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Competitive Customization

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We consider a duopoly market with heterogeneous customer tastes. The firms play a two-stage game. First, each firm chooses whether to invest in mass customization, which would enable it to offer customized products that increasingly match each customer's ideal product as the chosen customization level increases. A firm that chooses not to invest in mass customization serves a standard product. Second, the firms competitively price their product lines. We characterize each firm's investment in mass customization and study its dependence on competitive position, as determined by its cost efficiency and perceived quality vis-à-vis its competitor. We find that the value of mass customization critically depends on the firm's competitive position. It may not be desirable even at zero cost due to its negative effect on price competition. A firm with an overall cost and quality disadvantage never unilaterally adopts mass customization. We show that allowing firms to set different prices for each product configuration leads to a broader adoption of mass customization compared to when they are restricted to uniform prices. However, a firm's chosen customization level may be higher with uniform prices. Our analysis also helps a customizing firm determine whether to target its process improvement efforts for a lower cost or a higher customization level.

Key words: mass customization; product differentiation; price differentiation; customization level; competition
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1. Introduction

Advances in manufacturing and information technologies have increased the interest of both practitioners and academics in *mass customization* (MC), the ability to create individually customized products at a cost that is on par with the cost of mass production (Tseng and Jiao 2001). The concept of MC has been known for decades (Davis 1987, Pine 1993), and there are well-known working examples such as Dell, Lands' End (Piccoli et al. 2003), mi adidas (Seifert 2002), and National Bicycle (Kotha 1995).[1] On the other hand, firms such as Levi Strauss and Mattel have experimented with MC and abandoned these initiatives, and mass-customizers such as Cmax.com, selling customized sports shoes, and Reflect.com, selling custom beauty products, have gone out of business. Notwithstanding claims that it will become a competitive necessity (Pine 1993), customizers do not always compete effectively against more traditional firms, and much of the promise of MC still lies in the future.

Indeed, when MC pays off has been an important research question; there is a growing discussion on its limits and drawbacks (Huffmann and Kahn 1998, Ahlström and Westbrook 1999, Agrawal et al. 2001, Zipkin 2001, Piller et al. 2004). We think that at this juncture it is fruitful to develop a theory that explains what factors drive the adoption of MC under competition. While we identify a number of such factors, perhaps our most important result is that the value (and consequent adoption) of MC depends on the firm's traditional strengths vis-à-vis its competition. Our results suggest that MC by itself cannot create competitive advantage; what it can do is give firms with an existing traditional (cost or quality) advantage further leverage to increase their profits and improve their market positions.[2] Thus, MC is not an

[1] Other examples and recent advances in MC practice can be found in Tseng and Piller (2003).

[2] In our model, a firm's traditional advantage is captured by its margin advantage, which is determined by the firm's perceived

effective competitive strategy for a firm with an inferior cost or quality position. Such a firm should focus on improving its traditional operations (e.g., reducing variable costs) rather than on implementing MC. This is in contrast to a monopoly, which can increase its profit by investing in either improving its traditional operations or in MC.

Firms have to decide not only whether to customize their products but also the level of customization. For example, Home Depot lets customers choose the color of its rugs but not the motif, whereas Rug Rats, a Farmville, Virginia, manufacturer, customizes both the color and the motif (*Wall Street Journal* 2004). NikeID offers custom-colored sneakers and allows customers to imprint their names on the shoe, but it does not offer customized fit (width, length, etc.), whereas mi adidas offers customized fit in addition to customized colors and imprinted names. In the case of apparel, customization can take multiple forms from incorporating simple customer input of different measurements to custom design using sophisticated body scanners. Likewise, the study by Ulrich et al. (1998) of the bicycle industry shows that bicycle manufacturers differ in their customization levels. Because choosing the right customization level has become an important strategic decision, we also study this here.

In current practice, firms are often restricted to a uniform price due to lack of information on customers' willingness to pay as well as other rigidities. However, it has been suggested that the most advanced forms of MC will combine product customization with price customization (cf. Piller and Stotko 2002) and perhaps other dimensions of the marketing mix (Wind 2001).[3] Indeed, firms selling customized information goods often resort to price differentiation (Shapiro and Varian 1998). Whether more firms will adopt such practices depends on the value of price differentiation for firms that offer customized products. We thus compare the case where MC is associated with price differentiation to the case where the customizing firm must sell all product configurations at the same price. We study how price differentiation affects the market outcomes and what factors affect its value for the customizing firm.

1.1. Overview of Results

The core issues studied in this paper are the following:

(i) When should a firm customize and to what extent? How does the result depend on the firm's competitive position?

(ii) What will be the structure of markets where competing firms can acquire MC capabilities?

(iii) How do the answers to these questions depend on the MC firms' ability to offer different product configurations at different prices?

To address these issues, we consider a market with heterogeneous customer tastes served by a duopoly. In the first stage, each firm decides whether to adopt MC as well as its customization level. It provides increasingly better matching products to its customers' tastes as its chosen customization level increases. A firm may also choose not to invest in customization and to sell a standard product. In the second stage, the firms competitively price their products. We consider two scenarios with regard to customizing firms' pricing policies. They may be restricted to a uniform price, or they may set a different price for each customized product configuration. We solve for the resulting equilibria, and study and compare them for both scenarios.

We find that firms considering MC should carefully assess their competitive positions before jumping on the MC bandwagon. MC may not be desirable in a competitive market even at zero cost, due to its adverse effect on price competition. Specifically, MC is beneficial only for a firm with a sufficiently strong competitive position, which is determined by its perceived quality and cost efficiency vis-à-vis its competitor. We show that, in equilibrium, a firm with an overall cost and quality disadvantage never unilaterally adopts MC.

Turning to the equilibrium market structure, when firms are restricted to uniform prices there is room for at most one customizing firm in the market. On the other hand, allowing the firms to set price menus for each product configuration may compel both to adopt MC. In general, allowing price menus leads to a wider adoption of MC. However, a firm's chosen customization level can be higher under uniform prices. We also

quality and cost vis-à-vis its competition. This is defined explicitly in §2.

[3] Additional references on this point are cited in the review of the literature, below.

Table 1 Modeling Assumptions for Related Papers on MC

	Firms			Product/price customization		Choice between standard/custom products driven by	
Papers	Monopoly	Symmetric duopoly	Asymmetric duopoly	Product only	Price and product	Competitive position	Customer characteristics
This paper	✓	✓	✓	✓	✓	✓	✓
Jiang et al. (2006)	✓				✓		✓
Syam et al. (2005)		✓		✓			✓
Syam and Kumar (2006)		✓		✓			✓
Alptekinoğlu and Corbett (2008)	✓	✓	✓	✓		Determined exogenously	
Dewan et al. (2003)	✓	✓			✓		✓

find a degree of substitutability between product and price customization, showing that the additional benefit of price customization on top of product customization decreases as a firm achieves a higher level of product customization.

