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Published in:
Management Science

Published: 01/11/2024

Document Version:
Post-print, also known as Accepted Author Manuscript, Peer-reviewed or Author Final version

Publication record in CityU Scholars:
Go to record

Published version (DOI):
10.1287/mnsc.2021.04025

Publication details:
Guo, L. (2024). The Voice of Customers in Customization. *Management Science*, *70*(11), 7579-7596.
https://doi.org/10.1287/mnsc.2021.04025

Guo, L. (2024). The Voice of Customers in Customization. *Management Science, 70*(11), 7579-7596. https://doi.org/10.1287/mnsc.2021.04025

The Voice of Customers in Customization*

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ABSTRACT

Recent years have seen a growth in customized products and services. As a prerequisite for customization, private information on individual customers' quality preferences needs to be uncovered. Sellers can listen to customers about their stated or self-reported preferences through direct communication (e.g., conversation, survey). Alternatively, customer preferences can be inferred from their behavior when they are given the rights to self-design the quality. In this research we endogenize the viability of customization by investigating whether and when customers may reveal their stated/inferred preferences truthfully. We find that, for either preference-learning approach, customers would voice their preferences faithfully if and only if they are sufficiently heterogenous. Equilibrium preference revelation, and hence endogenous customization, tend to be sustained by intermediate seller bargaining power or non-extreme production/selling costs. We examine how the preference-learning approaches may differ in the endogenous feasibility of customization, equilibrium qualities, and the parties' expected payoffs. We show that giving up the design right need not always be harmful for the seller, and gaining it can make the buyers worse off, especially when fixed costs of customization are considered.

Keywords: customization, personalization, product design, cheap talk, signaling, bargaining, strategic communication

* This paper benefited from insightful comments of the DE (Eric Anderson), the AE, three anonymous reviewers, and participants at the 2022 Marketing Science Conference and the Quantitative Marketing Conference at Xiamen University. Financial support of a DAG grant offered by the Hong Kong RGC is acknowledged. Address for correspondence: Department of Marketing, City University of Hong Kong, Kowloon, Hong Kong, China. Email: liang.guo@cityu.edu.hk.

1 Introduction

It is usually believed that sellers can benefit from customizing their offerings (e.g., quality, price) to match buyers' heterogenous preferences (i.e., first- or third-degree discrimination). In business-to-business (B2B) markets, products and services (e.g., accessories, chips, components, equipment, machinery, software, systems) are normally provided to meet customers' specifications (Ghosh et all. 2006, Wang et al. 2017). Customization can also be seen in business-to-consumer (B2C) settings: big-ticket items (furniture, homeware), entertainment (hotels, tours), fashion (apparel, cosmetics, footwear), specialized products (eyewear, food, gifts, jewelry) and services (consulting, home building/renovation/cleaning). Thanks to technology advances (flexible manufacturing, 3D printing), firms can increasingly offer personalized solutions and recent years have seen an unprecedented growth of customization (Piller et al. 2004). For instance, Ford permits buyers to submit design requests on important dimensions such as size, height, fixture, storage, etc (Basu and Bhaskaran 2018). Eyewear retailers such as Paris Miki work diligently with consumers to configure the characteristics of tailored eyeglasses (lens size, shape, nose bridge, hinge, arms) (Gilmore and Pine 1997). Jewellery retailers such as Argos allow consumers to design and order 3D-printed bangles, rings, earrings and pendants (Deloitte 2015). Another example is the "Burberry Bespoke" system that supports personalized design of fashion goods (Huang et al. 2018).[1]

As a critical or initial step for customization, buyer preferences need to be uncovered (Zipkin 2001, Murthi and Sarkar 2003, Kramer 2007, Wang et al. 2017). In general, there are two common ways for potential customers to voice their preferences. The first one is direct communication. Industrial buyers can convey to suppliers their needs and expectations via a variety of means (e.g., business meetings, virtual conferences, telephones, emails). Similarly, marketers can elicit preference information by using traditional instruments such as interviews, surveys, conjoint analyses, and so on. Alternatively, firms can construct user design systems and allow buyers to specify the attributes of products or services they demand to purchase. This self-design approach is commonly seen in the customization program of many firms (e.g., Ford, Argos, Burberry).

Therefore, sellers can learn about buyer preferences by asking them directly prior to customization, or by making inference from observing their self-manipulated designs during the process of customization. Accordingly, we refer to the approach of direct asking as *A-Learning*, and that of observational learning as *O-Learning*, respectively, which differ in the manner and the timing of preference revelation. Another essential difference between the customization strategies is that buyers gain more decision rights under O-Learning.

[1] According to a survey by Deloitte (2015), many respondents (on average 36 percent) are interested in purchasing customized products and services and are willing to pay a price premium, especially in entertainment and leisure categories and big-ticket items. They also indicate a high level of expectation to engage in the customization process.

Would these approaches necessarily uncover buyer preferences? This basic issue has been ignored in previous research. However, it is not clear why buyers would always voice their preferences faithfully. Customers may exaggerate their preferences to induce firms to design products with higher quality. On the other hand, buyers may understate their preferences to negotiate lower prices. As a result, buyers may be motivated to be misleading in direct communication with sellers. They may be intentionally biased as well in responding to preference solicitation/elicitation questions that are used as the input for customization.[2] More generally, stated or self-reported preferences need not be truthful (e.g., Franke et al. 2009). Similarly, the tradeoff between quality and price may lead buyers to strategically distort their self-designs under the O-Learning approach. Therefore, it is utterly important to study the issue of truthful preference revelation in customization.

Our main objective in this research is to investigate incentive compatibility under the two customization strategies. We examine whether and when buyers may credibly convey their preferences through cheap-talk communication. We also identify conditions under which self-designs may accurately reflect buyer preferences. Essentially, by studying truthful preference revelation, we endogenize the feasibility of customization for the A-Learning and the O-Learning approaches.[3] Moreover, we investigate how the equilibrium payoffs may vary across the customization approaches.

We consider a market with a seller and two types of buyers. Each buyer is privately informed whether its quality preference is high or low. The seller can possibly offer a line of products with different qualities. The seller incurs a selling cost of interacting and serving each buyer, which is increasing in quality. After the design is determined, the seller bargains with each buyer about the transaction price to split the incremental surplus (i.e., buyer valuation minus production cost) according to their relative bargaining power. Products can be potentially customized, in two different ways, to match the buyers' preferences. Under the A-Learning approach, each buyer can directly reveal its preference at free will to the seller who then decides on the product quality. Communication is cheap talk in the sense that it does not directly affect the buyer's expected payoff. In contrast, under the O-Learning approach, each buyer can make a take-it-or-leave-it design request (on product quality) to the seller. Customized pricing is then feasible if and only if the seller learns about the buyer's preference in the design process.

We demonstrate that, under the A-Learning approach, there exists a separating equilibrium whereby the buyers' preferences are credibly conveyed to enable endogenous customization, if and

[2]Note that normally incentives in conjoint analyses are not offered at the same scale or to the same customers as in real transactions. Therefore, responses in incentive-based conjoint studies may be unbiased at the aggregate, but need not reflect true preferences of individual customers, especially for industrial markets.

[3]The customization approaches we consider are similar to those in Randall et al. (2007), which they term as *need-based* versus *parameter-based* user design systems. Their focus is on the comparison of user expertise and design performance, whereas ours is on incentive compatibility in preference revelation.

only if the buyers differ sufficiently in their quality preferences. This is because the seller's perception about a buyer's preference type can generate an endogenous tradeoff: a higher-quality product would be offered to the high-preference buyers at higher negotiated price. Therefore, as buyer heterogeneity increases, the gap between the seller's optimal product offerings would be enlarged: the quality of the low-end product would be too low for the high type, while the expected price of the high-end product would be too high for the low type. As a result, both types of buyers would be dissuaded from misreporting their preferences to mimic their counter type.

Interestingly, the chance to sustain the separating equilibrium may first increase and then decrease, as the seller becomes more powerful or as production or selling becomes more costly. This is because the impact of each of these changes on truthful communication differs qualitatively across the buyer types. For example, as the seller bargaining power increases, the low type's incentive for deceptive communication would be reduced, whereas that of the high type would be enhanced and may become the binding constraint in supporting or failing the separating equilibrium. Similarly, the impacts of making production versus selling more costly on equilibrium preference revelation are mirror images to each other: both would exhibit an inverted-U pattern, although they would oppositely influence the buyers' incentives for truthful communication.

The results on the O-Learning case are analogous. A cheap-signaling equilibrium may arise under which each buyer makes a design proposal as if its preference were *a priori* known to the seller (i.e., the buyers' first-best outcomes), if and only if the buyers are sufficiently different in their preferences. It is the quality-price tradeoff that leads the buyers to self-sort themselves in the design process. We find that varying the parameters on seller bargaining power or production/selling costs can non-monotonically affect the emergence of equilibrium separation. It is also because these changes can cast reversed influences on the buyers' incentives to manipulate the seller's perception about their preferences. Moreover, surprisingly, the cheap-signaling equilibrium is the only separating equilibrium, which is fundamentally different from that in standard signaling games. This is because, unlike standard settings, there is no universally desirable seller perception that is beneficial for both buyer types, and their incentives for imitation are in opposite direction.

By sustaining informative communication, the A-Learning approach can yield customized qualities that are more efficient than those under the screening benchmark in which the seller designs a line of products for the buyers to self select (Moorthy 1984). Consequently, the seller is better off but the high-type buyers are worse off, as cannibalization within the product line is endogenously removed. In contrast, the customized qualities proposed by the buyers under the O-Learning approach may be socially excessive. The seller's expected payoff can be either higher or lower under the cheap-signaling equilibrium than under the screening benchmark. Similar ambiguity can arise for the high-type buyers. It is because, although the buyers gain more design rights from the seller, they would no longer enjoy the rent caused by information asymmetry. Nevertheless, the low-type buyers always benefit from either of the customization strategies.

We find that customization is less likely to emerge endogenously when the seller seeks to uncover buyer preferences via A-Learning than through O-Learning, if and only if the seller bargaining power is relatively low. In terms of the equilibrium expected payoffs, the seller and the buyers are generally better off retaining/gaining the rights to design the product qualities. However, the seller need not always benefit from soliciting or eliciting buyer preferences directly, if the incremental cost of dosing so is not completely zero. Analogously, the buyers may be hurt by being given the design rights, even if the efforts to engage in the customization process are low (but not negligible).

We also examine how the results may be modified under the alternative case of ex ante pricing for the O-Learning customization. In addition, we show that our main results continue to hold qualitatively for any finite number of buyer types.

This paper is related to several streams of research. There is a large and growing set of studies that investigate whether and how firms should customize their offerings in monopoly or competitive markets (e.g., Dewan et al. 2003, Syam et al. 2005, Syam et al. 2008, Xia and Rajagopalan 2009). We contribute to this literature in two important ways. First, we relax the assumption that a firm's capability to access information on customer preferences is exogenously given. Although prior studies have recognized that preference information is the prerequisite for customization, it is typically taken for granted that the information can be accurately collected by firms (potentially at a cost). Our objective in this research is instead to endogenize the viability of customization by examining whether and when strategic customers may voice their preferences truthfully. Second, we consider vertical preference for quality, whereas it is standard in the customization literature to focus on horizontally differentiated markets.[4]

The second related literature is on strategic information transmission via cheap talk (also termed as costless signaling). Since the pioneering work of Crawford and Sobel (1982), a large literature has accumulated to identify various mechanisms that can establish the credibility of costless signaling: facilitating matching and coordination between parties with aligned interests (e.g., Bagwell and Ramey 1993), information sender's incentive to differentially influence multiple information receivers (e.g., Farrell and Gibbons 1989), restrictions on communication device for multidimensional private information (e.g., Chakraborty and Harbaugh 2010, 2014), and social interaction among consumers (e.g., Kuksov et al. 2013). Another notable mechanism is the endogeneity of the receiver's preference

[4]One exception is Basu and Bhaskaran (2018) whose focus is on co-designs where customers can spend costly efforts to increase their valuation for quality. Another crucial difference is that they assume that customers' efforts are observable to the firm but still cannot signal their privately informed type, whereas we examine whether and when customers may reveal their preferences via either cheap-talk communication or design choice.

as a result of uncertainty-reducing search (Gardete and Guo 2021, Guo 2022). There are also studies in Marketing that investigate how firms can credibly communicate their cost information to consumers (e.g., Shin 2005). We consider a novel setting where the sender is the buyers and the credibility of communication is due to the tradeoff between quality and price.[5]

Our analysis on the O-Learning customization is connected to the huge literature on costly signaling. For instance, Kihlstrom and Riordan (1984) and Milgrom and Roberts (1986) study how firms can use advertising spending to signal their product quality. As we will elaborate, our setup differs from the standard signaling models in that no seller perception is jointly preferred by both buyer types. This is why there is only a cheap-signaling equilibrium in our setting.

