}{\theta_H} > \phi^U$, $N^U N$ *is the optimal design, where* $q_G = \theta_L, \theta_H > q_B > \theta_L$, *and* $\beta_G = \beta_B = 0$.

Furthermore, in both cases, the upgrade fee $f$ can take any value within the range $[0, \bar{\alpha}_G(\theta_H - \theta_L)|q_G - q_B|]$, and the price $p_i$ and the refund rate $\beta_i$ of the higher-quality product linearly decrease in $f$.

Theorem 3 suggests that when valuation heterogeneity is high ($\frac{\theta_L}{\theta_H} \leq \phi^U$), the firm should offer a single high-quality, refundable product to good-signal customers. The upgrade fee $f$ can take any value within a range as long as the price $p_G$ and the refund rate $\beta_G$ are adjusted accordingly; the higher $f$ is, the lower $p_G$ and $\beta_G$ are. Specifically, if the firm makes upgrade free ($f = 0$), product G becomes fully refundable ($\beta_G = 1$), and the firm charges the maximum willingness to pay $\theta_H^2$ for product G. Bad-signal customers are always awarded a zero-quality product at zero price. Effectively, this allows bad-signal customers to buy ex post should their valuations turn out to be high.[2] This essentially yields the same revenue and market outcome as in RR without the service upgrade option. Thus, the variety reduction effect characterized in Corollary 1 is sustained even in the presence of service upgrade. This also conforms to airline practice for business-class tickets, where the refund policy and purchase timing are quite flexible and service quality is consistently high.

When valuation heterogeneity is relatively low ($\frac{\theta_L}{\theta_H} > \phi^U$), no refund is allowed; a low-quality product is offered to good-signal customers and a good-quality product is offered to bad-signal customers,

**Table 7.** Implications of the Optimal Product Line Design

| Characteristics of valuation uncertainty | Optimal product line (G for good-signal customers; B for bad-signal customers) | Allow standard-quality refund | | Information provision strategy |
|---|---|---|---|---|
| High valuation heterogeneity | G: high quality, partial/full refund; B: high quality, full refund | Yes | Yes | No action |
| Moderate valuation heterogeneity, low signal quality | G: good quality, no refund; B: high quality, full refund | No | No | Weaken signal |
| Moderate valuation heterogeneity, high signal quality | G: high quality, partial refund; B: low quality, no refund | No | Yes | Strengthen signal |
| Low valuation heterogeneity | G: good quality, no refund; B: low quality, no refund | No | Yes | Weaken signal |

and the former will upgrade to the good-quality product if their valuations turn out to be high.[3] The market outcome is the same as in NN without the service upgrade option. However, the customers are getting a *reversed* signal-based quality assignment, in that good-signal customers will obtain a lower-quality product than bad-signal customers because of the availability of service upgrade. This allows the firm to extract all surplus from customers regardless of their signal types, which cannot be obtained without service upgrade (e.g., good-signal customers receive positive surplus under NN according to Lemma 2). This is consistent with the practice of some service providers, such as theme parks and concerts venues, who are more likely to allow service upgrades than refunds.

In general, service upgrade suppresses refund customization, and only market outcomes resembling RR and NN without service upgrade may appear. Therefore, it is still beneficial for the firm to adopt refunds under some conditions.

## 7. Concluding Remarks

In this paper, we investigate the optimal product line design with endogenous consumer refund policies. In our model, returns occur because of customer valuation uncertainty, reflected by the heterogeneity in their true valuations revealed ex post and the imperfect signals that determine their perceived valuations ex ante. We study how the valuation uncertainty may affect the quality and refund options available to customers. In general, higher quality and more liberal refund terms are offered with higher valuation heterogeneity. Specifically, when the valuation heterogeneity is high, the firm can safely rely on a single-quality design with full refunds, whereas when the valuation heterogeneity is low, a dual-quality design with no refund. When the valuation heterogeneity is moderate, the firm should customize both quality and refunds, and it is the signal quality that determines which customer segment will get the refunds. We also study the effect of either quality or refund standardization, and whether the firm may have incentive to reduce valuation uncertainty via ex ante information provision. Our main results are summarized in Table 7. The findings are consistent with many observations in practice and offer some general guidelines for managers to create the best service offerings for their target market.

There are several meaningful dimensions in which this paper can be extended. First, we focused on quality-related cost and ignored other related costs. It would be valuable to examine the impact of the fixed salvage value and transaction costs (e.g., Economides 1999) on the optimal product line and refund policies.

Second, given the perishability of service capacity, it is promising to consider the problem under a multiperiod capacitated setting and study the extent to which the perishability and capacity availability may affect the optimal product line. Although the capacity issue has not been the central focus for most marketing papers, its relevance has been shown to be critical in some recent literature (Xie and Gerstner 2007, Liu and Xiao 2008, Guo 2009).

Third, there are different ways to specify valuation uncertainty and how this uncertainty resolves over time. For example, valuation uncertainty for an air ticket can be caused by whether the trip will be made or preferences for different departure times, resulting in quite different valuation heterogeneity ex post. It would be interesting to investigate the implications of such differences in the future.

Finally, whereas our results are derived under a monopolistic setting, it would also be interesting to investigate them in a competitive environment. The effect of competition has been studied in several recent papers (e.g., Guo 2009, Shulman et al. 2011). However, to our knowledge, competitive product line design with consumer refunds has not been considered so far. This is another fruitful avenue for future research.

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### Endnotes

[1] We use “product” and “service” interchangeably throughout this paper.

[2] In fact, all customers are indifferent between the two products—regardless of their signal, one may either purchase product G up front or buy nothing (product B) and upgrade to G later.

[3] In this instance, good-signal customers are indifferent between the two products, whereas bad-signal customers strictly prefer product B.

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