Finally, our results may help a customizing firm determine whether to target its process improvement efforts for a lower cost or a higher customization level. We show that the choice is tilted in favor of customization as the firm's competitive position gets stronger, and vice versa. In other words, cost efficiency is largely driven by the firm's incentive to protect its market share from competition, whereas customization flexibility is largely driven by the firm's desire to extract more surplus from its customers.

1.2. Literature Review

A number of papers have looked at related issues; their key modeling assumptions are summarized and compared in Table 1. Here, we highlight the differences between their results and ours, as well as the drivers of these differences. As is clear from the table, these papers could not address our core issue, the effect of the pricing regime on the adoption of MC, because each of them assumes either uniform or differential prices, but not both. Furthermore, all but Alptekinoğlu and Corbett (2008) assume symmetric firms and hence cannot address the effect of a firm's competitive position on its customization choices (see core issue (i)). Alptekinoğlu and Corbett (2008) study conditions under which a firm that sells standard products can coexist with one that sells custom products, finding that the standard firm may survive even when it is at a cost disadvantage. Our results show that this is driven by the pricing regime and will never happen when the customizing firm can set differential prices.[4]

Studying information goods, Dewan et al. (2003) find that simultaneous adoption of customization in a duopoly does not intensify price competition, which is in contrast to our findings. This is driven by the fact that in their model, unlike ours, custom products do not compete head to head due to the firms' nonoverlapping customization spans. Similar to Dewan et al. (2003), Syam et al. (2005) and Syam and Kumar (2006) assume symmetric firms with zero production costs and examine MC from a marketing perspective, focusing on the effects of consumer preferences. Syam et al. (2005) consider a product with two attributes and study which attributes will be customized in a duopoly equilibrium. They find that, depending on consumers' cognitive burden, either both firms customize their products or both sell only standard products, and when they customize, both do so for only one attribute. In contrast, we identify equilibria where only one firm sells customized products, and any degree of customization is possible, including complete customization, depending on the firms' margins. Both differences are due to the fact that Syam et al. (2005) assume symmetric firms, whereas the margin differences between the firms are key drivers of our results. Syam and Kumar (2006)

[4] Specifically, their analysis corresponds to pricing game (CU, T) in Lemma 1. In contrast, in pricing game (CM, T) in Lemma 1, a standard firm with a cost disadvantage cannot survive. In a different line of research, incorporating inventory and congestion dynamics, Mendelson and Parlaktürk (2005) also study the competition between a firm that sells standard products and a firm that sells custom products.

consider two consumer segments with different transportation cost parameters, i.e., sensitivities to product misfit; they study the firms' choice of customization level in a duopoly. They find that the firms choose the same customization level unless the gap between the two consumer segments is sufficiently large. In our model, all consumers have the same transportation cost parameter, but the firms choose asymmetric customization levels. Syam and Kumar (2006) find that when the gap between the segments is sufficiently large, only one firm sells customized products. However, the choice of firm is arbitrary, whereas in our model the firms' customization decisions are driven by their relative competitive positions. Clearly, when the drivers of MC are differences between the firms, these drivers cannot be identified when the firms are completely symmetric. Furthermore, allowing for different costs and customization levels enables us to study the trade-off between improving customization level and unit cost, which, along with the substitutability between price and product customization, cannot be analyzed in the above papers.

As seen in Table 1, there is no consensus in the literature on the use of price differentiation in conjunction with MC. Studies of flexible manufacturing in the economics literature (cf. Eaton and Schmitt 1994, Norman and Thisse 1999) take for granted that products customized for horizontal (taste) attributes are sold at different prices. When the product being customized is essentially information, price differentiation is often applied in practice (Shapiro and Varian 1998, Liechty et al. 2001, Aron et al. 2005). Piller and Stotko (2002) suggest that there are different degrees of MC, with the most advanced taking advantage of both product and price customization. Similarly, Riemer and Totz (2003) discuss how MC can be used to combat uniform pricing through the individualization of both products and prices. Wind (2001) and Wind and Rangaswamy (2001, p. 13) suggest that "customerization" is "the next revolution in MC," moving from product customization to marketing customization, with customized pricing being an important element of the marketing mix (see also Slywotzky et al. 2000).

Price customization has attracted more attention than product customization in the economics and marketing literature (see reviews in Varian 1989 and Stole 2007). Thisse and Vives (1988) and Fudenberg and Tirole (2000) study the effect of customized prices on price competition and analyze its impact on firm profits and consumer welfare. Contrary to basic intuition, these papers find that firms may not benefit from customized prices, identifying a prisoner's dilemma. The marketing literature on targeted pricing reaches similar conclusions (Shaffer and Zhang 1995, 2002). Liu and Zhang (2006) show that targeted prices may not be beneficial even for a monopoly retailer when the manufacturer's pricing is taken into account. Acquisti and Varian (2005) show that a monopolist may benefit from targeted pricing based on purchase history, and Choudhary et al. (2005) study how such pricing affects the quality choice of two competing firms. Because these papers do not consider product customization, however, they cannot address our core research questions.

MC enables a firm to postpone product differentiation after receiving customer orders. Anand and Girotra (2006), Goyal and Netessine (2006), and Röller and Tombak (1993) study the effect of competition on postponement strategies in different contexts. Eaton and Schmitt (1994) show that a flexible manufacturing system (FMS), which allows for product and price customization, promotes concentration, and Norman and Thisse (1999) show that the introduction of FMS can lead to more aggressive pricing policies, although this may deter entry and not benefit consumers. Finally, Balasubramanian (1998) analyzes the price competition between a direct seller with endogenous market coverage and multiple traditional marketers, showing that under certain assumptions the direct seller chooses to target only a fraction of the market even if it is costless to target the entire market.

The remainder of this paper is as follows. We describe our model in §2 and characterize the pricing equilibrium in §3. We discuss the competitive value of MC in §4 and characterize the investment equilibrium in §5. We consider a customizing firm's choice between improving its unit cost and its customization level in §6. Our concluding remarks are in §7. All proofs are in the online supplement.[5]

[5] An online supplement to this paper is available on the *Manufacturing & Service Operations Management* website (http://msom.pubs.informs.org/ecompanion.html).