2 Assumptions

We consider the interaction between a seller and two types of buyers. The total size of the buyers is normalized to one. The parties can represent firms in a B2B setting (e.g., suppliers, manufacturers, retailers).[6] To facilitate exposition, we refer to the seller's offering as the product. All parties are risk neutral. The outside option of no trade is normalized to zero for all parties.

The seller can potentially offer a line of product variants. Each product variant is characterized by a set of vertical attributes, which can be summarized by a composite index $q \geq 0$ and referred to as the quality. We consider and distinguish between two types of *variable costs* for each product variant. The first is the marginal cost of producing and/or delivering the product, kq^2, where $k > 0$. The second is referred to as the *selling cost*, sq^2, where $s > 0$, which is particularly relevant in many B2B or service markets and falls under the umbrella of transaction costs. For example, firms usually invest human and financial resources to set up new projects, develop initial solutions, make business proposals/quotes, and so on (Wang et al. 2017). They may promote their products by generating and distributing prototypes, samples, brochures, free gifts, etc. The selling process can be costly in training staff, providing sales assistance, and so on (Piller et al. 2004, Shin 2005).

These costs are typically increasing in the size of the potential customers, i.e., they are not fixed even in the absence of customization. In addition, note that both the production and the selling costs are assumed to be increasing in the quality q.[7] In practice, it is normally more costly to initiate

[5] See also Guo (2023b) on the credibility of communication in a pandemic setting.

[6] Our model can also capture many services and B2C markets (e.g., big-ticket items, entertainment, fashion, and specialized products), to the extent that they satisfy the main assumptions (i.e., bilateral bargaining, and sunk selling costs that increase with product quality/complexity).

[7] The quadratic cost functions ensure that the objective function (of the seller or the buyers) is concave in q and hence the solution is interior. However, as suggested by a reviewer, we acknowledge that there may be circumstances under which the selling cost does not increases with quality.

and sell more sophisticated projects and complex products/services with higher quality, because it would require more resources, skills and efforts for project setup, prototype/sample production, salesforce training and engagement, etc. Nevertheless, we highlight the distinction that, although the production cost is sales-based, the selling cost is sunk investment that need not result in a sale. For instance, the distribution of prototypes, samples, brochures, and free gifts may not always be converted to sales. Similarly, a car dealer must spend time and efforts to assist the test drive of a potential customer who may or may not place an order in the end (Shin 2005). Therefore, as will become clearer, only the production cost is relevant when the transaction price is determined between the seller and each of the buyers.

Each buyer has a one-unit demand and can purchase any of the product variants. If a buyer purchases product variant q at price p, the net payoff would be

$$u = \theta q - p, \tag{1}$$

where θ captures the buyer's preference for quality. The quality preference takes two levels: $\theta \in \Theta \equiv \{\theta_H, \theta_L\}$, where $\theta_H > \theta_L > 0$. The common prior belief is that θ is equal to θ_H for a proportion $\alpha_H = \alpha \in (0,1)$ of the buyers and the complementary proportion $\alpha_L = 1 - \alpha$ of the buyers have $\theta = \theta_L$. Each buyer is privately informed of its θ. We refer to the buyers with θ_H or θ_L as the high type or the low type, respectively. The parameters θ_H, θ_L, and α are common knowledge.

Neither the seller nor the buyers have the monopoly power in pricing, i.e., the surplus of trade (e.g., $\theta q - kq^2$) cannot be completely extracted by either party. To simplify matters, we assume that, in the transaction between the seller and each buyer, either party can get the opportunity to make a take-it-or-leave-it price offer to the counter party, with probability $\gamma \in (0,1)$ and $1 - \gamma$, respectively. The parameter γ captures the proportion of net surplus the seller can secure in dealing with a buyer. This setup can be interpreted in two ways. First, it can capture in a reduced form the outcome of bilateral bargaining, where γ represents the seller's relative bargaining power (Marx and Shaffer 2007, 2010). Transaction prices are ubiquitously negotiated in many markets (Iyer and Villas-Boas 2003, Guo and Iyer 2013), no matter the products/services are customized or not (e.g., eyewear, furniture, home renovation, jewelery). Note that our setup yields the same outcome as in the generalized Nash bargaining or standard sequential bargaining models under symmetric information (e.g., the Rubinstein alternate-offer bargaining game).[8] Alternatively, our setup can

[8]Our main results (on the two games with pre-sale preference learning) would remain the same by adopting the traditional bargaining models, given that the buyers' type is revealed in equilibrium and the seller's off-equilibrium belief is passive (Iyer and Villas-Boas 2003, Tirole 2009, Guo 2022, 2023a, 2023c). Nevertheless, it is infeasible to construct or adapt a tractable bargaining process for our benchmark, which involves screening the privately informed buyers by multiple products: we are not aware of such model in the literature. Therefore, we resort to the simple bargaining setting of Marx and Shaffer (2007, 2010), not only for the sake of parsimony but also because of the need

be interpreted as one of imperfect competition. That is, with probability γ the seller remains a monopoly and, with probability $1-\gamma$, the buyers may consider other competitors with identical offerings. The pricing outcome in our setting would be equivalent to that under this partially competitive fringe. To facilitate exposition, we adopt the bargaining interpretation. Note also that we would obtain the special case of monopolistic seller when $\gamma \to 1$.

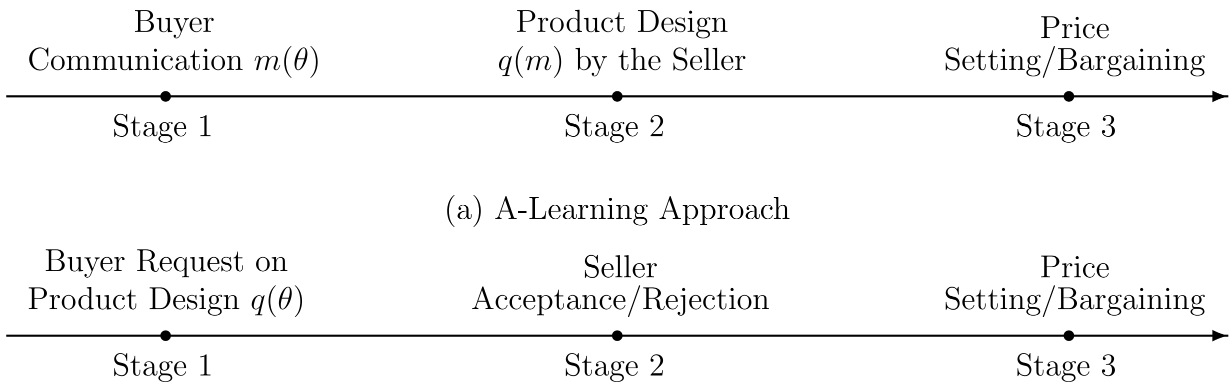
We compare three different strategies to design/sell the product line. First, as the benchmark, we consider the seller offering a menu of products for the buyers to self select (i.e., screening or second-degree price discrimination). There are two stages of actions. At the beginning of the first stage, each buyer is privately informed of its type (θ_H or θ_L). The seller designs and commits to a menu of products with qualities q_H and q_L and posted prices p_H and p_L. The seller then incurs the selling costs, as the buyers ask for prototypes, samples, brochures, sales assistance and so on for the product they intend to buy. It is common that sampling (e.g., request and examine detailed information/prototypes, test drive) is costly for the buyers, so they do not sample all products in the menu provided by the seller.[9] In particular, the per-buyer cost of selling the high-quality or the low-quality product (to a high-type or a low-type buyer) is $s{q_H}^2$ or $s{q_L}^2$, respectively. The selling costs become sunk in the second stage in which the transaction prices for the product line are determined in the negotiations of the seller-buyer pairs. That is, the prices paid by a buyer would be equal to the posted prices (p_H and p_L) if the seller turns out to have the pricing power, and equal to the production costs ($k{q_H}^2$ and $k{q_L}^2$) if otherwise. Each buyer then decides whether to choose one of the product variants or the outside option.

As our main focus, we consider two alternative strategies to learn about buyer preferences (on θ) in customizing the products. The customization approaches differ in the manner and the timing of preference learning and consequently in how the learned preferences can be used in the process of customization. The sequence of actions for each of the two games, corresponding to the respective customization strategy, is illustrated in Figure 1.

The first customization strategy, which we label as the *A-Learning* approach, starts with asking directly each buyer about its quality preference. This approach is represented by a three-stage game as shown in Figure 1(a). Upon privately knowing θ in the first stage, each buyer can communicate with the seller by sending a message $m \in M$ about θ. Both the communication *per se* and the specific content of the message are costless and unverifiable (i.e., cheap talk). In addition, the choice of the message content is not restricted by, and need not be dependent on, the buyer's type. That

to circumvent the conceptual and technical challenge in specifying a bargaining process for the benchmark.

[9] It is likely that in the benchmark each buyer may sample the whole menu of products and thus the seller may incur the selling costs on both products for each buyer, especially when the sampling time/efforts are negligible for the buyers. Nevertheless, considering this case would barely change our main results (i.e., only part of Propositions 5 and 6) without providing substantially new insights.



(a) A-Learning Approach

(b) O-Learning Approach

Figure 1: Timing of the Customization Strategies

is, the message space M can be arbitrarily set, as long as the parties can mutually understand the language of communication: the mapping from the buyer's quality preference to the message (i.e., the communication strategy $m(\theta) : \Theta \to M$). Nevertheless, it is without loss of generality (for the separating equilibrium) to focus on the message space that contains two distinctive elements: $M \equiv \{m_L, m_H\}$, because there are two buyer types. In practice, there are a variety of A-Learning methods. Sellers can solicit information about buyer preferences via face-to-face conversations, telephones, emails, or instant communication tools. Alternatively, preference information can be elicited by using interviews, surveys, conjoint analyses, and so on. It is typical in these scenarios that the buyers may not respond truthfully to the preference solicitation/elicitation questions.

The (potentially customized) products are designed in the second stage of the game. The seller decides on the quality to be offered to each buyer, by taking into account the buyer's preference that may be conveyed by the self-reported message m. This amounts to specifying the design function $q(m)$. The seller then incurs the selling cost sq^2 for each buyer who is expected to purchase the product q. Finally, in the third stage the transaction price for each seller-buyer pair is determined and the parties split their net surplus of transaction according to their relative bargaining powers. This price setting/bargaining stage is similar to the last stage in the benchmark, except that here each buyer may be offered only its custom-designed product (if communication is informative).

The other customization strategy, which we refer to as the *O-Learning* approach, is illustrated in Figure 1(b). It involves the seller making inference about each buyer's preference by observing the buyer's behavior. In the first stage of the game, each buyer can submit a request to the seller, indicating the quality it demands the seller to design for its customized product. Let the request strategy be the function $q(\theta) : \Theta \to \mathbb{R}^+$, mapping the buyer's privately informed preference θ to the proposed quality. The seller then decides in the second stage whether to accept or reject each buyer's proposal. If a proposal is rejected, the game is over and each party's payoff would be zero. Otherwise, the seller designs the product at the buyer's requested quality q and incurs the selling cost sq^2. Finally, the third-stage price determination for the tailor-made product between each seller-buyer dyad is the same as that in the A-Learning approach. Note that the O-Learning strategy involves essentially a joint-design process whereby the buyers are transferred more decision rights. It is from observing a buyer's requested quality in jointly designing the product that the seller can potentially update its belief about the buyer's preference. That is, the process of design customization generates an opportunity for the buyers to signal their preferences to the seller.

The feasibility of customization is endogenous: it relies on the buyers choosing to reveal their preferences in equilibrium. Under the A-Learning approach, equilibrium preference revelation via credible communication is the basis to customize the qualities and the prices of the products. Nevertheless, it is during design customization that the seller learns the buyers' preferences under the O-Learning approach. As a result, the seller can use the learned preference information only for price customization but not directly for quality customization *per se*. In comparison, under the screening benchmark, the seller learns the buyers' preferences only after they have made their purchase decisions, implying that neither the qualities nor the prices can be directly customized.

For most of our analysis, we intentionally assume that neither the preference learning nor the customization processes involve any (fixed) cost for either the seller or the buyers. Moreover, it is deliberately assumed that they do not directly improve the buyers' utility or generate any benefit either. These assumptions allows us to capture the strategic impacts of the A-Learning and the O-Learning approaches on the equilibrium product qualities and the parties' equilibrium payoffs.

3 Analysis and Results

We first derive the equilibrium solutions under each of the three design strategies. Our major focus is on whether and when customization may arise endogenously. We also investigate how the customized designs may differ from those under the screening benchmark, and how customization may influence the equilibrium payoffs. In addition, we compare the equilibrium outcomes between the two customization strategies. We use the superscripts B, A, and O to represent the equilibrium outcomes for the benchmark and the two customization strategies, respectively.

