Chapter 11
Competing Through Mass Customization

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Abstract We consider a market with heterogeneous customer tastes served by a duopoly. In our base model the firms first decide whether to adopt MC, which enables a firm to provide each customer her ideal product configuration. A firm that chooses not to invest in MC serves a standard product. Following investment decisions, the firms competitively price their products. A customer evaluates a product alternative considering its price and misfit relative to her ideal point (and delay in our extended model). We solve for the resulting equilibrium and study its characteristics. We then study the competition between a firm that adopted MC and a firm that continues to sell standard products in more detail extending our base model to account for some key operational differences between these two firms: While the firm selling standard products usually carries product inventories, the firm selling custom products does not carry inventory, it makes-to-order and its customers incur waiting costs until they receive their orders. Our results are useful for characterizing conditions that favor custom and standard products under competition. We find that the value of mass customization critically depends on the firm's competitive position, determined by its cost efficiency and perceived quality vis-à-vis its competitor: 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 adopts mass customization. We show that allowing firms to set custom prices for each product configuration leads to a broader adoption of mass customization compared to when they are restricted to uniform prices. Furthermore, we find that a customizing firm's profit is *not* monotone in the market size and its ease of customization when competing against a firm selling standard products. We show that its competitive position crucially affects its ideal market size and its returns from improving the ease of customization.

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11.1 Introduction

Following the shift of power to consumers, they are increasingly demanding products that closely match their individual preferences (Frazier 2001). We are far from one color only Ford Model T; the number of vehicle models increased from 140 to 260 between the early 1970s and late 1990s where each model was offered in numerous styles and colors (Cox and Alm 1998). Indeed, selection has increased significantly over time for a variety of products. For example, the number of distinct breakfast cereals increased from 160 to 340, the number of soft drink brands from 20 to 87, and the number of running shoe styles increased from 5 to 285 during the same time period. With the advances in manufacturing and information technologies, rather than keep increasing their number of product variants, many firms are adopting an alternative approach based on *mass customization* (MC) (Pine 1993; Feitzinger and Lee 1997; Zipkin 2001), whereby they attempt to give each customer exactly what she asked for by offering individually customized products. Lands' End (Piccoli et al. 2003), mi adidas (Seifert 2002), Dell (Dell and Fredman 2000), and NikeID are some well known working examples.[1]

Anecdotal examples show that MC enables a firm to increase its unit selling price about 50% (Mirapaul 2001; Keenan and Crockett 2002), and empirical studies show that customers may be willing to pay as much as 150% more for a product that fits better to their needs than the second best solution available (Piller 2004). It is suggested that MC can help a variety of domestic industries fight the outsourcing of production to low-cost overseas manufacturers (Keenan et al. 2004; Schuler and Buehlmann 2003; Karnes and Karnes 2000). The US furniture industry is one example: US manufacturers are more successful against imports in market sectors where they offer more customization (Lihra et al. 2005). Keenan et al. (2004) argue that MC can give competitive advantage to the domestic EU apparel industry against mass production alternatives in developing countries. Indeed, MC is not conducive to outsourcing as standard mass production since it requires promptness, higher skilled labor, specialized business processes, and machinery. Anderson (2004) argues that "outsourcing is at odds with the inventory-less aspect of build-to-order & MC, since outsourcing is usually a batch operation."

The literature recognizes that MC is no panacea on the other hand (Zipkin 2001; Agrawal et al. 2001; Ahlström and Westbrook 1999). Zipkin (2001) points out that many product markets are not attractive for MC. Pine (1993) identifies conditions under which MC is attractive vis-à-vis mass production. Indeed, there are many recent examples of firms that abandoned MC initiatives or had gone out of business selling customized products (e.g., Levi Strauss, Reflect.com, Mattel, CMax.com), and in many markets firms following MC are competing against firms that continue to offer standard products. Thus, it is important to identify the conditions that make MC an attractive strategy vis-à-vis selling standard products.

[1] Other examples can be found in Moser and Piller (2006), which are a collection of MC case studies.

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). Riemer and Totz (2003) discuss how MC can be used to combat uniform pricing through the individualization of both products and prices. 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 customized prices for firms that offer customized products.