Table 2 Notation and Parametric Assumptions

Symbols		Assumptions
θ	Customer type	$\theta \in [0, 1]$
ζ	Base product type	$\zeta \in \{0, 1\}$
r	Intensity of customer preferences	$r < (m_1 + m_2)/3$
w	Reservation value	$w > 0$
p	Unit price	
c	Unit cost	
m	$w - c$, Maximum margin	$m > 0$
k	Customization level	$k \in [0, 1]$
Π	Profit before investment cost	
$S(k)$	Fixed cost of achieving customization level k	$S(k) > 0, S'(k) \geq 0, S''(k) \geq 0$ for $k \in [0, 1]$
T	Traditional firm	
CU	Customizing firm with a uniform price	
CM	Customizing firm with menu prices	

2. Model

We consider a market with two firms serving customers with heterogeneous preferences for product attributes. Similar to Chen et al. (1998) and De Groote (1994), we model these preferences along the Hotelling Line (cf. Hotelling 1929, Lancaster 1990). Each customer's ideal product $\theta \in [0, 1]$ is represented by the customer's location on the unit interval.[6] Each firm has a base product $\zeta \in \{0, 1\}$, and the firms' base products are located at the opposite ends of the unit interval, a standard assumption in Hotelling-based competition models (cf. Tirole 1988, Chapter 7). The distance between a customer and the firm's product position results in disutility or customer sacrifice relative to her preferred product configuration (Pine 1993). However, a firm can lessen or eliminate the customer sacrifice by customizing its product. In the remainder of this section, we specify our demand model, the firms' costs and decisions, and describe how they compete. Our notation and parametric assumptions are summarized in Table 2.

2.1. Demand

Customers are uniformly distributed over $[0, 1]$ and have a total mass of 1. Each customer decides whether to buy the product and from what firm after observing the firms' products, prices, and customization levels. If buying the product yields positive utility, the customer purchases only one unit from the firm that provides the highest utility.

The utility of a type-θ customer from base product ζ is given by

$$U(\theta, \zeta) = w_i - p_i - r|\theta - \zeta|. \quad (1)$$

The reservation value w_i is the customer's willingness to pay for her ideal product, where each firm i can have a different reservation value due to superiority in product quality or service. The customer's utility decreases by p_i, the unit price of the product, and it decreases further by $r|\theta - \zeta|$, the disutility of misfit due to the customer's sacrifice from her ideal product, where $r \in R^+$ represents the intensity of customer preferences and $|\theta - \zeta|$ is the distance from the customer's ideal product.

We extend the classical Hotelling framework to incorporate customization, which reduces or eliminates customer sacrifice. Specifically, the customer's utility from a customized product is given by

$$U(\theta, \zeta, k_i) = w_i - p_i - r(1 - k_i)|\theta - \zeta|. \quad (2)$$

The utility function in (2) is the same as in Syam and Kumar (2006), where the level of customization $k \in [0, 1]$ represents the percentage of relevant attributes that the MC firm can customize. As k increases, the firm customizes more attributes and thus provides better-matching products to its customers. When $k = 1$, the MC firm customizes all relevant attributes and eliminates the customer sacrifice altogether, providing each customer with her ideal product.

Indeed, a firm may offer a higher customization level by customizing more product attributes. For instance, apparel manufacturers can provide better physical and fashion fit by customizing more attributes such as the color, rise, front pocket style, leg, waist, inseam, and seat shape of their pants. Similarly, kitchen cabinet manufacturers can increase the level of customization by customizing more attributes such as the type of wood, molding style, finishing (color, lacquer, and distressing), hardware (nickel, brass, etc.), and type of glass used in the cabinets (Lihra et al. 2005).

Equation (2) assumes that an MC firm knows the customer types and offers each customer the product

[6] This is also known as horizontal or spatial product differentiation (cf. Tirole 1988, Chapter 7). See Lancaster (1979) for a discussion of mapping location models to characteristics spaces.

customized for her type, rather than a product customized for another type. This is clearly the optimal policy when the customer types are observable, as is often the case when the customer visits a brick and mortar store or when the firm inspects the customer's premises prior to customization. It is also interesting to study the case where the customer type is known to the consumer but not to the firm. This is analyzed in Appendix B. Mainly, we find that asymmetric information does not change our insights. However, a pure-strategy equilibrium does not always exist in that setting.

2.2. Firm's Costs and Decisions

Each firm decides whether to adopt MC and its customization level. A firm that does not adopt MC is called a *traditional* firm (T). A traditional firm does not customize its product; i.e., it has $k = 0$. It sells only its base product and sets a uniform price. On the other hand, a firm that adopts MC is called a *customizing* firm (CM or CU). We consider two alternative scenarios with regard to a customizing firm's pricing policy. Under the uniform price scenario a customizing firm (CU) is restricted to a uniform price. Under the menu price scenario, a customizing firm (CM) can set a different price for each customized product configuration. Thus, all customers receive the same price under uniform prices, whereas each customer may receive a different price under menu prices.

A firm that does not adopt MC does not incur any investment cost, whereas a firm that chooses to adopt MC incurs a fixed cost $S(k) > 0$ to achieve customization level $k \in [0, 1]$, which enables it to decrease the customer sacrifice by a factor of k.[7] We assume that $S(k)$ is convex and nondecreasing in k. Each firm incurs a unit production cost c, which can be different across firms due to differences in the efficiency of their processes. In the spirit of MC's premise of achieving mass-production efficiency (Tseng and Jiao 2001, Pine 1993), we assume that adopting MC entails only a fixed cost and does not affect the firm's marginal cost. We define a firm's *maximum margin* $m = w - c$ by the difference between its reservation value and its unit cost, which determines its overall competitive position. Finally, to avoid trivial cases, we assume that $m > 0$ for all firms.

[7] In particular, we assume $S(0) > 0$, reflecting the firm's commitment to offer customized products.

2.3. Competition

We characterize the firms' investments in MC as well as their chosen customization levels and study how these decisions are affected by competitive factors. Specifically, we consider two firms serving base products $\zeta_1 = 0$, $\zeta_2 = 1$ with reservation values w_1, w_2 and unit costs c_1, c_2 resulting in maximum margins $m_i = w_i - c_i$. We define a firm's *margin advantage* as its maximum margin in excess of its competitor's ($m_i - m_j$ for firm i). We say that firm i has a margin advantage (disadvantage) when $m_i \geq m_j$ ($m_i < m_j$). By definition, $m_i - m_j = (w_i - w_j) - (c_i - c_j)$, where we interpret the first term as the quality differential and the second term as the cost differential between the firms.

We assume that the intensity of customer preferences r is sufficiently small to avoid the trivial cases, where each firm has a local monopoly over its loyal customers (in its neighborhood) and there is no competition. Formally, we assume that $r < (m_1 + m_2)/3$, which guarantees that the market is strictly covered in equilibrium and that firms compete. We say that the market is strictly covered under prices p_1, p_2 if there exists $\epsilon > 0$ such that all customers buy a product under prices $p_1 - \epsilon$ and $p_2 - \epsilon$.