3.1 Benchmark

Our benchmark model extends in two ways the standard problem of monopolistic screening (e.g., Moorthy 1984). The first is that the prices are subject to negotiations such that the seller cannot extract all surplus of trade even if the buyer types were *a priori* known. We also distinguish the seller's production costs from the selling costs that cannot be recouped in the negotiation. Nevertheless, the solution approach is similar to that in a monopolistic setting. The seller designs a line of products with qualities (q_H, q_L) and prices (p_H, p_L), which are intended to be chosen by the high-type and the low-type buyers, respectively.

Consider the final stage of price setting/bargaining. With probability γ, the seller gets the opportunity to sell the products at the posted prices (p_H, p_L). When the buyers turn out to have the pricing power (with probability $1-\gamma$), the products' transaction prices would be equal to the production costs $k{q_i}^2$ and the seller's payoff would be zero. That is, the seller bears the selling cost $s{q_i}^2$, but can retain only an expected share γ of the incremental surplus, $p_i - k{q_i}^2$, for each buyer of type $i \in \{H, L\}$. Therefore, the seller's first-stage screening problem is to solve

$$\max_{q_H, q_L, p_H, p_L} \left\{ V = \sum_{i=H,L} \alpha_i [\gamma(p_i - k{q_i}^2) - s{q_i}^2] \right\}, \tag{2}$$

subject to

$$\theta_i q_i - p_i \geq 0, \forall i \in \{H, L\}, \tag{IR_i}$$

$$\theta_i q_i - p_i \geq \theta_i q_j - p_j, \forall i \neq j \in \{H, L\}. \tag{$IC_{i,j}$}$$

As is well known, only the individual rationality constraint for the low type (IR_L) and the incentive compatibility constraint for the high type $(IC_{H,L})$ are binding, which yield the seller-optimal prices $p_L = \theta_L q_L$ and $p_H = p_L + \theta_H(q_H - q_L) = \theta_H q_H - (\theta_H - \theta_L)q_L$. Substituting the binding constraints leads us to reduce the seller's optimization problem as

$$\max_{q_H, q_L} \left\{ V = \alpha_H[\gamma(\theta_H q_H - (\theta_H - \theta_L)q_L - k{q_H}^2) - s{q_H}^2] + \alpha_L[\gamma(\theta_L q_L - k{q_L}^2) - s{q_L}^2] \right\}. \tag{3}$$

Lemma 1 *The equilibrium qualities under the screening benchmark are given by* $q_H^B = \frac{\gamma\theta_H}{2s+2\gamma k}$ *and* $q_L^B = \max\left\{\frac{\gamma(\theta_L - \alpha\theta_H)}{(1-\alpha)(2s+2\gamma k)}, 0\right\}$.

There are two forces that lead to lower equilibrium qualities than the efficient levels that maximize social welfare, i.e., $q_i^B < q_i^S \equiv \frac{\theta_i}{2s+2k}$, $i \in \{H, L\}$. The first is the standard cannibalization effect: to facilitate the sorting between the privately informed buyers, the quality q_L^B of the low-end product must be reduced to make it less attractive to the high type (i.e., to decrease their information rent). When the size and/or the quality preference of the high type is high enough, the seller would even eliminate the low-end product altogether (i.e., $q_L^B = 0$ when $\theta_L \leq \alpha\theta_H$).[10] In addition, the seller's incentive for quality provision is socially suboptimal because its ability to appropriate the incremental surplus is imperfect ($\gamma < 1$). This second force decreases the optimal qualities of both products in the product line.[11] Note that the optimal quality q_H^B of the high-end product is the first best for the seller (i.e., equal to that under symmetric information) but still below that for the social planner. Intuitively, both q_H^B and q_L^B would be higher, as the seller's bargaining power γ increases or the products become less costly to produce or sell (i.e., k or s becomes smaller).

Unsurprisingly, the seller's equilibrium payoff V^B increases with its bargaining power γ. What about the buyers? As shown in the Appendix, the equilibrium payoff of the high-type buyers, U_H^B, first increases and then decreases with the seller's bargaining power γ (i.e., an inverted-U pattern). This is because a change in γ can generate two forces. On the one hand, a higher γ implies that the seller is able to split a larger share of the total pie in the transactions with the buyers. On the other hand, a more powerful seller would be increasingly motivated to provide higher-quality products, thus enlarging the total pie. The interaction of these countervailing effects would yield the non-monotonic impact on the high-type buyers' equilibrium payoff. Similarly, a change in γ can exhibit non-monotonic influence on the low-type buyers' equilibrium payoff U_L^B.

3.2 Customization under A-Learning

We consider the game in Figure 1(a) where the seller asks the buyers directly about their quality preferences before designing and selling the products. Our solution concept is the perfect Bayesian equilibrium (PBE). It stipulates that the seller's belief about the buyers is consistent with the buyers' equilibrium communication strategy $m(\theta)$, and that each party's decisions are optimally made given its belief and the other party's optimal behavior. Note first that, as in all cheap-talk models, there always exists an equilibrium in which the buyers' message is uninformative and the seller's belief about the buyers' preferences remains the prior. Under this babbling (pooling) equilibrium, the parties' behaviors and payoffs would be exactly the same as those in the benchmark.

[10]It is never optimal in our setting to serve both types of buyers using a single product, because it is a special case of the problem of product line design where q_H is restricted to be equal to q_L. This is driven by our implicit assumption that there is no upper-bound constraint on quality. As shown in Anderson and Dana (2009), should there be a binding quality constraint, the seller may find it optimal to sell one single product to both buyer types. Moreover, if our setup did not satisfy the log supermodularity condition for the surplus function (and the quality constraint were present), it would never be optimal to screen the buyers with products of different qualities.

[11]Relatedly, Anderson (2002) shows that a firm may invest excessively in product configuration that is socially inefficient but can reduce consumers' valuation heterogeneity to improve the firm's surplus-extracting ability.

Our focus is on whether and when an informative-communication equilibrium may emerge such that the buyers' preferences are credibly conveyed to enable endogenous customization in designing and pricing the products. Under this separating equilibrium, a buyer's message is $m(\theta_H) = m_H$ or $m(\theta_L) = m_L$, depending on whether its true preference θ is θ_H or θ_L. Conditional on receiving m, let the seller's updated belief be $\hat{\theta}(m) : M \to \Theta$. The PBE requires that $\hat{\theta}(m_H) = \theta_H$ and $\hat{\theta}(m_L) = \theta_L$ along the equilibrium path. To characterize the informative equilibrium, we first investigate the seller's optimal design decision, $q(\hat{\theta})$, given the updated belief $\hat{\theta}$, which is equivalent to specifying the optimal design function $q(m)$ in Figure 1(a). We then derive each buyer's expected payoff, conditional on its true type θ and the seller's belief $\hat{\theta}$ to be induced. This allows us to present conditions under which the separating equilibrium in buyer communication can be sustained.

Consider how the seller in the second stage of the game would customize the product designed to a buyer whose quality preference is believed to be $\hat{\theta}$. It is clear that the seller's expected payoff of offering the product at quality q to this buyer would be

$$v(q, \hat{\theta}) = \gamma(\hat{\theta}q - kq^2) - sq^2. \tag{4}$$

It follows from maximizing (4) that the seller's optimal design decision is given by $q(\hat{\theta}) = \frac{\gamma\hat{\theta}}{2s+2\gamma k}$. Given this, each of the buyers with true preference $\theta \in \{\theta_H, \theta_L\}$ who are nonetheless believed by the seller to be of type $\hat{\theta}$ would anticipate to receive the following expected payoff:

$$u(\theta, \hat{\theta}) = \gamma \max\{\theta q(\hat{\theta}) - \hat{\theta}q(\hat{\theta}), 0\} + (1-\gamma)\max\{\theta q(\hat{\theta}) - kq(\hat{\theta})^2, 0\}, \tag{5}$$

because the price would be $\hat{\theta}q(\hat{\theta})$ or $kq(\hat{\theta})^2$, depending on whether the seller or the buyer would end up being the price setter (with the respective probability γ or $1-\gamma$).

For the first-stage cheap-talk communication to be credible, it must be the case that the buyers prefer to faithfully report their true preferences, given that the self-claimed type is to be believed by the seller. In other words, communication would be truthful in equilibrium if and only if the following incentive compatibility (IC) conditions are satisfied.

$$\text{IC}_H : u(\theta_H, \theta_H) \geq u(\theta_H, \theta_L), \tag{6}$$

$$\text{IC}_L : u(\theta_L, \theta_L) \geq u(\theta_L, \theta_H). \tag{7}$$

Proposition 1 *Informative communication under the A-Learning customization can arise in equilibrium if and only if* $\frac{\theta_H}{\theta_L} \geq \Delta \equiv \max\left\{\frac{\gamma[2s+(1+\gamma)k]}{(1-\gamma)(2s+\gamma k)}, \frac{2s+\gamma k}{\gamma k}\right\}$.

This proposition presents the necessary and sufficient condition for the separating equilibrium of informative communication to emerge. As such, it also gives rise to the condition for customization to be endogenously feasible. The two components of the specified condition ensure that neither the high- nor the low-type buyers can benefit from being perceived as the other type, respectively. Basically, it requires that the buyers be sufficiently heterogenous in their quality preferences. This is because the seller's perception about the buyers' preference type is a "two-edged sword" in influencing the subsequent customization. On the one hand, the seller would offer higher quality to those buyers who are believed to value quality more: $q(\hat{\theta})$ increases with $\hat{\theta}$. Therefore, all else being equal, both buyer types would benefit from (over)stating their preferences to induce the seller to provide high quality. However, on the other hand, products with higher quality are more expensive. This would be the case even if the buyers turn out to have the pricing power, because the cost of production increases convexly with quality. Each buyer's optimal communication strategy is then determined by the tradeoff between quality and price. Intuitively, the buyers would self-sort themselves and truthful communication would be incentive compatible, if the buyers differ sufficiently in their willingness to pay for quality.

In particular, as for the high-type buyers, imitating the low type may backfire if the low type's preference for quality is too low, because the seller would be misled to offer a product with overly low quality. It turns out that truthful communication is beneficial for the high type if and only if $\frac{\theta_H}{\theta_L} \geq \Delta_H \equiv \frac{\gamma[2s+(1+\gamma)k]}{(1-\gamma)(2s+\gamma k)}$. Conversely, the potential downside of the low-type buyers overstating their preference is that they would have to pay a high price for a product that is intended to accommodate the high type's preference. As a result, it would be undesirable for the low-type buyers to misrepresent their preference if and only if $\frac{\theta_H}{\theta_L} \geq \Delta_L \equiv \frac{2s+\gamma k}{\gamma k}$.

How would the other parameters influence the emergence of the separating equilibrium? Examining the condition in Proposition 1, we can readily obtain the following results.

Proposition 2 *As the seller bargaining power increases (higher γ) or production or selling becomes more costly (higher k or s), the critical threshold of θ_H/θ_L (i.e., Δ) to sustain the separating equilibrium under the A-Learning customization first decreases and then increases.*

Varying the parameter on the seller bargaining power or on the production/selling cost would affect, in a non-monotonic manner, the likelihood of observing the separating equilibrium and hence of sustaining the viability of customization. Interestingly, the credibility of preference communication may become either easier or harder to be established, as the seller becomes more powerful or the production or the selling of the products becomes more costly. It is because the impact of each of these parameters on truthful communication differs qualitatively across the two buyer types.

Consider first the impact of the seller bargaining power. When γ is relatively low, the buyers would retain most of the generated surplus. It implies that the high-type buyers would have a strong incentive to reveal their preference: the IC_H constraint can be easily satisfied. The existence of the separating equilibrium would then hinge on the low-type buyers' incentive for truthful communication. As γ increases, the low-type buyers would be offered a more efficiently customized product if their preference is correctly communicated, but would have to pay an increasing price if they deceive the seller to offer the high-quality product. That is, the IC_L constraint would be relaxed and thus the chance to observe the separating equilibrium would be higher. However, as γ becomes relatively high, the coin would be flipped. The low-type buyers would clearly prefer not to overstate their preference, whereas the high-type buyers would be more hesitant about whether to understate their preference. It is then the satisfaction of the IC_H constraint that determines the emergence of the informative equilibrium. As a result, a higher γ would increase the high type's incentive for deceptive communication and thus reduce the likelihood to sustain the separating equilibrium.