We consider a market with heterogeneous customer tastes served by a duopoly. In our base model, each firm decides whether to adopt MC, which enables the firm providing each customer her ideal product configuration. A firm may also choose not to invest in MC and sell a standard product. Following investment decisions, the firms competitively price their products. A customer takes into account price and misfit relative to her ideal point (and delay in our extended model) to evaluate a product offer. 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 extend our base model in Sections 11.5 and 11.6. Here, we assume that the production technology investments are already made and we study the competition between a *customizing* firm that adopted MC and a *traditional* firm that continues to sell standard products. We explicitly model some important differences between the operations of customizing and traditional firms: A traditional firm usually carries inventory and fulfills customer demand from stock. In contrast, a customizing firm does not carry finished goods inventory as it customizes to order. There is a trade-off, however, as customers need to wait for custom orders, whereas a traditional seller can make the product immediately available from inventory.[2]

Our analysis enables us to study the attractiveness of MC in a competitive context. We address questions like: When should (not) a firm adopt MC? What will be the structure of markets where competing firm can adopt MC? How do the answers to these questions depend on MC firm's ability to customize prices? What market conditions make the MC or the traditional approach more profitable? How do these depend on the firms' competitive positions?

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; this is in contrast to a monopoly who always benefits from zero cost MC. Specifically, MC is beneficial only for a firm with a sufficiently strong competitive position, determined by its perceived quality and cost efficiency vis-à-vis its competitor. We show that in equilibrium, a firm with an overall cost/quality disadvantage never adopts MC. In addition, comparing equilibrium outcomes when firms set uniform prices and price menus, we show that allowing price menus leads to a wider adoption of MC.

We characterize the conditions in terms of market size, ease of customization, cost efficiency, and quality, which make MC more attractive for competing against

[2] This delay is, for example, one of the main reasons for few US consumers (7% in 2000) to order custom cars (Agrawal et al. 2001).

standard products. For example, we find that the relationship between the profitability of MC and market size is not monotone: A larger market can make MC less profitable due to the traditional competitor's scale economies. This relationship again critically depends on the customizing firm's perceived quality and cost efficiency vis-à-vis its competitor. When a customizing firm has a large cost/quality disadvantage, it may be better off in a smaller market where a traditional opponent cannot compete effectively due to its high inventory costs. Furthermore, contrary to one's basic intuition, we show that shorter customization times can make the customizing firm worse off due to its competitor's response. This is because customization delays create a degree of separation between customized and standard products, which softens price competition. When the customizing firm has a weak cost/quality position, speeding customization up reduces this separation, and this in turn reduces its profit.

MC is a growing area of research. This chapter is based on the research presented in Mendelson and Parlaktürk (2008a,b).[3] Here, we briefly point to the other work in this area that also considers MC in competitive contexts.[4] Alptekinoḡlu and Corbett (2008) study duopoly competition between a traditional firm and a customizing firm, finding that the traditional firm can attain positive profit even with a cost disadvantage. Alptekinoḡlu and Corbett (2008) assume production technology choices as given whereas in this chapter we study when competing firms choose to adopt MC. Dewan et al. (2003) consider two symmetric firms offering a standard product and a range of customized products. They show that a firm can deter entry by over-customizing its product in a sequential entry game. Syam et al. (2005) also consider two symmetric firms that can customize two attributes and they study which attributes are customized in equilibrium, finding that both firms either choose not to customize any attribute or they both customize one (the same) attribute. The assumption of equal (zero) unit costs in Dewan et al. (2003) and Syam et al. (2005) is critical, as the firms always choose symmetric strategies (when they move simultaneously). In contrast, the margin differences between the firms are key drivers of our results and we identify equilibria where only one firm chooses to sell customized products. Similarly, Syam and Kumar (2006) consider two symmetric firms and two consumer segments with different "transportation" cost parameters, i.e., sensitivities to product misfit, and they study the firms' choice of customization level. 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 make asymmetric choices (i.e., only one firm choosing to offer customized products). Clearly, when the drivers of MC are differences between the firms, these drivers cannot be identified when the firms are completely symmetric.