The order of events is as follows. The firms first make their investments in customization by deciding whether to adopt MC and at what level; i.e., they choose customization level k. We assume that a firm breaks all ties in favor of a higher customization level. Following the investment decisions, the firms price their products. We consider two alternative scenarios. Under uniform prices, the firms simultaneously set uniform prices for all product types. Under menu prices the firms first set the price of their base products and then the customizing firms (if any) set the price premiums for their customized products, i.e., $p(\theta)$, $\theta \neq \zeta$.[8] After the prices are set, customers

[8] The order of events is the same as in Thisse and Vives (1988) in which the firm that sets a price menu follows the firm that sets a uniform price. When a CM-firm competes with a T-firm, simultaneous moves in pricing would not yield a pure strategy equilibrium with *undominated* strategies (firms not setting prices below their costs) and positive market shares for both firms. This is also pointed out by Thisse and Vives (1988) for their model.

make their purchasing decisions. Thus, a firm chooses between T and CU or between T and CM. If a firm is to choose between CU and CM, it is straightforward to show that CM always dominates CU; i.e., a customizing firm always prefers a price menu to a uniform price. In this case, the firms may get trapped in a prisoner's dilemma, with both firms preferring CU but choosing CM in equilibrium.

We study the subgame perfect Nash equilibrium (SPNE) using backward induction. We consider two consecutive games. In the adoption game, firms choose their investments in MC. In the pricing game, firms competitively set their prices. We begin by solving the pricing game for each outcome of the adoption game.

3. Pricing Game

Once the firms set their prices, customers make their buying decisions. Specifically, a type-θ customer buys from firm i if $U(\theta, p_i, \zeta_i, k_i) > \max(0, U(\theta, p_j, \zeta_j, k_j))$. We assume that customers break all ties in favor of the socially efficient outcome, choosing the firm with a larger profit margin. When every customer buys a product, the marginal customer θ^m is given by $U(\theta^m, p_1, \zeta_1, k_1) = U(\theta^m, p_2, \zeta_2, k_2)$ such that customers $\theta < \theta^m$ buy from Firm 1 and customers $\theta > \theta^m$ buy from Firm 2, leading to market shares θ^m and $1 - \theta^m$.

A firm sets its price policy to maximize its total profit. In particular, T- and CU-firms set their prices to maximize the product of their profit margin and market share. On the other hand, a CM-firm sets the maximum price for each configuration that leaves its customers indifferent to their next best alternative (either buying from the other firm or not buying at all), as long as this price is above its unit cost. When this price is below its unit cost, the price for that configuration is set equal to the unit cost. Let Π_i be firm i's profit from sales, i.e., its profit before subtracting the investment cost. The following lemma summarizes the firms' equilibrium prices p_i and profits Π_i in each pricing game when both firms have a positive market share.[9] In general, one firm might dominate the market, leaving zero market share for its competitor; the general statement of the lemma that covers this case is stated in the online appendix.

Lemma 1. *In the pricing game, the firms' equilibrium prices and profits when both firms have positive market shares are shown in Table* 3.

Lemma 1 shows that the competitor's price decreases—that is, the intensity of price competition increases as a firm moves from T to CU and on to CM. Ultimately, two CM-firms are locked in Bertrand competition for each customer type, with one firm always setting its price equal to its unit cost. Furthermore, the lemma shows that the region in which both firms have positive market shares shrinks; that is, survival becomes harder as firms move from T to CU and on to CM.[10]

We next study the firms' investments in MC given the resulting pay-offs in the pricing game. We first discuss the competitive value of MC (§4) that helps form the best responses in the adoption game. We then characterize and discuss the equilibrium of the adoption game (§5).

4. Competitive Value of MC

MC helps a firm create value for its customers, and helps a monopoly extract more surplus from its customers (monopoly results are in Appendix A). However, when a firm adopts MC in duopoly competition, its competitor sets a more aggressive price in response, which limits the firm's gain from customization.

We study the value of MC in two different settings, depending on the type of competitor, i.e., a traditional or a customizing firm. Let $\Pi_i^{v,u}$ denote firm i's pay-off in the pricing game (profit before investment cost). Firms i and j follow strategies v and u, respectively, where v, u: T, CU, CM. We define

$$\begin{aligned} \Delta_1^v(k_1) &= \Pi_1^{v,\mathrm{T}}(k_1) - \Pi_1^{\mathrm{T},\mathrm{T}}, \\ \delta_1^v(k_1, k_2) &= \Pi_1^{v,v}(k_1, k_2) - \Pi_1^{\mathrm{T},v}(k_2), \end{aligned} \qquad v\text{: CU, CM}, \quad (3)$$

[9] We state the result for the (T, T) pricing game which coincides with Tirole (1988) for completeness. The special case $k_1 = 1$ under the (CU, T) pricing game is consistent with Alptekinoğlu and Corbett (2008).

[10] For the special case $k_1 = 1$ (i.e., perfect customization), in line with Alptekinoğlu and Corbett (2008), a traditional firm can earn a positive market share even with a cost disadvantage in the (CU, T) game. In contrast, we find that it cannot survive with a cost disadvantage in the (CM, T) game.