Similarly, the impact of changing the parameter k exhibits an inverted-U pattern. An increase in k tends to raise the costs of production and hence the expected prices. This implies that, all else being equal, both buyer types' incentives to be perceived as the high type would be undermined. In other words, the high-type buyers would be less inclined to communicate truthfully, whereas the opposite would hold for the low type. Nevertheless, the ease at which the incentive constraint may be binding is not the same across the buyer types. This is because, comparatively speaking, the high-type buyers have a higher preference to be offered the high-quality product than the low-type buyers. Therefore, when k is relatively low, IC_L is critical in sustaining the separating equilibrium, which nonetheless can be relaxed as k increases. However, when k becomes high enough such that the high-type buyers' incentive for truthful communication becomes sufficiently low and hence pivotal, an increase in k would make it harder to establish the separating equilibrium.

The changes in the buyers' incentives for truthful communication in response to more costly selling are the opposite of those in response to more costly production. Unlike the production costs, the selling costs are sunk and do not directly affect the incremental surplus to be shared between the parties in the pricing stage. As a result, the parameter s may influence the buyers' quality-price tradeoff only indirectly through affecting the seller's optimal design decision. Recall that the quality for either customized product decreases with s: $q(\hat{\theta}) = \frac{\gamma\hat{\theta}}{2s+2\gamma k}$. This implies that an increase in s tends to reduce the marginal production cost and hence enhance each buyer's incentive to be perceived as the high type. Therefore, when s is relatively low, whether the separating equilibrium can arise hinges on the high type's IC_H constraint, which would be easier to be satisfied as s increases. When s becomes high enough, the low-type buyers' incentive becomes critical, whereas an increase in s would make it harder for them to communicate truthfully. In other words, although the parameters s and k have reversed influences on each buyer's communication strategy, their impacts on the emergence of the separating equilibrium are qualitatively similar to each other.

An alternative way to present the results in Proposition 2 is that, if we fix the buyers' quality preferences (θ_H and θ_L), the separating equilibrium can arise only when the seller's bargaining power is intermediate. That is, we must have $\gamma \geq \gamma_l \equiv \frac{2s\theta_L}{k(\theta_H-\theta_L)}$ for the low type's incentive for truthful communication to be compatible, and γ must be lower than some threshold γ_h to achieve incentive compatibility for the high type.[12] Similar pattern can be seen with respect to the parameters on the production and the selling costs.[13]

Next, we compare the equilibrium outcome with that under the screening benchmark. Note that the customized qualities under the informative equilibrium are $q_i^A = q(\theta_i) = \frac{\gamma\theta_i}{2s+2\gamma k}$, $i \in \{H, L\}$. It is then evident that $q_H^A = q_H^B$ and $q_L^A > q_L^B$ (see Lemma 1). Recall that the seller may offer only one product to serve the high-type buyers under the screening benchmark (when $q_L^B = 0$). Therefore, endogenous customization leads the seller to offer not only higher quality for the low-end product, but also (potentially) more products. Intuitively, as the buyers' preferences are revealed in the separating equilibrium, the seller no longer needs to distort the low-end product downward.

The seller's expected payoff under the informative equilibrium is

$$V^A = \sum_{i=H,L} \alpha_i v(q_i^A, \theta_i), \tag{8}$$

where the payoff function $v(q, \hat{\theta})$ is given by (4). It is clear that $V^A > V^B$. Truthful communication removes the concern for cannibalization that is otherwise inherent in screening the privately informed buyers. This allows the seller to obtain the first-best expected payoff as that under symmetric information, by mitigating the downward distortion in the design of the product for the low-type buyers as well as by eliminating the information rent conceded to the high-type buyers.

As a result of being deprived of the information rent, the high-type buyers' equilibrium expected payoff is weakly lower than that under the benchmark: $U_H^A = u(\theta_H, \theta_H) = (1-\gamma)(\theta_H q_H^A - k{q_H^A}^2) \leq \gamma(\theta_H - \theta_L)q_L^B + (1-\gamma)(\theta_H q_H^B - k{q_H^B}^2) = U_H^B$ because $q_H^A = q_H^B$. In contrast, the low-type buyers are better off under the informative equilibrium: $U_L^A = u(\theta_L, \theta_L) = (1-\gamma)(\theta_L q_L^A - k{q_L^A}^2) \geq (1-\gamma)\max\left\{\theta_L q_H^B - k{q_H^B}^2, \theta_L q_L^B - k{q_L^B}^2\right\} = U_L^B$, where $\theta_L q_L^A - k{q_L^A}^2 \geq \theta_L q_H^B - k{q_H^B}^2$ is because of IC_L (and $q_H^A = q_H^B$) and $\theta_L q_L^A - k{q_L^A}^2 > \theta_L q_L^B - k{q_L^B}^2$ is due to $q_L^A > q_L^B$. Intuitively, as the high-type buyers reveal their preference truthfully, the quality offered to the low-type buyers would be less distorted such that a larger incremental surplus would be generated.

[12]Note that $\Delta \to +\infty$ as γ approaches zero or one, which implies that the separating equilibrium under the A-Learning customization cannot be sustained for finite θ_H/θ_L.

[13]Note that $\Delta \to +\infty$ as $k \to 0$ or $s \to +\infty$, and $\Delta \to \frac{1+\gamma}{1-\gamma}$ as $k \to +\infty$ or $s \to 0$. Therefore, to sustain the separating equilibrium, for $\theta_H/\theta_L < \frac{1+\gamma}{1-\gamma}$, it must be neither too cheap nor too costly to produce/sell the products; for $\theta_H/\theta_L \geq \frac{1+\gamma}{1-\gamma}$, k cannot be too low and s cannot be too high.

Moreover, we can investigate the selection between the pooling and the separating equilibria, when both are existing for the communication game (i.e., $\theta_H/\theta_L \geq \Delta$). Recall that the pooling equilibrium is equivalent to the benchmark case. Therefore, it follows from the above discussion that, both the seller and the low-type buyers are better off under the separating equilibrium than under the pooling equilibrium, whereas the high-type buyers would be indifferent if $\theta_L \leq \alpha\theta_H$ (such that $q_L^B = 0$). It follows that, when $\theta_L \leq \min\{\theta_H/\Delta, \alpha\theta_H\}$, we can use the "Pareto-dominance" criterion to select the separating equilibrium.

3.3 Customization under O-Learning

We now analyze the game in Figure 1(b) where each of the buyers can make a take-it-or-leave-it proposal to the seller on the product quality. Under the PBE, the seller's posterior perception about the preference type of a buyer who submits request q, $\hat{\theta}(q)$, is consistent with the buyers' equilibrium strategy for quality request, $q(\theta)$. Furthermore, given the seller's equilibrium belief updating, the parties' behaviors are optimal responses to each other at each stage of the game. We concentrate on pure-strategy separating equilibrium. This implies that there would be two quality levels to be proposed by the buyers in equilibrium, $q(\theta_H) = q_H$ and $q(\theta_L) = q_L$, which would yield the equilibrium posterior perceptions $\hat{\theta}(q_H) = \theta_H$ and $\hat{\theta}(q_L) = \theta_L$, respectively.

To characterize the separating equilibrium and the existence condition, we need to derive each buyer's expected payoff when the customized product is at quality q and the seller's perception is $\hat{\theta}$. To this end, note that the seller would charge $p = \hat{\theta}q$ or expect to be offered $p = kq^2$, in case the seller or the buyer obtains the pricing power, respectively. This implies that the seller would accept the design request q from a buyer who is believed to have quality preference $\hat{\theta}$ if and only if $\gamma(\hat{\theta}q - kq^2) - sq^2 \geq 0$, i.e., $q \leq \frac{\gamma\hat{\theta}}{s+\gamma k}$. In addition, the buyer with true preference $\theta \in \{\theta_H, \theta_L\}$ who is nonetheless believed by the seller to be of type $\hat{\theta}$ would anticipate to receive the following expected payoff from a product of quality q (conditional on being accepted by the seller):

$$\mu(q, \theta, \hat{\theta}) = \gamma \max\{\theta q - \hat{\theta}q, 0\} + (1-\gamma)\max\{\theta q - kq^2, 0\}. \tag{9}$$

Suppose first that the buyer's preference θ is *a priori* known to the seller. The buyer would determine how to make the design proposal by solving

$$\max_{q \leq \frac{\gamma\theta}{s+\gamma k}} \left\{\mu(q, \theta, \theta) = (1-\gamma)(\theta q - kq^2)\right\}. \tag{10}$$

This yields the buyer's first-best quality under symmetric information: $q^*(\theta) = \min\left\{\frac{\gamma\theta}{s+\gamma k}, \frac{\theta}{2k}\right\}$. For it to be an equilibrium under asymmetric information, we need the following constraints:

$$\text{IC}_H^{'} : \mu(q^*(\theta_H), \theta_H, \theta_H) \geq \mu(q^*(\theta_L), \theta_H, \theta_L), \tag{11}$$

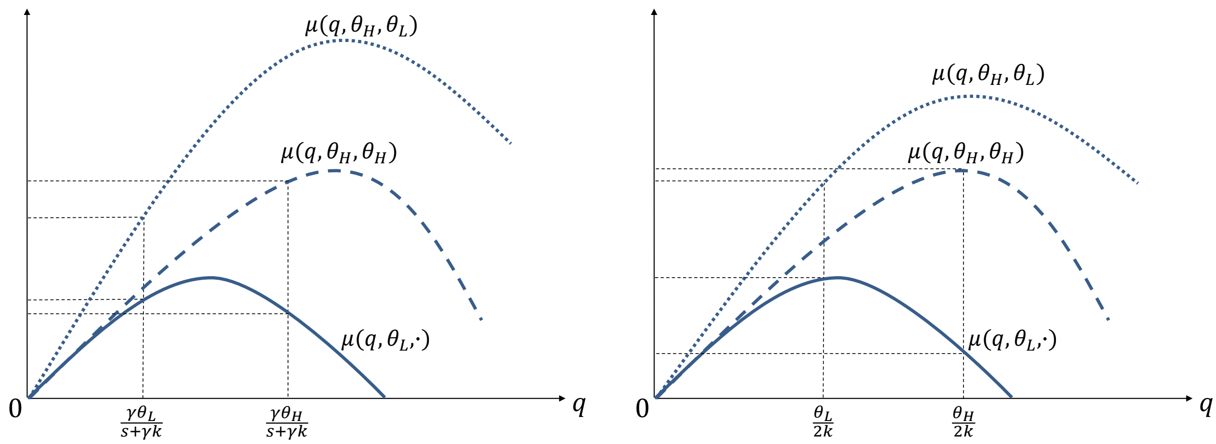
$$\text{IC}_L^{'} : \mu(q^*(\theta_L), \theta_L, \theta_L) \geq \mu(q^*(\theta_H), \theta_L, \theta_H). \tag{12}$$

Proposition 3 *There exists a separating equilibrium under the O-Learning customization, where* $q_H^O = q^*(\theta_H)$ *and* $q_L^O = q^*(\theta_L)$*, if and only if* $\theta_H/\theta_L \geq \Lambda \equiv \max\{\min\{\Lambda_{H1}, \Lambda_{H2}\}, \Lambda_L\}$*, where* $\Lambda_{H1} \equiv \frac{\gamma(s+k)}{(1-\gamma)s}$*,* $\Lambda_{H2} \equiv \frac{1+\gamma}{1-\gamma}$*, and* $\Lambda_L \equiv \frac{s}{\gamma k}$*. The equilibrium beliefs are* $\hat{\theta}(q_H^O) = \theta_H$ *and* $\hat{\theta}(q_L^O) = \theta_L$*. The out-of-equilibrium beliefs are:* $\hat{\theta}(q) = \theta_L$ *for* $q \notin \{q_H^O, q_L^O\}$ *if* $\gamma \leq s/k$*, and* $\hat{\theta}(q) = \theta_H$ *for* $q \notin \{q_H^O, q_L^O\}$ *if* $\gamma \geq s/k$*.*

There may exist a cheap-signaling equilibrium under which the buyers propose to customize the qualities of the products as if their preferences were ex ante known to the seller. That is, it is possible that each buyer type is better off choosing its own optimal product design under complete information, $q^*(\theta)$, rather than mimicking that of the other type. As a result, the buyers' private information on their quality preferences can be revealed in equilibrium without distorting their first-best designs. As shown in Proposition 3, the necessary and sufficient condition for the emergence of the cheap-signaling equilibrium is that the two types of buyers have sufficiently different preferences for quality. This is because the seller's belief about the buyers' type can yield a quality-price tradeoff for the buyers, which is analogous to the case of cheap-talk communication (see Proposition 1). Nevertheless, there is difference in how the tradeoff is manifested, because now the seller has less control over the qualities of the products.