[3] Specifically, we consider a special case of Mendelson and Parlaktürk (2008a) in this chapter. An MC firm chooses its desired customization level in Mendelson and Parlaktürk (2008a) that determines its ability to reduce product misfit for each customer while we restrict the firm to one of the two extremes, none vs. perfect customization, in this chapter.

[4] A related paper that considers MC in a monopoly context is Jiang et al. (2006).

The above literature focuses on the firm's product variety and pricing decisions and – with the exception of Mendelson and Parlaktürk (2008b) – it does not consider the roles of inventory fulfillment and queuing delays, which are important operational characteristics of the problem. In this chapter, we also explicitly model these operational features, incorporating the stocking of standard products and the make-to-order nature of customized products (with its associated queuing delay), in addition to product variety and pricing. For a monopoly, Alptekinoglu and Corbett (2007) also incorporate these operational elements, and they study which customer segments are served with standard and custom products under more general demand functions. Xia and Rajagopalan (2006) study duopoly competition where each firm can choose to sell either standard or custom products and they also incorporate customization delay in their model. However, the customization delay in Xia and Rajagopalan (2006) is deterministic (there is no capacity constraint), so it does not depend on the congestion or utilization of the customizing firm. Furthermore, they do not model fulfillment of standard products, e.g., the standard products do not incur holding costs.

In the remainder of the chapter, we describe our base model in Section 11.2. We characterize the pricing equilibrium in Section 11.3. We discuss the competitive value of MC and characterize when firms adopt it in Section 11.4. Then we focus on the competition between a firm selling mass-customized products and a firm selling standard products and we extend our base model to account for some key operational differences between these two approaches in Section 11.5. We then discuss how some market and operating characteristics affect the profitability of MC under competition in Section 11.6. Our concluding remarks are in Section 11.7. The proofs of all results can be found in Mendelson and Parlaktürk (2008a,b).

11.2 Model

We consider a market with two firms and customers who have heterogenous preferences for product attributes. Similar to Chen et al. (1998), we model these preferences along the Hotelling Line (Hotelling 1929): Each customer's ideal product θ is represented by the customer's location on the unit interval $[0,1]$. This can represent, for example, preferences for the size or color of a piece of apparel. Each firm has a single product ζ and the firms' products are located at the opposite ends of the unit interval, $\zeta_1 = 0, \zeta_2 = 1$, a standard assumption in Hotelling-based competition models (see e.g., Tirole (1988), Chapter 7).[5] Later on, we study what happens when a firm can offer multiple standard products in Section 11.5. The distance between a customer and the firm's product position results in customer sacrifice relative to her

[5] Indeed, locating its product maximally differentiated from the competitor is optimal for each firm in most cases (d'Aspremont et al. 1979) as it avoids unbridled price competition. However, this may not be true when the firms are sufficiently asymmetric. Dewan et al. (2003), Syam et al. (2005) and Syam and Kumar (2006) also assume duopoly firms with single standard products and maximal differentiation for studying MC.

ideal product. However, a firm can eliminate the customer sacrifice by customizing its product to the customer's liking. In the remainder of this section, we specify our demand model and describe the firms' decisions and operations.

Customer Choice:

Customers trade off price and disutility of sacrifice from their ideal product in their decision making. When a type-θ customer buys Firm i's standard product, her utility is equal to

$$U(\theta, \zeta_i, w_i, p_i) = w_i - p_i - r|\theta - \zeta_i|, \tag{11.1}$$

where the reservation value w_i is the customer's willingness to pay for her ideal product, and each firm can have a different reservation value due to difference in the perceived product quality. The customer utility decreases by $r|\theta - \zeta_i|$, the disutility of misfit, where r shows the intensity of customer preferences and $|\theta - \zeta_i|$ is the distance from customer's ideal product. The customer can avoid this disutility by buying a product customized exactly for her ideal configuration, i.e., $\zeta = \theta$, if it is offered.[6]

Customers arrive to the market at rate, or demand intensity λ, and they differ only in their ideal product types θ which are uniformly distributed over $[0, 1]$. Each customer buys one unit of the product that gives her the highest utility. We assume that the reservation values w_i are sufficiently high so all customers derive nonnegative utility from buying a product.[7]

Firm's Decisions:

Each firm first decides whether to adopt MC. Adopting MC entails a fixed investment cost K. A firm that does not adopt MC is called a *traditional* firm (T). A traditional firm does not customize its product, it sells only a single product type 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 customizing firm's pricing policy. In the uniform price scenario, a customizing firm (CU) is restricted to a uniform price whereas in the menu price scenario, a customizing firm (CM) can set a different price for each customized product configuration.