Table 3 Equilibrium of the Pricing Game

Pricing game	Region where both firms have positive market shares	Equilibrium prices and profits in the pricing game
(T, T)	$-3 < \frac{m_1 - m_2}{r} < 3$	$p_1 = \frac{m_1 - m_2 + 3r}{3} + c_1, \quad p_2 = \frac{m_2 - m_1 + 3r}{3} + c_2,$ $\Pi_1 = \frac{(m_1 - m_2 + 3r)^2}{18r}, \quad \Pi_2 = \frac{(m_2 - m_1 + 3r)^2}{18r}$
(CU, T)	$-(3 - k_1) < \frac{m_1 - m_2}{r} < (3 - 2k_1)$	$p_1 = \frac{m_1 - m_2 + (3 - k_1)r}{3} + c_1, \quad p_2 = \frac{m_2 - m_1 + (3 - 2k_1)r}{3} + c_2,$ $\Pi_1 = \frac{(m_1 - m_2 + (3 - k_1)r)^2}{9(2 - k_1)r}, \quad \Pi_2 = \frac{(m_2 - m_1 + (3 - 2k_1)r)^2}{9(2 - k_1)r}$
(CU, CU)	$-(3 - k_1 - 2k_2) < \frac{m_1 - m_2}{r} < (3 - 2k_1 - k_2)$	$p_1 = \frac{m_1 - m_2 + (3 - k_1 - 2k_2)r}{3} + c_1,$ $p_2 = \frac{m_2 - m_1 + (3 - 2k_1 - k_2)r}{3} + c_2,$ $\Pi_1 = \frac{(m_1 - m_2 + (3 - k_1 - 2k_2)r)^2}{9(2 - k_1 - k_2)r}, \quad \Pi_2 = \frac{(m_2 - m_1 + (3 - 2k_1 - k_2)r)^2}{9(2 - k_1 - k_2)r}$
(CM, T)	$-(3 - k_1) < \frac{m_1 - m_2}{r} < (1 - k_1)$	$p_1(\theta) = [m_1 - m_2 + r - (2 - k_1)\theta r]^+ + c_1,$ $p_2 = \frac{m_2 - m_1 + (1 - k_1)r}{2} + c_2,$ $\Pi_1 = \frac{(m_1 - m_2 + (3 - k_1)r)^2}{8(2 - k_1)r}, \quad \Pi_2 = \frac{(m_2 - m_1 + (1 - k_1)r)^2}{4(2 - k_1)r}$
(CM, CM)	$-(1 - k_2) < \frac{m_1 - m_2}{r} < (1 - k_1)$	$p_1(\theta) = [m_1 - m_2 + (1 - k_2)r - (2 - k_1 - k_2)\theta r]^+ + c_1$ $p_2(\theta) = [m_2 - m_1 - (1 - k_2)r + (2 - k_1 - k_2)\theta r]^+ + c_2$ $\Pi_1 = \frac{(m_1 - m_2 + (1 - k_2)r)^2}{2(2 - k_1 - k_2)r}, \quad \Pi_2 = \frac{(m_2 - m_1 + (1 - k_1)r)^2}{2(2 - k_1 - k_2)r}$

so Δ_1 (or δ_1) measures the change in Firm 1's profit in the pricing game after it adopts MC against a traditional firm (or a customizing firm with k_2). Δ_2 and δ_2 are defined similarly.

Propositions 2 and 3 characterize Δ and δ, describing when MC has positive returns.

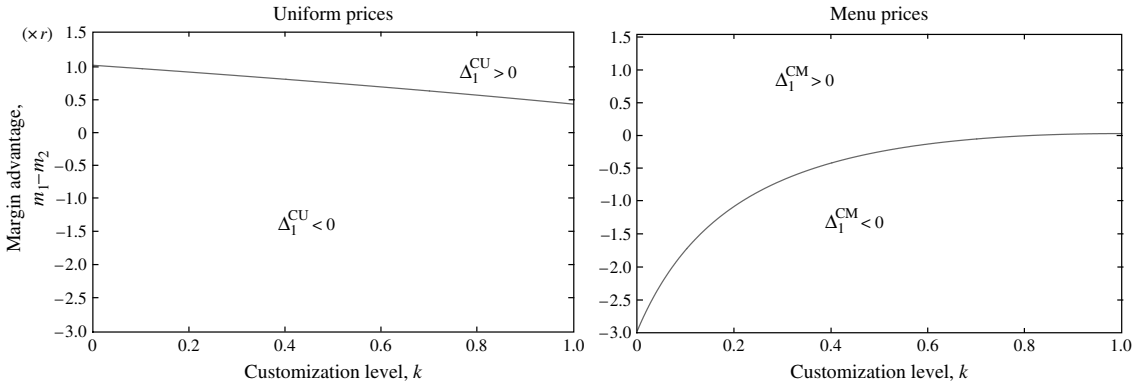
Proposition 2. (i) $\Delta_i^{\mathrm{CM}}(k_i) \geq 0$ *if and only if* $m_i - m_j \geq f(k_i)$, *where* $f(k) = 3((2\sqrt{2-k} - 1)k - 1)r/(1 + 4k)$ *such that* $f(k) \leq 0$ *for* $0 \leq k \leq 1$.

(ii) $\Delta_i^{\mathrm{CU}}(k_i) \geq 0$ *if and only if* $m_i - m_j \geq g(k_i)$, *where* $g(k) = (\sqrt{2(2-k)} - 1)r$ *such that* $g(k) \geq 0$ *for* $0 \leq k \leq 1$.

By Proposition 2, adoption of MC may be detrimental to the firm because it intensifies price competition. In particular, firm i cannot benefit from adopting MC unless the margin differential $m_i - m_j$ is sufficiently favorable (which in turn depends on the quality and cost differential between the two firms, $m_i = w_i - c_i$). The intuition behind this result is as follows: When a firm adopts MC, its traditional competitor drops its price to defend its turf. When the margin differential $m_i - m_j$ is sufficiently favorable for firm i, it can make money while dropping its price in response to its traditional competitor. Therefore, in this case MC is profitable in spite of the competitor's price drop. On the other hand, when the margin differential $m_i - m_j$ is not sufficiently favorable for firm i, its competitor's price response makes adopting MC a losing proposition.

Figure 1 shows the sign of the value of adopting MC Δ_1 as a function of the firm's margin advantage and customization level. The figure shows that there is a quality and cost prerequisite (relative to the competitor) below which a firm never benefits from customizing its product. This threshold is higher when the firm is restricted to a uniform price. However, the gap decreases in the customization level. When restricted to a uniform price, the firm with the mar-

Figure 1 Value of Adopting MC Against a Traditional Competitor Under Uniform and Menu Prices



Note. The vertical axes are scaled with r, the intensity of customer preferences, so the figures show the value of MC for *any* set of parameters.

gin disadvantage ($m_1 < m_2$ for Firm 1) is always better off staying as a traditional firm. In contrast, when the firm is allowed to set a price menu for different product types, MC is always valuable to a firm with the margin advantage ($m_1 \geq m_2$ for Firm 1).

Proposition 3 describes the value of adopting MC against a customizing competitor.

Proposition 3. (i) $\delta_i^{CM}(k_i, k_j) \geq 0$.

(ii) $\delta_i^{CU}(k_i, k_j) \geq 0$ *if and only if* $m_i - m_j \geq h(k_i, k_j)$, *where* $h(k_i, k_j) = (\sqrt{(2-k_i-k_j)(2-k_j)} - (1-k_j))r$ *such that* $h(k) \geq 0$ *for* $0 \leq k \leq 1$.

Proposition 3(i) shows that when the firms set different prices for each product type, adopting MC always increases a firm's pay-off in the pricing game against a customizing competitor. Intuitively, the firm need not worry about the adverse effect of adopting MC on the pricing game because its customizing competitor will set the most aggressive pricing policy regardless, lowering the price to marginal cost whenever necessary to win every niche. On the other hand, when the firms are restricted to a uniform price, adopting MC has an adverse effect on the pricing game, inducing the customizing competitor to set a lower price. Proposition 3(ii) shows that the firm can benefit from customization only if it has a margin advantage.