The buyers' tradeoff between quality and price is illustrated in Figure 2. For a given q the high-type buyers always benefit from being perceived as the low type to induce the seller to charge a lower price (i.e., $\mu(q, \theta_H, \theta_H) < \mu(q, \theta_H, \theta_L)$), whereas the downside of mimicking the low type is that the requested quality would be lower. This is similar to that under cheap-talk communication. In contrast, the low-type buyers' potential gain from imitating the high type comes from persuading the seller to accept a higher quality (i.e., $\mu(q, \theta_L, \theta_H) = \mu(q, \theta_L, \theta_L)$). The buyers now can make take-it-or-leave-it quality offers, but not all proposal would be accepted by the seller who would bear the selling and the production costs. Relatively speaking, the seller is more willing to take a proposal from the high-type buyers: the highest acceptable quality $\frac{\gamma\hat{\theta}}{s+\gamma k}$ increases with the perceived type $\hat{\theta}$. Therefore, the low-type buyers might deviate from their first-best design $q^*(\theta_L)$ only if the seller-acceptance constraint is indeed binding (i.e., in case (a) but not in case (b) of Figure 2).

Note that Proposition 3 employs different out-of-equilibrium beliefs, depending on whether the constraint of seller acceptance is binding in the first-best designs $q^*(\theta)$. The cheap-signaling



(a) $\gamma \leq s/k$ (b) $\gamma \geq s/k$

Figure 2: Cheap Signaling under O-Learning Customization

equilibrium can be supported by other, but not all, out-of-equilibrium beliefs. For example, in the case $\gamma \leq s/k$, the low-type buyers would deviate to some $q = \frac{\gamma\theta_L}{s+\gamma k} + \epsilon$ if $\hat{\theta}(q) = \theta_H$, where ϵ is a sufficiently small, positive number. Conversely, in the case $\gamma \geq s/k$, the high-type buyers may deviate to some $q = \frac{\theta_H}{2k} - \epsilon$ if $\hat{\theta}(q) = \theta_L$, even when deviating to $q^*(\theta_L) = \frac{\theta_L}{2k}$ is undesirable.

We can reconstruct the existence condition in Proposition 3 to examine how the other parameters may influence the emergence of the cheap-signaling equilibrium.

Proposition 4 *As the seller bargaining power increases (higher γ) or production or selling becomes more costly (higher k or s), the critical value of θ_H/θ_L (i.e., Λ) to sustain the cheap-signaling equilibrium under the O-Learning customization first decreases and then increases.*

These non-monotonic results are similar to those in Proposition 2 for the A-Learning customization. The economic mechanism is also that the two types of buyers differ in how the parameters may influence their incentives to manipulate the seller's perception about their preferences. First, consider the change in the seller bargaining power. When γ is relatively low, the equilibrium separation between the buyers hinges on whether the low type's incentive can be satisfied. Nevertheless, a higher γ would increase the seller's highest acceptable quality for either perceived buyer type. This would mitigate the low-type buyers' incentive for imitation in the customization request. However, for relatively high γ the high-type buyers' incentive would be relevant, which is harder to be satisfied as γ increases to enlarge the gain from deceiving the seller into underpricing. Overall, an increasing γ can generate an inverted-U impact on the chance to sustain the cheap-signaling equilibrium.

Similarly, more costly production/selling not only has opposite influence on, but can also change the relative strength of, the different buyers' incentives for imitation. In particular, as a higher k decreases the comparative benefit for high quality, the high-type (the low-type) buyers are less (more) motivated to be differentiated from their counter type, respectively. At the same time, a higher k can increase the high type's imitation incentive above that of the low type. As a result, the impact of k on equilibrium separation first increases and then decreases. The case of more costly selling is the mirror image. Put differently, a higher s increases the buyers' relative benefit from high quality, which would first facilitate the emergence of the separating equilibrium by reducing the high type's imitation incentive, and then impede equilibrium separation by enhancing the low type's imitation incentive and making it stronger than that of the high type.

Proposition 4 also implies that the cheap-signaling equilibrium tends to be sustained by intermediate parameters. For instance, it can arise if and only if $\gamma_L \leq \gamma \leq \max\{\gamma_{H1}, \gamma_{H2}\}$, where $\gamma_L \equiv \frac{s\theta_L}{k\theta_H}$, $\gamma_{H1} \equiv \frac{s\theta_H}{s\theta_H+(s+k)\theta_L}$, and $\gamma_{H2} \equiv \frac{\theta_H-\theta_L}{\theta_H+\theta_L}$. If the seller bargaining power is high enough (i.e., $\gamma > \max\{\gamma_{H1}, \gamma_{H2}\}$), the high-type buyers prefer to be perceived as the low type to save the subsequent expected payment. If the seller bargaining power is too low (i.e., $\gamma < \gamma_L$), the low-type buyers would pretend to be the high type in order to deceive the seller to accept a higher quality.

What would happen when the cheap-signaling equilibrium does not arise? Can there be any other separating equilibrium? As we show in the Appendix, the answer is no. When $\theta_H/\theta_L < \min\{\Lambda_{H1}, \Lambda_{H2}\}$ such that the high-type buyers benefit from imitating $q^*(\theta_L)$, the low-type buyers cannot willingly distort their quality proposal to signal their true preference. This is because the low-type buyers are always better off deviating from any candidate strategy $q_L \neq q^*(\theta_L)$ to $q^*(\theta_L)$ under any off-the-equilibrium belief. Moreover, when $\theta_H/\theta_L < \Lambda_L$ such that the cheap-signaling equilibrium fails because the low-type buyers are better off mimicking $q^*(\theta_H)$, the high-type buyers cannot figure out any other q_H that is acceptable to the seller, beneficial for themselves, while undesirable for the low-type buyers to mimic. Therefore, the cheap-signaling equilibrium is the only separating equilibrium in our setting.

This finding differs fundamentally from that in standard signaling models. Typically, the types of a privately informed player can be credibly separated (i.e., signaled) by distorting the first-best action of one type to the extent that is unworthy for the other type to imitate, if the types differ in their marginal benefits of the action. This so-called single-crossing condition does exist in our setup: the marginal valuation for quality is higher for the type θ_H than for θ_L. However, the inherent incentives for imitation and separation are basically different across the settings. In standard signaling games, both types desire to be perceived as a particular type such that both imitation (by the undesirable type) and separation (by the desirable type) are unilateral and are the twins to each other. In contrast, there is no such universally desirable type in our setting. Conditional on seller acceptance, the high type is strictly better off being perceived as the low type for any given q, while the low type is indifferent. Unconditional on seller acceptance, nevertheless, the seller's perception $\hat{\theta}$ that is advantageous for the high-type buyers would depend on q, whereas the low-type buyers would benefit from being believed to be the high type (to improve seller acceptance). Therefore, the buyers' incentives for imitation are mostly bilateral and in opposite direction. Actually, because of the lack of a commonly desirable type, there is no inherent tension between imitation and separation across the two types of buyers. This is why in our setting the buyers' true types can be revealed in equilibrium under the first-best qualities, but not through distorted designs.

Next, we compare the cheap-signaling equilibrium with the screening benchmark. The equilibrium qualities under the O-Learning customization are $q_i^O = q^*(\theta_i) = \min\left\{\frac{\gamma\theta_i}{s+\gamma k}, \frac{\theta_i}{2k}\right\}$, $i \in \{H, L\}$. It is straightforward that $q_H^O > q_H^B$ and $q_L^O > q_L^B$. Intuitively, empowering the buyers in the customization process leads to higher qualities for both buyer types.

The seller's expected payoff under the cheap-signaling equilibrium is

$$V^O = \sum_{i=H,L} \alpha_i v(q_i^O, \theta_i), \tag{13}$$

where the payoff function $v(q, \hat{\theta})$ is in (4). How does this compare to that under the benchmark?

Proposition 5 *The seller's expected payoff under the cheap-signaling equilibrium is lower than that under the screening benchmark ($V^O < V^B$) if $\alpha \to 0$, $\alpha \to 1$, or $\gamma_L \leq \gamma \leq \min\{\gamma_{H1}, s/k\}$. The seller's expected payoff under the cheap-signaling equilibrium is higher than that under the screening benchmark ($V^O > V^B$) if $s \to 0$.*

There are pros and cons in transferring the decision rights to the buyers to customize the design of the products. First, as mentioned above, the buyers would over-design the products and request qualities that are too high for the seller. This is because they fail to internalize the seller's selling costs that would become sunk when prices are negotiated. The seller's expected payoff would then be negatively influenced. On the other hand, the buyers' self-tailored designs would in equilibrium reflect their true preferences, thus permitting the seller to customize the pricing of the products. This means that the seller can save the information rent, which would necessarily be given to the high-type buyers (due to cannibalization) when otherwise only a menu of products can be offered for the privately informed buyers to self select. In other words, holding the design qualities fixed, the O-Learning customization allows the seller to extract more buyer surplus. Proposition 5 presents sufficient conditions under which either of the two forces is dominant over the other one.

In particular, when the composition of the buyers is sufficiently extreme such that one type of buyers contribute to most of the seller's expected payoff (i.e., $\alpha \to 0$ or $\alpha \to 1$), the seller would be worse off under the O-Learning customization than under the benchmark. This is because the influence of cannibalization in screening would be minimized, as the size of one buyer type dominates that of the other type. Excessive design under self customization would become the major concern and hurt the seller. Similarly, when the seller's bargaining power γ is not too high, the buyers would propose design qualities that leave zero expected payoff to the seller (i.e., $V^O = 0$).

Interestingly, the seller can benefit from giving up the design rights to the buyers. As demonstrated in Proposition 5, one sufficient condition for this to happen is that the selling cost is sufficiently low. When s is small enough, the problem of over-design is not severe and the buyers' proposed qualities would converge to those that maximize the seller's objective function (i.e., the first best). As a result, the saving of the information rent would be the dominant force and the seller would be better off permitting the buyers to self customize their products (i.e., $V^O > V^B$).

What about the buyers' equilibrium expected payoffs? The low-type buyers are clearly better off under the cheap-signaling equilibrium than under the benchmark. When they are given the decision rights, they would simply design their customized product to maximize their expected payoff (subject to seller acceptance). However, the change in the higher-type buyers' equilibrium expected payoffs is more ambiguous. They would be able to design the product to their best interest, but at the expense of losing the information rent.

Proposition 6 *The high-type buyers' expected payoff under the cheap-signaling equilibrium is higher than that under the screening benchmark ($U_H^O > U_H^B$) if $\theta_L \leq \alpha\theta_H$. The high-type buyers' expected payoff under the cheap-signaling equilibrium is lower than that under the screening benchmark ($U_H^O \leq U_H^B$) if $s \to 0$.*

We identify sufficient conditions under which the design rights are beneficial or harmful for the high-type buyers. When the size and/or the quality preference of the high type is sufficiently high, the seller would offer only one product to minimize cannibalization under the benchmark (i.e., $q_L^B = 0$). As a result, the high-type buyers would earn zero information rent and thus would be better off being given the decision rights to customize their product. On the other hand, if the selling cost is sufficiently low (i.e., $s \to 0$), the quality of the high-end product would converge to the socially optimal level, no matter who is the design maker, i.e., $q_H^O = q_H^B = q_H^S = \frac{\theta_H}{2k}$. This implies that the high-type buyers would then be (weakly) better off under the screening benchmark.

3.4 Comparison between the Customization Strategies

We now compare the outcomes of the separating equilibria between the two customization strategies. First, the equilibrium qualities under the A-Learning customization are lower than those under the

O-Learning customization: $q_i^A = \frac{\gamma\theta_i}{2s+2\gamma k} < q_i^O = \min\left\{\frac{\gamma\theta_i}{s+\gamma k}, \frac{\theta_i}{2k}\right\}$, $i \in \{H, L\}$. This result is intuitive and driven by whether the design maker may internalize the selling costs (of the seller).

Next, we investigate the equilibrium emergence of customization across the two strategies. To this end, we compare the likelihood of observing the separating equilibrium.

Proposition 7 *The critical value of θ_H/θ_L to sustain the separating equilibrium is larger under the A-Learning customization than under the O-Learning customization (i.e., $\Delta > \Lambda$) if and only if $\gamma < \max\left\{\frac{2s}{2s+k}, \frac{\sqrt{s^2+4sk}-s}{2k}\right\}$.*

Customization is less likely to emerge endogenously when the seller attempts to learn the buyers' preferences through direct communication than through indirect inference, if the seller's bargaining power is relatively low. The reverse would be true if the seller becomes relatively more powerful. It follows that there are circumstances under which product customization is feasible under one of the two preference-learning approaches but not under the other one. This result is driven by how the different buyers' incentives to reveal their types truthfully may change qualitatively within and across the preference-learning scenarios. On one hand, as we have elaborated, for either A-Learning or O-Learning, whether the buyer types can be revealed in equilibrium depends on the low (high) type's incentive compatibility when γ is low (high). This is because an increase in γ tends to improve the seller's surplus-extracting ability and hence undermine both buyer types' relative gain from a higher quality. Moreover, as we show in the proof, the low-type buyers' motivation for truthful revelation is lower under the A-Learning than under the O-Learning case (i.e., $\Delta_L > \Lambda_L$), whereas the reverse holds for the high-type buyers (i.e., $\Delta_H < \min\{\Lambda_{H1}, \Lambda_{H2}\}$). Intuitively, this is because, for both buyer types, the relative appeal of high quality over high price diminishes as the quality increases (due to increasing marginal costs). As a result, the low-type buyers become less eager, but the high-type buyers are more eager, to imitate their counter type, as the product qualities increase from A-Learning to O-Learning (i.e., $q_i^A < q_i^O$). Therefore, either direct communication or buyer empowerment may lead to a higher likelihood of sustaining customization, depending on whether the seller bargaining power is high or low, respectively.