Each firm incurs a unit production cost c, which can be different across two firms due to differences in the efficiency of their processes. We assume that adopting MC entails only a fixed cost and it does not affect the firm's marginal cost. This is in line with the MC's premise of achieving mass-production efficiency (Tseng and Jiao

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[6] Here, we assume that MC enables a firm to completely eliminate customers' sacrifice, however in practice this depends on the degree the firm chooses to customize its product, a higher degree of customization leading to a smaller customer sacrifice. This is explored in depth in Mendelson and Parlaktürk (2008a).

[7] This is standard in the literature (e.g., Syam et al. 2005; Dewan et al. 2003; Thisse and Vives 1988) and a sufficient condition in our context is to assume $w_1 + w_2 - (c_1 + c_2) > 3r$, where c_i is the unit cost of Firm i as described in the following.

2001; Pine 1993).[8] We define Firm i's *maximum margin* $m_i = w_i - c_i$ by the difference between its reservation value and its unit cost, and $m_i - m_j$ determines its competitive position vis-à-vis Firm j. We say that Firm i has a margin advantage (disadvantage) when $m_i > m_j$ ($m_i < m_j$). By definition, $m_i - m_j = (w_i - w_j) - (c_i - c_j)$, where the first term shows the quality differential and the second term shows the cost differential between the firms.

Following the firm's investment decisions (whether to adopt MC), the firms competitively price their products. We consider two alternative scenarios. Under uniform prices, the firms simultaneously set uniform prices for all of their product types, whereas under menu prices the firms first set the price of their standard products and then the customizing firms (if any) set the price premiums for their customized products. After the prices are set, customers make their purchasing decisions. So, a firm chooses either between T and CU or between T and CM. It is straightforward to show that CM always dominates CU if a firm is to choose between CU and CM.

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

11.3 Pricing Game

After observing the firms' product prices, customers make their purchasing decisions. Specifically, a type-θ customer buys from Firm i if

$$U(\theta, p_i, \zeta_i) > \max(0, U(\theta, p_j, \zeta_j)).$$

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 $U(\theta^m, p_1, \zeta_1) = U(\theta^m, p_2, \zeta_2)$, 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.

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[8] In some cases MC can lead to cost savings due to eliminating inventory risks and holding costs, while in some cases it can lead to additional costs due to the need for more sophisticated labor and machinery. Overall, if MC increases the firm's unit cost, this will only strengthen our key message while making the analysis cumbersome.

The following Lemma summarizes the firms' equilibrium prices and profits (i.e., their profits before subtracting investment costs) in the pricing games.

Lemma 1. *The firms' equilibrium prices and profits are as follows in each pricing game.*