4.1. Additional Value of Price Customization

The additional value of price customization, which is given by $\Pi_1^{CM,T} - \Pi_1^{CU,T}$, decreases in the firm's product customization level k when both firms have positive market shares. The customers' willingness to pay becomes more homogeneous as the firm's product customization level improves and the benefit of setting different prices decreases.

For a monopoly, the benefit of price customization vanishes when the firm achieves the perfect product customization, $k = 1$. In contrast to the monopoly, the value of price customization does not vanish even when $k = 1$ in competition. Price flexibility has an additional benefit, as it enables the firm to set competitive prices for product configurations that are closer to the competitor's base product while keeping higher prices for more remote products.

5. Adoption Game

In this section, we characterize the equilibrium of the adoption game where the firms decide whether to customize their products and, if so, to what customization level. Specifically, a firm incurs a nondecreasing fixed cost $S(k)$ to be able to customize its product with customization level k. Some additional notation is useful for describing the equilibrium. We define for v: CU, CM,

$$\begin{aligned} \hat{\Delta}_1^v &= \max_{0\leq k_1\leq 1} [\Pi_1^{v,T}(k_1) - \Pi_1^{T,T} - S(k_1)], \\ \hat{\delta}_1^v(k_2) &= \max_{0\leq k_1\leq 1} [\Pi_1^{v,v}(k_1, k_2) - \Pi_1^{T,v}(k_2) - S(k_1)], \end{aligned} \tag{4}$$

where $\hat{\Delta}_1$ denotes Firm 1's maximum profit from adopting MC against a traditional competitor. Likewise, $\hat{\delta}_1(k_2)$ is the maximum profit against a customizing competitor with customization level k_2. Parallel notation is defined for Firm 2.

In addition, let $k_i^{v,u}$ denote firm i's equilibrium customization level in a (v, u) game, that is, when

firms i and j follow v and u, respectively. When only one firm adopts customization either in (CU, T) or in (CM, T), k is unique, as firms break all ties in favor of a higher customization level. In (CM, CM), the equilibrium customization levels need not be unique and $K^{\mathrm{CM,CM}}$ shows the set of equilibrium (pure strategy) customization levels.[11] Finally, (CU, CU) is never an equilibrium, so we need not define $k^{\mathrm{CU,CU}}$. We are now ready to state the equilibrium.

Proposition 4. *Let* $m_1 \geq m_2$. *The* SPNE *of the adoption game is as follows*

(i) *For uniform prices*: (T, T) *if* $\hat{\Delta}_1^{\mathrm{CU}} < 0$, (CU, T) *otherwise*.

(ii) *For menu prices*:

	$\hat{\Delta}_1^{\mathrm{CM}} < 0$	$\hat{\Delta}_1^{\mathrm{CM}} \geq 0$
$\hat{\delta}_2^{\mathrm{CM}}(k_1^{\mathrm{CM,T}}) < 0$	(T, T)	(CM, T)
$\hat{\delta}_{\min}^{\mathrm{CM}} < 0 \leq \hat{\delta}_2^{\mathrm{CM}}(k_1^{\mathrm{CM,T}})$	(T, T)	*No pure strategy equilibria*
$0 \leq \hat{\delta}_{\min}^{\mathrm{CM}}$	(CM, CM) & (T, T)	(CM, CM)

where $\hat{\delta}_{\min}^{\mathrm{CM}} = \sup_{k \in K^{\mathrm{CM,CM}}} \min(\hat{\delta}_1^{\mathrm{CM}}(k_2), \hat{\delta}_2^{\mathrm{CM}}(k_1))$.

Notice that when $\hat{\Delta}_1^{\mathrm{CM}} \geq 0$ and $\hat{\delta}_{\min}^{\mathrm{CM}} < 0 \leq \hat{\delta}_2^{\mathrm{CM}}(k_1^{\mathrm{CM,T}})$, a pure strategy equilibrium does not exist. This is because Firm 1 prefers to adopt MC if and only if Firm 2 does not adopt MC, because $\hat{\Delta}_1^{\mathrm{CM}} \geq 0$ and $\hat{\delta}_{\min}^{\mathrm{CM}} < 0$. However, Firm 2 follows if Firm 1 adopts MC, as $\hat{\delta}_2^{\mathrm{CM}}(k_1^{\mathrm{CM,T}}) \geq 0$.

Proposition 4 shows that a firm with a margin disadvantage never unilaterally adopts MC in equilibrium. (Figure 2 displays the equilibrium for one example.) The intuition for this result follows from the analysis of Proposition 2: Contemplating that its competitor will drop its price to protect its turf, the firm needs to consider the value of MC in the face of such a price drop. When the firm has a sufficiently large margin advantage, it can make money while dropping its price in response to its traditional competitor. However, when the firm has a margin disadvantage, its competitor's price response always makes adopting MC unprofitable.

This competitive effect depends on the customizing firm's pricing regime. Under menu prices, the competitor's lead may compel both firms, including the firm with a margin disadvantage, to adopt MC. Intuitively, when competing against a CM-firm, the firm does not need to worry about the effect of its decision on the price competition because the CM-competitor cannot further drop its prices—which are already set at cost—to attract new customers. However, when competing against a CU-firm, the firm considers the effect on price competition and it does not adopt MC even at zero cost.

As a special case, when the firms have symmetric margins no firm unilaterally adopts MC in equilibrium. This is formalized in the following corollary.

Corollary 5. *Let* $m_1 = m_2$.

(i) *For uniform prices*: (T, T) *is the unique* SPNE.

(ii) *For menu prices*: (T, T) *and* (CM, CM) *are the only* SPNE; *i.e.*, (CM, T) *or* (T, CM) *are never* SPNE.

Proposition 4 shows that allowing firms to set price menus for different configurations leads to a wider adoption of MC because the firms can better take advantage of their customized product lines. Specifically, MC is adopted under menu prices, but not under uniform prices, when $\hat{\Delta}_1^{\mathrm{CU}} < 0 \leq \max(\hat{\Delta}_1^{\mathrm{CM}}, \hat{\delta}_{\min}^{\mathrm{CM}})$ for $m_1 \geq m_2$.[12] In particular, there is room for at most one customizing firm in the market when the firms are restricted to uniform prices. However, restricting a customizing firm to a uniform price can induce a higher customization level as shown by the following proposition, which compares the customizing firm's chosen customization levels in (CM, T) and (CU, T).