So far we concentrate on the strategic impacts of the two customization approaches relative to the benchmark, assuming that they do not involve any cost for any party. Nevertheless, in practice the customization cost need not be zero and may vary across the preference-learning methods. Developing and implementing preference solicitation/elicitation instruments (e.g., meetings, surveys) may be more costly for the seller than delegating the design decisions to the buyers. Conversely, it may be less effortful for the buyers to respond to preference solicitation/elicitation questions than to engage in the customization process to figure out their preferred designs. To account for these considerations, we now enrich the analysis by assuming that the seller's incremental fixed cost of A-Learning relative to O-Learning is $F > 0$, and that the buyers' incremental fixed cost of O-Learning relative to A-Learning is $G > 0$.

Proposition 8 *Comparing the expected payoffs between the separating equilibria of A-Learning and O-Learning, we have: (i)* $V^A > V^O$*; (ii) For any* $F > 0$*, there exists a* $\tilde{s}_F > 0$ *such that* $V^A - F < V^O$ *if* $s < \tilde{s}_F$*; (iii)* $U_i^A < U_i^O$*,* $i \in \{H, L\}$*; and (iv) For any* $G > 0$*, there exists a* $\tilde{s}_{iG} > 0$ *such that* $U_i^A > U_i^O - G$ *if* $s < \tilde{s}_{iG}$*,* $i \in \{H, L\}$*.*

Since the buyers' privately informed types would be revealed in equilibrium, the comparisons of the expected payoffs across the preference-learning cases are determined by the optimality of the equilibrium qualities. It is then not surprising that, absent cost considerations (i.e., $F = G = 0$), the parties are better off retaining or gaining the rights to decide on the product qualities, i.e., $V^A > V^O$ and $U_i^A < U_i^O$. Nevertheless, the differences in the equilibrium qualities between A-Learning and O-Learning would converge to zero (i.e., $q_i^A \to q_i^O$) as the selling costs become negligible (i.e., $s \to 0$). The parties' (gross) expected payoffs would then be sufficiently indistinguishable across the customization approaches. Therefore, the seller may be worse off soliciting or eliciting buyer preferences directly, even when the incremental cost of doing so is small (i.e., $V^A - F < V^O$). Analogously, it is possible that the buyers' incremental value of gaining the decision rights cannot compensate for the extra efforts expended in the customization process (i.e., $U_i^A > U_i^O - G$).

4 Extensions

4.1 Ex Ante Pricing under O-Learning

We have assumed in the O-Learning customization that the transaction price is determined in the last stage of the game after the seller customizes the design of the product at a buyer's requested quality and incurs the selling cost. This can be justified by the observation that, in many B2B or service markets, even though the buyers can self-select the quality (e.g., materials), the detailed characteristics and the transaction terms cannot be fully described or specified in advance contracts. Therefore, the determination of actual prices has to be postponed until the product/service is delivered. In addition, sellers may offer refunds for tailor-made products and services that are returned or cancelled (Esenduran et al. 2022). In general, advance contracts are typically incomplete and price renegotiations are feasible or inevitable (Iyer and Villas-Boas 2003, Guo and Iyer 2013). Another consideration is that we intentionally retain the same timing for price determination as in the other two selling strategies (i.e., the benchmark and the A-Learning customization).

Nevertheless, in many self-design scenarios in practice, the parties may commit contractually to non-changeable or non-renegotiable transaction terms including the price. We now consider this alternative case of ex ante pricing by integrating the last two stages of the game in Figure 1(b) (see the details in the Appendix). As the selling costs are internalized in price negotiation, the parties' incentives for quality design (under symmetric information) would be perfectly aligned. The low-type buyers would always communicate truthfully, whereas the high-type buyers would have a higher imitation incentive. As a result, ex ante pricing makes the cheap-signaling equilibrium easier (harder) to be sustained, when the seller bargaining power is relatively small (large). Nevertheless, ex ante pricing tends to reduce the endogenous viability of customization under the O-Learning approach relative to that under the A-Learning approach. In addition, the equilibrium qualities under ex ante pricing are socially optimal, higher (lower) than those under ex post pricing if and only if the seller bargaining power is low (high), and always higher than those under the benchmark or under the A-Learning customization. The internalization of the selling costs under ex ante pricing is always beneficial for the seller. However, the buyers' expected payoffs under the cheap-signaling equilibrium can be either higher or lower than those under ex post pricing, the A-Learning customization, or the benchmark. Interestingly, the impact of sharing the selling costs can be beneficial for the buyers by aligning the parties' interests in quality design, or become so negative to overshadow the positive effects of improving design efficiency and/or gaining the design rights.

4.2 Multiple Buyer Types

We now consider an extended setting with multiple buyer types who differ in their preferences for quality. Let $\Theta \equiv \{\theta_1, \theta_2, \cdots, \theta_n\}$ be the set of the buyers' preference levels, where $0 < \theta_1 < \theta_2 < \cdots < \theta_n$, and $n > 2$ is the number of buyer types. Let the proportion of the buyers with $\theta_i \in \Theta$ be $\alpha_i \in (0, 1)$, $i = 1, 2, \cdots, n$, where $\sum_{i=1}^{n} \alpha_i = 1$.

The analysis and results of the general setup are similar to those of the two-type case. It is evident that informative communication under the A-Learning customization can arise in equilibrium if and only if $\theta_i/\theta_{i-1} \geq \Delta$ for all $i = 2, 3, \cdots, n$ (Proposition 1), and that there exists a cheap signaling equilibrium under the O-Learning customization if and only if $\theta_i/\theta_{i-1} \geq \Lambda$ for all $i = 2, 3, \cdots, n$ (Proposition 3). The comparative-statics results in Propositions 2 and 4, about how the parameters may influence the emergence of the separating equilibria, continue to hold. In addition, we can obtain qualitatively similar results in comparing the equilibrium qualities and expected payoffs. For example, as $s \to 0$, the expected payoff under the cheap-signaling equilibrium is higher than that under the screening benchmark for the seller (Proposition 5), but lower for the buyers of the highest type (Proposition 6). Moreover, we continue to generate the same results as in Propositions

7 and 8 regarding the comparison between the two customization strategies. Therefore, our main insights can be readily sustained even in the setting with multiple buyer types.[14]

5 Concluding Remarks

Many sellers seek to provide tailored solutions to meet customers' specific preferences. To this end, preference information of individual customers is essential. Yet customers may misrepresent their privately informed preferences to strategically manipulate the customization process. In this research we endogenize the feasibility of customization by investigating whether and when customers may truthfully reveal their quality preferences. We consider two common customization approaches where customers may voice their preferences through either self-report (A-Learning) or self-design (O-Learning), respectively. We identify conditions under which customization becomes viable as the equilibrium outcome rather than as the seller's endowed capability. We also examine how endogenous customization may influence equilibrium qualities and expected payoffs.

We find that the customers would credibly communicate their preferences even though talk is cheap, if and only if they are sufficiently heterogenous in their preferences. In addition, the separating equilibrium tends to be sustained when the seller bargaining power is neither too low nor too high or when the cost of production or selling is intermediate. We obtain similar results when the customers signal their preferences through their self-design.

Nevertheless, there are non-trivial differences in the equilibrium outcomes across the customization approaches. In comparison to the screening benchmark, the A-Learning approach brings the customized qualities up and closer to the efficient levels, whereas the O-Learning approach may lead to socially excessive qualities. The A-Learning customization benefits the seller and hurts the high-type buyers by removing information asymmetry, but the payoff impact of the other customization approach is less unambiguous. In direct comparison between the two approaches, we find that customization is less likely to arise endogenously under A-Learning than under O-Learning if the seller bargaining power is relatively low, and vice versa. Moreover, the seller is generally better off under the A-Learning case and the reverse is true for the buyers, whereas there are conditions under which the payoff implications are reversed if direct communication involves a small cost for the seller or self-design is not completely effortless for the buyers, respectively.

Our research can provide managerial insights to firms about how to customize their offerings.

[14] As corollary of Propositions 1 and 3, there cannot be any separating equilibrium in the setting with continuous buyer types, under either customization approach, because the sufficiently similar buyers would mimic each other's play. Nevertheless, the setup with (many but finite) discrete buyer types may be practically more relevant than the continuous one, because it is rare (if not impossible) for firms to offer an infinite number of customized products.

First, our results can help gauge when customization can be endogenously feasible under either or both of the preference-learning approaches. When customer preferences cannot be faithfully voiced in equilibrium via the A-Learning or the O-Learning approach, firms would have to resort to other information (e.g., demographics) to customize their products and services at the segment rather than at the individual level. Nevertheless, there are scenarios under which standard tools to solicit/elicit preference information (e.g., conversation, meeting, survey, interview) are indeed incentive compatible but customers may not reveal their preferences in self-designs, and vice versa. It is under these conditions that customization can be implemented by using one, but not both, of the A-Learning and the O-Learning approaches. Our results can also help decide how to choose between the customization approaches, when both are endogenously feasible. In particular, we compare the equilibrium expected payoffs between A-Learning and O-Learning, and demonstrate that delegating the design rights to the customers can be harmful or beneficial for the seller.

In addition, firms can benefit from our research in evaluating how the relative feasibility and the profitability of the customization approaches may vary with supply and demand characteristics. The positive effect of customer heterogeneity on equilibrium preference revelation is quite intuitive, whereas the non-monotonic impacts of the other parameters (i.e., bargaining power, production costs, selling costs) are more nuanced.

There may be other preference-revelation means, especially in B2B markets. For example, customers may collect trustable evidence about their types or seek verifications from reputed third parties. They may also use other costly instruments (e.g., R&D investments) to signal their preferences for quality. However, these means are generally more costly, and hence less desirable, than the two customization approaches we consider. Moreover, they tend to be less viable than the A-Learning or the O-Learning method. Quality preferences are generally latent and unstable and, consequently, less verifiable than physical product attributes (e.g., quality *per se*). This is why we focus on the two supposedly costless customization approaches that are frequently used in practice (Randall et al. 2007). Nevertheless, future research can study the other revelation methods, especially when A-Learning and O-Learning fail to reveal the customers' preferences.

There are several directions to extend the current research. The two customization approaches we consider need not always be substitutes. Future research can investigate whether, when, and how they may be combined to improve the scope of customization. In addition, it may be interesting to investigate whether and when customers may voice their preferences truthfully in horizontally differentiated markets, which is the focus of the extant literature. Another direction is to examine the impact of market structure (e.g., competition, channel) on the feasibility and the payoff implication of customization strategies. Moreover, future research can study incentive issues in other related contexts with customer engagement (e.g., product co-design).

Appendix

Buyer Equilibrium Payoffs under the Benchmark: Consider first the high-type buyers. We need to determine how they make their product choice in case they have the power to set the prices at the production costs. Note that $q_H^B = \frac{\gamma\theta_H}{2s+2\gamma k} < \frac{\theta_H}{2k}$ and $q_L^B = \max\left\{\frac{\gamma(\theta_L-\alpha\theta_H)}{(1-\alpha)(2s+2\gamma k)}, 0\right\} < \frac{\theta_L}{2k}$. It follows that $\theta_H q_H^B - k{q_H^B}^2 > \theta_H q_L^B - k{q_L^B}^2 \geq 0$, which implies that in equilibrium the high-type buyers would always choose the high-end product. Therefore, the high-type buyers' equilibrium payoff is given by

$$U_H^B = \gamma(\theta_H - \theta_L)q_L^B + (1-\gamma)(\theta_H q_H^B - k{q_H^B}^2).$$

It can be readily verified that $\frac{\partial U_H^B}{\partial\gamma}|_{\gamma=0} > 0$ and $\frac{\partial U_H^B}{\partial\gamma}|_{\gamma=1} < 0$. In addition, it can be shown that $(s+\gamma k)^3\frac{\partial U_H^B}{\partial\gamma}$ is concave in γ, which implies that $\frac{\partial U_H^B}{\partial\gamma}$ crosses zero only once for $\gamma \in (0,1)$. This proves that $\frac{\partial U_H^B}{\partial\gamma}$ is positive (negative) when γ is less (higher) than some threshold.