Pricing Game	*Region*	*Equilibrium prices and profits in the pricing game*
(T,T)	$m_1 - m_2 \leq -3r$	$p_1 = c_1$, $p_2 = -m_1 + m_2 - r + c_2$, $\Pi_1 = 0$, $\Pi_2 = \lambda(-m_1 + m_2 - r)$
	$-3r < m_1 - m_2 < 3r$	$p_1 = \frac{m_1 - m_2 + 3r}{3} + c_1$, $p_2 = \frac{m_2 - m_1 + 3r}{3} + c_2$, $\Pi_1 = \frac{\lambda(m_1 - m_2 + 3r)^2}{18r}$, $\Pi_2 = \frac{\lambda(m_2 - m_1 + 3r)^2}{18r}$
	$m_1 - m_2 \geq 3r$	$p_1 = m_1 - m_2 - r + c_1$, $p_2 = c_2$, $\Pi_1 = \lambda(m_1 - m_2 - r)$, $\Pi_2 = 0$
(CU,T)	$m_1 - m_2 \leq -2r$	$p_1 = c_1$, $p_2 = -m_1 + m_2 - r + c_2$, $\Pi_1 = 0$, $\Pi_2 = \lambda(-m_1 + m_2 - r)$
	$-2r < m_1 - m_2 < r$	$p_1 = \frac{m_1 - m_2 + 2r}{3} + c_1$, $p_2 = \frac{m_2 - m_1 + r}{3} + c_2$, $\Pi_1 = \frac{\lambda(m_1 - m_2 + 2r)^2}{9r}$, $\Pi_2 = \frac{\lambda(m_2 - m_1 + r)^2}{9r}$
	$m_1 - m_2 \geq r$	$p_1 = m_1 - m_2 + c_1$, $p_2 = c_2$, $\Pi_1 = \lambda(m_1 - m_2)$, $\Pi_2 = 0$
(CM,T)	$m_1 - m_2 \leq -2r$	$p_1(\theta) = c_1$, $p_2 = -m_1 + m_2 - r + c_2$, $\Pi_1 = 0$, $\Pi_2 = \lambda(-m_1 + m_2 - r)$
	$-2r < m_1 - m_2 < 0$	$p_1(\theta) = [m_1 - m_2 + r - \theta r]^+ + c_1$, $p_2 = \frac{m_2 - m_1}{2} + c_2$, $\Pi_1 = \frac{\lambda(m_1 - m_2 + 2r)^2}{8r}$, $\Pi_2 = \frac{\lambda(m_2 - m_1)^2}{4r}$
	$m_1 - m_2 \geq 0$	$p_1(\theta) = m_1 - m_2 + r - \theta r + c_1$, $p_2 = c_2$, $\Pi_1 = \lambda(m_1 - m_2 + r/2)$, $\Pi_2 = 0$
(CU,CU)	$m_1 - m_2 \leq 0$	$p_1 = c_1$, $p_2 = -m_1 + m_2 + c_2$, $\Pi_1 = 0$, $\Pi_2 = \lambda(-m_1 + m_2)$
	$m_1 - m_2 > 0$	$p_1 = m_1 - m_2 + c_1$, $p_2 = c_2$, $\Pi_1 = \lambda(m_1 - m_2)$, $\Pi_2 = 0$
(CM,CM)	$m_1 - m_2 \leq 0$	$p_1(\theta) = c_1$, $p_2(\theta) = -m_1 + m_2 + c_2$, $\Pi_1 = 0$, $\Pi_2 = \lambda(-m_1 + m_2)$
	$m_1 - m_2 > 0$	$p_1(\theta)1 = m_1 - m_2 + c_1$, $p_2(\theta) = c_2$, $\Pi_1 = \lambda(m_1 - m_2)$, $\Pi_2 = 0$

Notice that when a firm has a sufficiently large margin advantage it dominates the market, leaving zero market share for its competitor. Furthermore, when both firms adopt MC either in uniform or menu price scenario ((CU,CU) or (CM,CM)), horizontal differentiation between the firms disappears as each firm provides the same product type – her ideal product configuration – to each customer. This results in head-to-head Bertrand competition always leaving one of the firms with zero market share.

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. Furthermore, the lemma shows that the region in which both firms have positive profits shrinks, that is, survival becomes harder as firms move from T, to CU and on to CM.

We next study the firms' investments in MC given the resulting payoffs in the pricing game.

11.4 The Adoption Game

In this section, we first discuss the competitive value of MC which helps forming the best responses in the adoption game. We then characterize and discuss the equilibrium of the adoption game.

Mass customization helps a firm create value for its customers, and it always helps a monopoly extract more surplus from its customers. 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 customizing its product.

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

The following propositions characterize when MC can yield positive returns showing the change in the firm's profit in the pricing game after it adopts MC.

Proposition 1. *(i)* $\Pi_1^{CU,T} \geq \Pi_1^{T,T}$ *if and only if* $m_1 - m_2 \geq (\sqrt{2}-1)r$.
(ii) $\Pi_1^{CM,T} \geq \Pi_1^{T,T}$ *if and only if* $m_1 - m_2 \geq 0$.

Proposition 1 shows that the adoption of MC does not necessarily yield higher profits; it can make the firm worse off because it intensifies price competition. In particular, Firm i cannot benefit from adopting MC even at zero cost 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 as $m_i = w_i - c_i$. In other words, there is a quality/cost prerequisite (relative to the competitor) below which a firm never benefits from customizing its product. Furthermore, this threshold is lower when the firm is able to customize prices in addition to customizing the product.