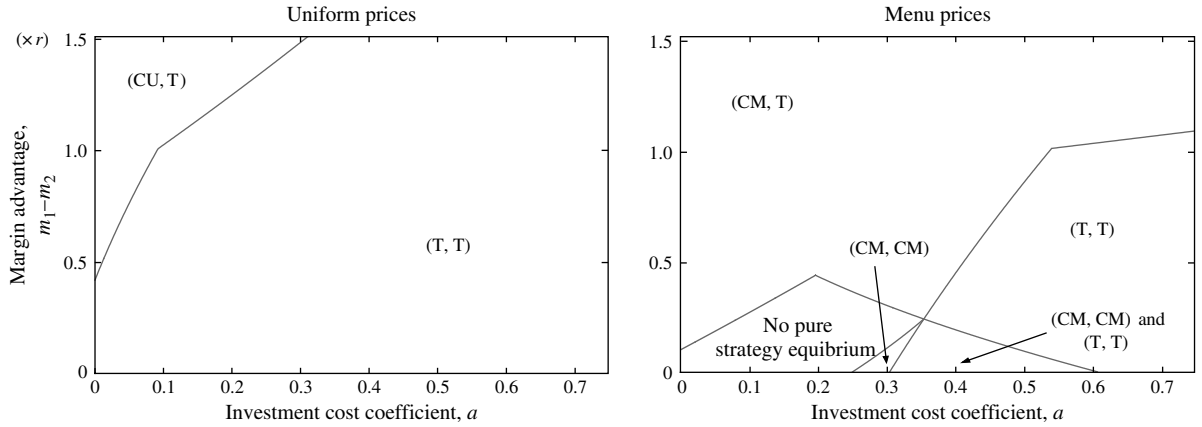
Proposition 6. *Let* $m_1 \geq m_2$. *There exists* $m^* \geq 0$ *such that* $k_1^{\mathrm{CU,T}} \geq k_1^{\mathrm{CM,T}}$ *if and only if* $m_1 - m_2 \geq m^*$.

Proposition 6 shows that a firm with a sufficiently strong margin advantage chooses a higher customization level when restricted to a uniform price. In this case, price and product customization act as substitutes: When price customization is unavailable, the firm uses a higher level of product customization instead. A better level of product customization helps a firm (i) increase its market share and (ii) extract more surplus from its customers. A CM-firm takes better advantage of the first benefit by setting differential prices (lower prices to attract nonbuying customers). On the other hand, the second benefit is more helpful

[11] The proof of Proposition 4 shows that $K^{\mathrm{CM,CM}}$ is nonempty.

[12] It is straightforward to show that $\hat{\Delta}_1^{\mathrm{CU}} \leq \hat{\Delta}_1^{\mathrm{CM}}$.

Figure 2 Equilibrium of the Adoption Game for Investment Cost Function $S(k) = a(k + 0.2)$ Under Uniform and Menu Prices



Notes. The vertical axes in both figures are scaled with r, the intensity of customer preferences. Therefore, given the above investment cost function, the figures show the equilibria for any set of parameters.

for a CU-firm, which leaves more money on the table: A CU-firm's uniform price should be sufficiently low to attract its marginal customer, forgoing the surplus that other customers are willing to pay, whereas a CM-firm sets the maximum price each customer is willing to pay, given her other options. When the firm has a strong margin advantage and in turn an already large market share, the first benefit is less valuable and the result follows.

It is interesting to compare the firms' chosen customization levels under menu prices. (Recall that both firms never adopt MC under uniform prices.) Let $\bar{k}_i^{\mathrm{CM,CM}} = \sup\{k_i\colon k \in K^{\mathrm{CM,CM}}\}$ and $\underline{k}_i^{\mathrm{CM,CM}} = \inf\{k_i\colon k \in K^{\mathrm{CM,CM}}\}$.

Proposition 7. *$\underline{k}_1^{\mathrm{CM,CM}} \geq \bar{k}_2^{\mathrm{CM,CM}}$ for $m_1 - m_2 \geq r/2$.*

The proposition shows that a firm with a sufficiently strong margin advantage always invests in customization more than its competitor when both firms adopt MC in the equilibrium. However, depending on the investment cost function $S(\cdot)$, the firm with a margin disadvantage may also choose a higher customization level when its disadvantage is small enough ($-r/2 < m_2 - m_1 < 0$ for Firm 2).

6. Process Improvement: Customization Level vs. Unit Cost

Our analysis so far has shown the complementarity between a firm's cost efficiency and its returns from investing in customization under competition. In this section, we compare a customizing firm's returns from improving its unit cost and its customization level. This is useful for deciding how to allocate the firm's limited resources between competing process improvement efforts. This problem is also closely related to a firm's choice on where to locate itself on the Hayes-Wheelwright product-process matrix. For example, a firm operating a job shop process competes mainly on the basis of its customization level, whereas a firm operating a continuous process competes mainly on the basis of its unit cost, and batch process and assembly lines are in between.

Following Proposition 4, a firm may be selling customized products in (CU, T) for uniform prices and (CM, T) and (CM, CM) for menu prices. Our results in this section will uniformly hold for each of these cases. Define

$$\Gamma_1^{v,u} = -\frac{d\Pi_1^{v,u}/dk_1}{d\Pi_1^{v,u}/dc_1}, \quad (v,u)\colon (\mathrm{CU,T}), (\mathrm{CM,T}), (\mathrm{CM,CM}) \tag{5}$$

the ratio of Firm 1's returns from improving its customization level and its unit cost. (When Γ_1 decreases, improving the customization level becomes relatively less desirable.) It is straightforward to show that a firm always benefits from an improvement in its unit cost. Therefore, when the sign of Γ is negative, investing in customization is undesirable. The following proposition shows that there is a monotone relation between Γ and the firm's margin advantage.

Proposition 8. *$\Gamma_1^{u,v}$ is nondecreasing in $(m_1 - m_2)$ for (u,v): (CU, T), (CM, T), (CM, CM).*

The proposition shows that when its opponent becomes more of a threat due to lower unit cost or improved quality, the firm has a higher relative return from improving its cost efficiency. On the other hand, when its opponent becomes less competitive, the firm has a higher relative return from improving its customization level. In sum, cost efficiency is largely driven by the firm's incentive to protect its market share from competition, whereas customization flexibility is largely driven by the firm's incentive to extract more surplus from its customers. At one extreme, Lemma 1 shows that a firm failing to achieve a positive market share can never gain it by improving its customization flexibility, whereas it can gain a positive market share by improving its cost efficiency.[13]

7. Concluding Remarks

This paper aims to contribute to the growing literature on the value and adoption of MC (Huffmann and Kahn 1998, Ahlström and Westbrook 1999, Agrawal et al. 2001, Zipkin 2001, Piller et al. 2004) by shedding light on its relation to the firm's competitive position. We characterize firms' investments in MC under competition and study the adoption of MC and the choice of customization levels. Specifically, we consider a market with heterogeneous customer tastes modeled by a location-based customer choice model. The market is served by two firms that differ in their cost efficiency and perceived quality, which determine their competitive positions. The firms compete in a two-stage game. First, each firm invests in MC, which enables it to offer customized products that increasingly match each customer's ideal product as the chosen customization level increases. Second, the firms competitively price their product lines. We consider two alternatives with regard to the customizing firms' price policies: when they are restricted to uniform prices, and when they can set a price menu for each product configuration. We solve for the resulting equilibria and study their characteristics for both scenarios.