Consider then the optimal product choice of the low-type buyers when they have the power to set the prices at the production costs. If $\theta_L < \alpha\theta_H$, only the high-end product is offered in equilibrium, which would be chosen by the low-type buyers for all $\gamma \in (0,1)$ (i.e., $\theta_L q_H^B - k{q_H^B}^2 > 0$) when and only when $\theta_L > \frac{k\theta_H}{2s+2k}$. If instead $\theta_L > \alpha\theta_H$, the low-type buyers would choose the high-end product for all $\gamma \in (0,1)$ (i.e., $\theta_L q_H^B - k{q_H^B}^2 > \theta_L q_L^B - k{q_L^B}^2 > 0$) when and only when $\theta_L > \frac{(1-2\alpha)k\theta_H}{2(1-\alpha)s+(1-2\alpha)k}$. Note that $\frac{k\theta_H}{2s+2k} < \alpha\theta_H$ implies $\min\left\{\frac{(1-2\alpha)k\theta_H}{2(1-\alpha)s+(1-2\alpha)k}, 1\right\} < \frac{k\theta_H}{2s+2k}$, and $\frac{k\theta_H}{2s+2k} > \alpha\theta_H$ implies $\frac{(1-2\alpha)k\theta_H}{2(1-\alpha)s+(1-2\alpha)k} > \frac{k\theta_H}{2s+2k}$. Overall, in equilibrium the low-type buyers with the pricing power would always choose the high-end product for $\theta_L > \max\left\{\frac{k\theta_H}{2s+2k}, \frac{(1-2\alpha)k\theta_H}{2(1-\alpha)s+(1-2\alpha)k}\right\}$. Therefore, the low-type buyers' equilibrium payoff for this parameter range is given by

$$U_L^B = (1-\gamma)(\theta_L q_H^B - k{q_H^B}^2) = \frac{\gamma(1-\gamma)\theta_H[(2s+2\gamma k)\theta_L - \gamma k\theta_H]}{4(s+\gamma k)^2}.$$

It can be readily verified that $\frac{\partial U_L^B}{\partial\gamma}|_{\gamma=0} = \frac{\theta_L\theta_H}{2s} > 0$, and that $\frac{\partial U_L^B}{\partial\gamma}|_{\gamma=1} < 0$ for $\theta_L > \frac{k\theta_H}{2s+2k}$. In addition, it can be shown that $(s+\gamma k)^3\frac{\partial U_H^B}{\partial\gamma}$ is concave (convex) in γ if $\theta_H < 2\theta_L$ (if $\theta_H > 2\theta_L$), which implies that $\frac{\partial U_L^B}{\partial\gamma}$ crosses zero only once for $\gamma \in (0,1)$. As a result, $\frac{\partial U_L^B}{\partial\gamma}$ is positive (negative) when γ is less (higher) than some threshold, if $\theta_L > \max\{\frac{k\theta_H}{2s+2k}, \frac{(1-2\alpha)k\theta_H}{2(1-\alpha)s+(1-2\alpha)k}\}$.

Proof of Proposition 1: Consider first the high-type buyers' incentive to communicate truthfully. It follows from $q(\hat{\theta}) = \frac{\gamma\hat{\theta}}{2s+2\gamma k}$ that $\theta_H q(\theta_H) - kq(\theta_H)^2 > 0$ and $\theta_H q(\theta_L) - kq(\theta_L)^2 > 0$. As a result, we have $u(\theta_H,\theta_H) = (1-\gamma)[\theta_H q(\theta_H) - kq(\theta_H)^2]$ and $u(\theta_H,\theta_L) = \gamma(\theta_H-\theta_L)q(\theta_L) + (1-\gamma)[\theta_H q(\theta_L) - kq(\theta_L)^2]$. It can then be readily verified that $u(\theta_H,\theta_H) > u(\theta_H,\theta_L)$ if and only if $\frac{\theta_H}{\theta_L} > \frac{\gamma[2s+(1+\gamma)k]}{(1-\gamma)(2s+\gamma k)}$. This yields the necessary and sufficient condition for IC_H to be satisfied.

Next, consider the low-type buyers' incentive for truthful communication. It follows from $q(\hat{\theta}) = \frac{\gamma\hat{\theta}}{2s+2\gamma k}$ that $\theta_L q(\theta_L) - kq(\theta_L)^2 > 0$. Therefore, $u(\theta_L, \theta_L) > u(\theta_L, \theta_H)$ if and only if $(1-\gamma)[\theta_L q(\theta_L) - kq(\theta_L)^2] > (1-\gamma)[\theta_L q(\theta_H) - kq(\theta_H)^2]$: note that if the low-type buyers induce the seller's updated belief $\hat{\theta} = \theta_H$ and the seller turns out to have the pricing power, the best deviating strategy for the buyers is to not buy the offered high-quality product because the charged price $\theta_H q(\theta_H)$ would be too high. This necessary and sufficient condition for IC$_L$ can be simplified as $\frac{\theta_H}{\theta_L} > \frac{2s+\gamma k}{\gamma k}$.

Proof of Proposition 3: Note that $q^*(\theta) = \frac{\gamma\theta}{s+\gamma k}$ when $\gamma \leq s/k$ and $q^*(\theta) = \frac{\theta}{2k}$ when $\gamma \geq s/k$. Note also that it follows from (9) that $\mu(q, \theta_H, \theta_H) = (1-\gamma)(\theta_H q - kq^2)$ and $\mu(q, \theta_H, \theta_L) = \gamma(\theta_H - \theta_L)q + (1-\gamma)(\theta_H q - kq^2)$. Similarly, we have $\mu(q, \theta_L, \theta_L) = \mu(q, \theta_L, \theta_H) = (1-\gamma)(\theta_L q - kq^2)$.

Consider first $\gamma \leq s/k$. Substituting $q^*(\theta) = \frac{\gamma\theta}{s+\gamma k}$, we have $\mu(q^*(\theta_H), \theta_H, \theta_H) \geq \mu(q^*(\theta_L), \theta_H, \theta_L)$ if and only if $\theta_H/\theta_L \geq \Lambda_{H1} \equiv \frac{\gamma(s+k)}{(1-\gamma)s}$, and $\mu(q^*(\theta_L), \theta_L, \theta_L) \geq \mu(q^*(\theta_H), \theta_L, \theta_H)$ if and only if $\theta_H/\theta_L \geq \Lambda_L \equiv \frac{s}{\gamma k}$. Note also that neither type would like to deviate to other q, given the out-of-equilibrium belief $\hat{\theta}(q) = \theta_L$ for $q \notin \{q_H^O, q_L^O\}$. This is because: any $q > q^*(\theta_L) = \frac{\gamma\theta_L}{s+\gamma k}$ (other than q_H^O) would be rejected by the seller, $\mu(q^*(\theta_L), \theta_H, \theta_L) > \max_{q<q^*(\theta_L)} \mu(q, \theta_H, \theta_L)$ (since $\mu(q, \theta_H, \theta_L)$ is concave in q and $q^*(\theta_L) = \frac{\gamma\theta_L}{s+\gamma k} < \frac{\gamma\theta_H}{s+\gamma k} \leq \frac{\theta_H}{2k} < argmax\mu(q, \theta_H, \theta_L)$), and $\mu(q^*(\theta_L), \theta_L, \theta_L) > \max_{q<q^*(\theta_L)} \mu(q, \theta_L, \theta_L)$ (since $\mu(q, \theta_L, \theta_L)$ is concave in q and $q^*(\theta_L) = \frac{\gamma\theta_L}{s+\gamma k} \leq argmax\mu(q, \theta_L, \theta_L) = \frac{\theta_L}{2k}$). This proves the existence of the separating equilibrium for the case $\gamma \leq s/k$.

Consider then $\gamma \geq s/k$. Substituting $q^*(\theta) = \frac{\theta}{2k}$, we have $\mu(q^*(\theta_H), \theta_H, \theta_H) \geq \mu(q^*(\theta_L), \theta_H, \theta_L)$ if and only if $\theta_H/\theta_L \geq \Lambda_{H2} \equiv \frac{1+\gamma}{1-\gamma}$, and $\mu(q^*(\theta_L), \theta_L, \theta_L)$ is always higher than $\mu(q^*(\theta_H), \theta_L, \theta_H)$. In addition, neither type would like to deviate to other q, given the out-of-equilibrium belief $\hat{\theta}(q) = \theta_H$ for $q \notin \{q_H^O, q_L^O\}$. This is because $q^*(\theta_H) = \frac{\theta_H}{2k} = argmax\mu(q, \theta_H, \theta_H)$, and $q^*(\theta_L) = \frac{\theta_L}{2k} = argmax\mu(q, \theta_L, \theta_L) = argmax\mu(q, \theta_L, \theta_H)$. This proves the existence of the separating equilibrium for the case $\gamma \geq s/k$.

Note that $\Lambda_{H1} \leq \Lambda_{H2}$ if and only if $\gamma \leq s/k$. This proves the proposition.

No Other Separating Equilibrium under the O-Learning Customization: Consider the case $\theta_H/\theta_L < \min\{\Lambda_{H1}, \Lambda_{H2}\}$ (or equivalently $\gamma > \max\{\gamma_{H1}, \gamma_{H2}\}$). Suppose otherwise that there exist a separating equilibrium, (q_H, q_L), where $q_H \neq q_L$ and the equilibrium beliefs are $\hat{\theta}(q_H) = \theta_H$ and $\hat{\theta}(q_L) = \theta_L$. We first show that it must be the case that $q_L = q^*(\theta_L)$. If $q_L \neq q^*(\theta_L)$, the low-type buyers would be better off deviating from q_L to $q = q^*(\theta_L)$ under any out-of-equilibrium belief for $\hat{\theta}(q = q^*(\theta_L))$. This is because: any $q_L > \frac{\gamma\theta_L}{s+\gamma k}$ would be rejected by the seller under the equilibrium belief $\hat{\theta}(q_L) = \theta_L$, $q^*(\theta_L) = argmax_{q \leq \frac{\gamma\theta_L}{s+\gamma k}} \mu(q, \theta_L, \theta_L)$, and $\mu(q, \theta_L, \theta_L) = \mu(q, \theta_L, \theta_H)$ for any q. It follows that the high-type buyers would be better off mimicking $q_L = q^*(\theta_L)$ than playing the equilibrium strategy q_H, because $\mu(q_H, \theta_H, \theta_H)|_{q_H \leq \frac{\gamma\theta_H}{s+\gamma k}} \leq \mu(q^*(\theta_H), \theta_H, \theta_H) < \mu(q^*(\theta_L), \theta_H, \theta_L)$, where the first inequality is due to $q^*(\theta_H) = argmax_{q \le \frac{\gamma\theta_H}{s+\gamma k}} \mu(q, \theta_H, \theta_H)$ and the second inequality follows from $\theta_H/\theta_L < \min\{\Lambda_{H1}, \Lambda_{H2}\}$ (see the proof for Proposition 3).

Consider then the case $\theta_H/\theta_L < \Lambda_L$ (or equivalently $\gamma < \gamma_L \equiv \frac{s\theta_L}{k\theta_H}$). It follows from $\gamma < \gamma_L$ that $\gamma < s/k$ and hence that $q^*(\theta) = \frac{\gamma\theta}{s+\gamma k} < \frac{\theta}{2k} = argmax\mu(q, \theta, \theta)$. Suppose otherwise that there exist a separating equilibrium, (q_H, q_L), where $q_H \neq q_L$ and the equilibrium beliefs are $\hat{\theta}(q_H) = \theta_H$ and $\hat{\theta}(q_L) = \theta_L$. Given the equilibrium beliefs, we must have $q_H \le \frac{\gamma\theta_H}{s+\gamma k}$ and $q_L \le \frac{\gamma\theta_L}{s+\gamma k}$. If $q_H > q_L$, the low-type buyers would be better off deviating from q_L to q_H. This is because: $\theta_H/\theta_L < \Lambda_L$ implies $\mu(q^*(\theta_L), \theta_L, \theta_L) < \mu(q^*(\theta_H), \theta_L, \theta_H)$ (see the proof for Proposition 3), $q_L \le q^*(\theta_L) = \frac{\gamma\theta_L}{s+\gamma k} < argmax\mu(q, \theta_L, \theta_L)$, and $\mu(q, \theta_L, \theta_L) = \mu(q, \theta_L, \theta_H)$ is concave in q. If $q_H < q_L$ instead, the high-type buyers would be better off mimicking q_L: $\mu(q_H, \theta_H, \theta_H) < \mu(q_L, \theta_H, \theta_H) < \mu(q_L, \theta_H, \theta_L)$, where the first inequality is because $q_L \le q^*(\theta_L) = \frac{\gamma\theta_L}{s+\gamma k} < argmax\mu(q, \theta_L, \theta_L) < argmax\mu(q, \theta_H, \theta_H)$ and $\mu(q, \theta_H, \theta_H)$ is concave in q.