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.

The next proposition describes the value of adopting MC against a customizing competitor.

Proposition 2. *(i)* $\Pi_1^{CU,CU} \geq \Pi_1^{T,CU}$ *if and only if* $m_1 - m_2 \geq 0$.
(ii) $\Pi_1^{CM,CM} \geq \Pi_1^{T,CM}$.

Proposition 2*(i)* shows that when the firms are restricted to a uniform price, a firm with a margin disadvantage (either due to low quality or high cost) does not benefit from adopting MC against a customizing competitor. On the other hand, when the firms set different prices for each product type, adopting MC always weakly increases a firm's payoff in the pricing game against a customizing competitor. However, a firm with a margin disadvantage does not get a positive market share in either case and it is better off staying as a traditional firm considering the cost of adopting MC technology.

It is interesting to consider the value of price customization in addition to product customization, which is given by $\Pi_1^{CM,T} - \Pi_1^{CU,T}$. For a monopoly, this is zero, as MC eliminates the differences in customers' willingness to pay by providing each customer her ideal product, the firm charges the same price, the reservation price which is the maximum price each customer is willing to pay. In contrast to the monopoly case, there is value to customizing prices in competition. This is because price flexibility enables the firm to set competitive prices for product configurations that are closer to the competitor's standard product while keeping higher prices for more remote products.

We are ready to characterize the equilibrium of the adoption game.

Proposition 3. *Let* $m_1 \geq m_2$. *The SPNE of the adoption game is as follows*

(i) For uniform prices:

a. *When* $K < \lambda r/9$, *equilibrium is* (T,T) *if* $\lambda(m_1 - m_2 - r)^2/(18r) - \lambda r/9 < K$, (CU,T) *otherwise.*
b. *When* $K \geq \lambda r/9$, *equilibrium is* (T,T) *if* $\lambda(m_1 - m_2)(12r - (m_1 - m_2))/(18r) - \lambda r/2 < K$, (CU,T) *otherwise.*

(ii) For menu prices: equilibrium is (T,T) *if* $\lambda(m_1 - m_2)(12r - (m_1 - m_2))/(18r) < K$, (CU,T) *otherwise.*

Proposition 3 shows that a firm with a margin disadvantage never unilaterally adopts MC in equilibrium even when the cost of technology is zero. The intuition for this result follows from Proposition 1: 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 reducing 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. As a special case, when the firms have symmetric margins, no firm adopts MC in equilibrium.

It is straightforward to show that the left-hand side in the condition in part *(ii)* of Proposition 3 is larger than those of part *(i)*. Thus, the proposition shows that allowing firms to set price menus for different configurations leads to a wider adoption of MC as the firms can better take advantage of their customized product lines.

In our model, both firms never adopt MC at the same time. This is because MC enables a firm provide each customer her ideal product configuration exactly and when both firms adopt MC, this eliminates the distance between them leading to Bertrand competition where one of the firms cannot get a positive market share. However, when MC does not eliminate customer sacrifice completely, both firms may adopt MC in equilibrium.[9] This is studied in Mendelson and Parlaktürk (2008a) where a customizing firm chooses its degree of customization which determines its ability to decrease a customer's sacrifice. With this extension, the firms with symmetric margins also adopt MC when the adoption cost is sufficiently small.

11.5 MC vs. Traditional Approach

So far we have discussed the firms' choice of production technology, that is the choice between MC vs. traditional approach of offering standard products, and we have characterized when firms adopt MC in duopoly. In this section, we assume that production technology decisions are already made and we study in more detail the duopoly competition between a customizing and a traditional firm. To this end, we extend our base model in various directions.

A traditional firm usually carries inventory and fulfills customer demand from stock. In contrast, a customizing firm does not carry finished good inventory as it customizes to order. However, customers need to wait for custom orders whereas a traditional firm can provide instant availability from inventory. We extend our base model to account for these key operational differences and we study their subsequent effects on the profitability of MC and traditional approach. Furthermore, we allow the traditional firm to offer more than one standard product configuration and determine the number of product variants it will carry considering its inventory holding and procurement costs. Here, we only consider the uniform price scenario, that is, each firm has to set a uniform price for all product configurations. The resulting insights also carry over to the menu price scenario as shown in Mendelson and Parlaktürk (2008b).