We find that the value of MC critically depends on the firm's competitive position. In particular, MC may have a negative return even before paying back the investment cost when the firm does not have a sufficiently strong competitive position (Propositions 2 and 3). We show that a firm with a margin disadvantage never unilaterally adopts MC in equilibrium (Proposition 4). Our results suggest that, under competition, a firm considering MC should first consider cost reduction or quality improvement efforts, and only then turn to MC. This is in contrast to the case of a monopoly, which does not face price competition and hence always benefits from costless customization.

Our analysis allows us to characterize the additional value of price customization for a mass-customizing firm and its overall effect on the market structure. We find that allowing price customization in conjunction with product customization leads to a broader adoption of MC because the firms can take better advantage of their customized product lines (Proposition 4). However, a firm's chosen level of product customization may be higher when it is restricted to uniform prices (Proposition 6). Along the same lines, we find that there is a degree of substitutability between product and price customization. The additional benefit of price customization decreases (it vanishes for a monopoly) as a firm achieves a higher level of product customization.

We also provide guidelines for a customizing firm in deciding how to allocate its resources between improving its customization level and unit cost. We show that when its opponent becomes more competitive (due to lower unit cost or improved quality), the firm has a higher relative return from improving its unit cost. On the other hand, when its opponent becomes less of a threat, the firm has higher relative returns from improving its customization level (Proposition 8).

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Appendix A. Monopoly

Consider a monopoly with a base product located at $\zeta = 1/2$. It is straightforward to show that this is the optimal product location for a monopoly.[14]

[13] Our results in this section equally apply when the firm has to decide whether to compete on the basis of quality or customization, because all of our results directly depend on a firm's maximum margin $m = w - c$.

[14] The location of the monopoly is not crucial for our results: Our conclusions would be the same if the monopolist were at one end of the line as opposed to the center.

Table A1 Monopoly's Profit from Sales

	Level of customization	Π		Market covered condition[a]
		Market not covered	Market covered	
T	$k=0$	$\frac{m^2}{2r}$	$(m-r/2)$	$m \geq r$
CU	$0<k<1$	$\frac{m^2}{2(1-k)r}$	$(m-(1-k)r/2)$	$m \geq (1-k)r$
	$k=1$		m	Always covered
CM	$0<k<1$	$\frac{m^2}{(1-k)r}$	$(m-(1-k)r/4)$	$m \geq (1-k)r/2$
	$k=1$		m	Always covered

[a]We say that the market is covered if all customers buy a product.

Proposition 9. (i) *The monopoly's profit from sales is given by Table* A1.

(ii) *The monopoly adopts MC if and only if* $\max_{0\leq k\leq 1}[\Pi^v(k)-\Pi^T-S(k)]\geq 0$ *for* v: CM *and* CU.

Appendix B. Asymmetric Customer Information

Our main model assumes that an MC firm knows the customer types. This can hold, for example, when the customer types are observable, as in the case of a customer visiting a brick and mortar store to have a tailor take her measurements or when a firm inspects a customer's kitchen prior to customizing a kitchen cabinet. In this appendix, we consider what happens when the customizing firm cannot observe the customer type, as may be the case, for example, when a customer orders custom apparel online for the first time. For the analysis, we extend the customer's utility function in (2) to include what happens when she buys a product customized for another type. When a type-θ customer buys the product customized for type θ', she incurs an additional disutility due to miscustomization, which is equal to the level of customization k (interpreted as the percentage of attributes that can be customized) times the disutility of misfit between the customer's true type and her declared type, $|\theta'-\theta|r$. Formally,

$$U(\theta,\theta',\zeta)=w_i-p_i(\theta')-r(1-k_i)|\theta-\zeta|-rk_i|\theta'-\theta|. \quad \text{(B1)}$$

We consider the implications of asymmetric information for uniform and menu prices.

Under uniform prices, i.e., when all product types are offered at the same price, each customer buys the product specifically customized for her type because it minimizes her misfit cost. Therefore, our results for uniform prices immediately extend to the case of asymmetric information. The pay-offs in the pricing game are the same as in Lemma 1, the equilibrium of the investment game is the same as in Proposition 4, and all of our results stay intact.

For menu prices, a pure strategy equilibrium does not exist in the pricing game for some feasible values of (k_1, k_2), as shown by the following lemma.

Lemma 10. *For menu prices, a pure strategy equilibrium exists in the pricing game if and only if* $k_1+k_2\leq 1$ *or* $2k_1+k_2>2$ *and* $2k_2+k_1>2$.

By Lemma 10, for any $0<k_i<1$ there is always a feasible k_j such that for (k_i, k_j) a pure strategy pricing equilibrium does not exist. As a result, it is impossible to specify the pay-off functions for the adoption game in the preceding stage. Therefore, the equilibrium of the investment game cannot be solved. However, we can characterize the equilibrium for the restricted adoption game, where the firms decide only whether to customize. A number of key insights can be derived in the context of the restricted adoption game. As we show below, these insights are preserved with asymmetric information.

Consider the restricted game where each firm decides whether to adopt MC with $k=1$. The cost of adopting MC is $S>0$. The following proposition describes the equilibrium of the restricted adoption game.

Proposition 11. *Let* $m_1\geq m_2$. *The* SPNE *of the restricted adoption game is as follows*.

(i) *For uniform prices*: (CU, T) *if*

$$\frac{12(m_1-m_2)r-(m_1-m_2)^2}{18r}-\frac{r}{2}\geq S, \quad \text{(T, T)}, \quad \textit{otherwise}.$$

(ii) *For menu prices*: (CM, T) *if*

$$\frac{12(m_1-m_2)r-(m_1-m_2)^2}{18r}\geq S, \quad \text{(T, T)}, \quad \textit{otherwise}.$$

The proposition shows that, similar to our main model, the competitive value of MC critically depends on a firm's margin advantage with asymmetric information as well. Also, as in our main model, a firm with a margin disadvantage never unilaterally adopts MC. The reason is the same, namely, the adoption of MC intensifies price competition. Furthermore, Proposition 11 also shows that the firms are more likely to adopt MC when they are allowed to set menu prices, as in our main model.

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