Proof of Proposition 5: When $\alpha \to 0$, we have $V^O \to \gamma(\theta_L q_L^O - k{q_L^O}^2) - s{q_L^O}^2$ and $V^B \to \gamma(\theta_L q_L^B - k{q_L^B}^2) - s{q_L^B}^2$. Note that $q_L^B \to \frac{\gamma\theta_L}{2s+2\gamma k} = argmax_q\{\gamma(\theta_L q - kq^2) - sq^2\}$ as $\alpha \to 0$ and that $q_L^O = q^*(\theta_L) = \min\{\frac{\gamma\theta_L}{s+\gamma k}, \frac{\theta_L}{2k}\} > \frac{\gamma\theta_L}{2s+2\gamma k}$, which implies $V^O < V^B$.

When $\alpha \to 1$, we have $V^O \to \gamma(\theta_H q_H^O - k{q_H^O}^2) - s{q_H^O}^2$ and $V^B \to \gamma(\theta_H q_H^B - k{q_H^B}^2) - s{q_H^B}^2$ (since q_L^B would be equal to zero). Note that $q_H^B = \frac{\gamma\theta_H}{2s+2\gamma k} = argmax_q\{\gamma(\theta_H q - kq^2) - sq^2\}$ and that $q_H^O = q^*(\theta_H) = \min\{\frac{\gamma\theta_H}{s+\gamma k}, \frac{\theta_H}{2k}\} > \frac{\gamma\theta_H}{2s+2\gamma k}$, which implies $V^O < V^B$.

When $\gamma_L \le \gamma \le \min\{\gamma_{H1}, s/k\}$, we have $q_i^O = \frac{\gamma\theta_i}{s+\gamma k}$, $i \in \{H, L\}$. This leads to $V^O = 0 < V^B$.

When $s \to 0$, we have $q_i^O = \frac{\theta_i}{2k} = q_i^S$ (if $\gamma \le \gamma_{H2} \equiv \frac{\theta_H - \theta_L}{\theta_H + \theta_L}$ such that the cheap-signaling equilibrium exists). It can then be readily shown that $V^O > V^B$.

Proof of Proposition 6: When $\alpha\theta_H \ge \theta_L$, we have $q_L^B = 0$ and hence $U_H^B = (1-\gamma)(\theta_H q_H^B - k{q_H^B}^2)$. Note that $U_H^O = (1-\gamma)(\theta_H q_H^O - k{q_H^O}^2)$. Note also that $q_H^B = \frac{\gamma\theta_H}{2s+2\gamma k} < q_H^O = q^*(\theta_H) = \min\{\frac{\gamma\theta_H}{s+\gamma k}, \frac{\theta_H}{2k}\}$ and that $\frac{\theta_H}{2k} = argmax_q\{\theta_H q - kq^2\}$, which implies $U_H^O > U_H^B$.

When $s \to 0$, both q_H^O and q_H^B converge to $\frac{\theta_H}{2k}$. It follows that $U_H^O = (1-\gamma)(\theta_H q_H^O - k{q_H^O}^2) \le U_H^B = \gamma(\theta_H - \theta_L)q_L^B + (1-\gamma)(\theta_H q_H^B - k{q_H^B}^2)$, where the inequality is strict when $q_L^B > 0$.

Proof of Proposition 7: It can be easily verified that $\Delta_H \equiv \frac{\gamma[2s+(1+\gamma)k]}{(1-\gamma)(2s+\gamma k)} < \Lambda_{H1} \equiv \frac{\gamma(s+k)}{(1-\gamma)s}$, $\Delta_H \equiv \frac{\gamma[2s+(1+\gamma)k]}{(1-\gamma)(2s+\gamma k)} < \Lambda_{H2} \equiv \frac{1+\gamma}{1-\gamma}$, and $\Delta_L \equiv \frac{2s+\gamma k}{\gamma k} > \Lambda_L \equiv \frac{s}{\gamma k}$. It follows that $\Delta > \Lambda$ if and only if $\Delta_L > \min\{\Lambda_{H1}, \Lambda_{H2}\}$, which can be reduced as $\gamma < \max\left\{\frac{2s}{2s+k}, \frac{\sqrt{s^2+4sk}-s}{2k}\right\}$.

Detailed Analysis for Ex Ante Pricing under O-Learning: We use the superscript N to denote the equilibrium outcome of this model variant of ex ante pricing. In contrast to ex post pricing in Section 3.3, the selling costs would not be sunk but would be internalized in the price negotiations. In particular, a buyer requesting q has to pay $p = kq^2 + sq^2$ (to cover the seller's full costs), but the seller would continue to charge $p = \hat{\theta}q$ (given the perceived buyer type $\hat{\theta}$), depending on who obtains the pricing power. As a result, the seller would accept the design request q from a buyer who is believed to be of type $\hat{\theta}$, if and only if $\gamma(\hat{\theta}q - kq^2 - sq^2) \geq 0$, i.e., $q \leq \frac{\hat{\theta}}{s+k}$. In addition, conditional on the true type θ and the to-be-induced type $\hat{\theta}$ (and on seller acceptance), the buyer's expected payoff of requesting q becomes

$$\mu(q, \theta, \hat{\theta}) = \gamma \max\{\theta q - \hat{\theta}q, 0\} + (1 - \gamma) \max\{\theta q - kq^2 - sq^2, 0\}.$$

By maximizing $\mu(q, \theta, \theta) = (1 - \gamma)(\theta q - kq^2 - sq^2)$, we can obtain the buyer's optimal design proposal under symmetric information, $q^{N*}(\theta) = \frac{\theta}{2s+2k}$, which would always be accepted by the seller (given $\hat{\theta} = \theta$ along the equilibrium path). Note that $q^{N*}(\theta)$ is higher (lower) than its counterpart under ex post pricing, $q^*(\theta) = \min\left\{\frac{\gamma\theta}{s+\gamma k}, \frac{\theta}{2k}\right\}$, if and only if γ is low (high). This is because, when both the production and the selling costs are internalized in the price negotiation, the seller-acceptance constraint would not be binding and the buyer's (non-constrained) optimal quality would be socially optimal (i.e., equal to q_i^S). In other words, the parties' incentives for quality design would be perfectly aligned, should the buyer's preference be symmetric information.

It can be readily shown that there exists a unique separating equilibrium in the buyers' first-stage design requests, where $q_H^N = q^{N*}(\theta_H)$ and $q_L^N = q^{N*}(\theta_L)$, if and only if $\theta_H/\theta_L \geq \Lambda_{H2} \equiv \frac{1+\gamma}{1-\gamma}$. The equilibrium qualities (q_i^N) are socially optimal and therefore higher than those under the benchmark (q_i^B) or under the A-Learning customization (q_i^A). In comparison to the case of ex post pricing (Proposition 3), $\Lambda_{H2} < \Lambda$ for relatively low γ and $\Lambda_{H2} \geq \Lambda$ for relatively high γ. It implies that the cheap-signaling equilibrium is easier (harder) to be sustained under ex ante pricing, when the seller bargaining power is relatively small (large). This is because, as the buyers' design requests would always be accepted in equilibrium by the seller, the low-type buyers' incentive compatibility constraint IC_L' would always be satisfied (akin to the scenario in Figure 2(b)), whereas the high-type buyers would have a (weakly) higher incentive to imitate the low type's design request: recall also that the low type's IC constraint would be tighter than that of the high type for relatively low γ, and vice versa for relatively high γ, when the O-Learning customization involves ex post pricing.

Moreover, the critical value of θ_H/θ_L to sustain the separating equilibrium is larger under the A-Learning customization than under the ex ant pricing variant of O-Learning customization ($\Delta > \Lambda_{H2}$) if and only if $\gamma < \frac{\sqrt{s^2+4sk}-s}{2k}$. This result is obtained by comparing Δ_L and Λ_{H2} (because $\Delta_H < \Lambda_{H2}$). It is qualitatively similar to that in Proposition 7. Nevertheless, ex ante pricing tends to reduce the endogenous viability of customization under the O-Learning approach relative to that under the A-Learning approach. That is, when $\frac{\sqrt{s^2+4sk}-s}{2k} < \gamma < \frac{2s}{2s+k}$, the threshold of θ_H/θ_L for the emergence of the separating equilibrium would be higher under the A-Learning than under the O-Learning strategy with ex post pricing, but the opposite would be true for ex ante pricing.

It is straightforward that, under the cheap-signaling equilibrium of the O-Learning customization, the ex ante pricing variant raises the seller's expected payoff in comparison to the ex post pricing variant (i.e., $V^N > V^O$). This is because the internalization of the selling costs in price negotiations can "kill two birds": the seller no longer needs to fully shoulder the selling costs, and the buyers' optimal quality requests would not be excessive anymore but become socially optimal. In the same vein, the seller's expected payoff is always higher than that under direct communication (i.e., $V^N > V^A$) and hence higher than that under the benchmark (i.e., $V^N > V^B$), contrasting Proposition 8(i) and 5, respectively. Therefore, the seller should adopt the O-Learning approach, despite the loss of the design rights, if it is feasible to force the sharing of the selling costs in ex ante contracts and to prevent price renegotiations.

The comparisons between the buyers' equilibrium expected payoffs are more ambiguous. On the one hand, the buyers need to partially bear the selling costs under ex ante pricing. On the other hand, the seller-acceptance constraint on the buyers' optimal design requests $q^{N*}(\theta)$ is always slack, which may not be the case under ex post pricing. We find that, under the cheap-signaling equilibrium of the O-Learning customization, the ex ante pricing variant improves the expected payoff of either buyer type in comparison to the ex post pricing variant (i.e., $U_i^N > U_i^O$) if and only if the seller's bargaining power is relatively low (i.e., $\gamma \leq \frac{2s^2+sk-2s\sqrt{s^2+sk}}{k^2}$). Interestingly, sharing the selling costs can benefit the buyers by aligning the parties' interests in quality design. Conversely, ex ante pricing can be harmful for either buyer type in comparison to ex post pricing (i.e., $U_i^N < U_i^O$) if and only if the seller's bargaining power is relatively high and/or the cost of selling is sufficiently low (i.e., $\gamma \geq \frac{2s^2+sk-2s\sqrt{s^2+sk}}{k^2}$ and/or $s \leq \frac{\gamma k}{1-2\sqrt{\gamma}}$). This implies that, somewhat surprisingly, it is when selling is less (rather than more) costly that the burden to share the selling costs is more likely to overshadow the relaxing of the seller-acceptance constraint so as to yield the net negative impact of ex ante pricing on the buyers' equilibrium expected payoffs. These results are because the seller's highest acceptable quality under ex post pricing, $\frac{\gamma\theta}{s+\gamma k}$, increases with the seller bargaining power γ and decreases with s.

Similarly, the expected payoff of either buyer type under the separating equilibrium can be either higher (if and only if $\gamma \leq \frac{\sqrt{s^2+sk}-s}{k}$) or lower (if and only if $\gamma \geq \frac{\sqrt{s^2+sk}-s}{k}$ and/or $s \leq \frac{\gamma^2 k}{1-2\gamma}$) under the ex ante pricing variant of the O-Learning customization than that under the A-Learning customization. Notably, in contrast to Proposition 8(iii), gaining the design rights may hurt the buyers (i.e., $U_i^N < U_i^A$) if they have to share the selling costs as an exchange. In addition, when α is not too high, we would obtain similar (ambiguous) patterns in comparing the low-type buyers' equilibrium expected payoffs between the ex ante pricing variant and the benchmark; when α is high we would have $U_L^N > U_L^B$ for any γ. The comparison of the high-type buyers' equilibrium expected payoffs is more involved due to the change in the information rent (in addition to the transfer of the design rights and the internalization of the selling costs). When the size and/or the quality preference of the high type is sufficiently high (e.g., $\theta_L \leq \alpha\theta_H$) such that the information-rent factor is negligible, it is possible that the high-type buyers' equilibrium expected payoff under the ex ante pricing variant is lower than that in the benchmark (i.e., $U_H^N < U_H^B$), which contrasts the result in the first part of Proposition 6. Moreover, when the selling cost becomes sufficiently low (i.e., $s \to 0$), the change in the equilibrium quality would be negligible (i.e., both q_H^N and q_H^B would converge to $q_H^S = \frac{\theta_H}{2k}$) and hence the impact of the information rent would be dominant. Consequently, as in the second part of Proposition 6, we would have $U_H^N \leq U_H^B$ for any γ as $s \to 0$. Thus the high-type buyers can be hurt by the O-Learning customization, despite their design rights and the beneficial effect of internalizing the selling costs (i.e., the alignment of the parties' design incentives).

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