In the following, we first describe the model extensions then we state and discuss the resulting equilibrium. We extend the customer's utility function to account for disutility of delay. Thus, customers trade off price, disutility of product misfit, and delay in their decision making. Specifically, when a type-θ customer buys product ζ from Firm i, her utility is equal to

$$U(\theta,\zeta,w_i,p_i,W_i) = w_i - p_i - r|\theta-\zeta| - vW_i. \tag{11.2}$$

[9] A firm with a margin disadvantage still never unilaterally adopts MC.

Note that the only difference between (11.1) and (11.2) is the last term in (11.2), where W_i is the average delay for getting a product from Firm i and v is the customers' sensitivity to delay. Customers incur delay due to waiting either for a custom product or for a backordered standard product. We assume that customers do not observe the queue length of the customizing firm and inventory position of the traditional firm. Thus, they make their decisions based on the average delay to maximize their expected utility. We derive the average delays in the following.

We use index c to denote the customizing firm. The customizing firm does not carry inventory. It customizes to order fulfilling customer orders on a first-come-first-served basis. The customization times are exponentially distributed with rate μ which reflects the ease of customization and firm's customization capacity. We assume that customers arrive to the market according to a Poisson process, thus customers who buy custom products form a Poisson process and the customizing firm is characterized by an M/M/1 queue. Therefore, the average delay for a customized product is

$$W_c = 1/(\mu - \lambda_c). \tag{11.3}$$

We assume $\lambda < \mu$, so that $W_c(\lambda_c) < \infty$ for all $\lambda_c < \lambda$. The customization capacity μ is exogenous, i.e., it cannot be changed within the timescale of our model. Mendelson and Parlaktürk (2008b) study what happens when the customizing firm can choose its capacity endogenously.

We use index t to denote the traditional firm. In addition to its unit price p_t, now the traditional firm decides how many products to offer n and their configurations $\zeta_j \in \Theta$ for $j : 1,...,n$. Once the firm determines its product offers, it outsources the production to a supplier with replenishment lead time l, and it replenishes its stocks at a fixed cost S per order at unit cost c_t. For each unit in stock, the firm also incurs inventory holding cost h per unit time. The traditional firm is considered to have unlimited supply. The firm follows a (Q,R) continuous review policy. The firm orders Q_j units whenever its inventory position of product variant j falls below $d_j + k\sigma_j$, where d_j and σ_j are the mean and the standard deviation of the lead time demand for that product variant and k is the *safety stock factor* (cf. Axsäter 1995). Our results are independent of the specific value of k. Mendelson and Parlaktürk (2008b) allow k to be chosen endogenously. The firm backorders any unmet demand which is fulfilled once the stocks for that variant become available. The delay due to backorders inflicts a cost on the firm's customers (see (11.2)) and affects their product choice.

It is straightforward to show that the demand for product variant j follows a Poisson process with mean λ_j, thus $d_j = \lambda_j l$ and $\sigma_j = \sqrt{\lambda_j l}$. We adopt the standard Normal approximation for Poisson demand (cf. Hadley and Whitin, 1963, Section 4.9) The firm's average number of backorders at any time for product variant j is

$$B(Q_j) = \sigma_j^2 \left[(1+k^2)(1-\Phi(k)) - k\phi(k)\right]/(2Q_j), \tag{11.4}$$

and its annual total inventory holding and fixed order cost are given by

$$C(\lambda_j, Q_j) = S\lambda_j/Q_j + h\left(Q_j/2 + \sigma_j k + B(Q_j)\right), \tag{11.5}$$

where $\Phi(\cdot)$ is the cumulative distribution and $\phi(\cdot)$ is the probability density function of a unit normal random variable. Thus, following Little's Law and (11.4), the average delay for standard product variant j due to backorders is

$$W_j = \left[(1+k^2)(1-\Phi(k)) - k\phi(k)\right] \sigma_j^2/(2Q_j\lambda_j), \tag{11.6}$$

and following (11.5), the optimal order quantity for a standard product with demand rate λ_j is

$$Q^*(\lambda_j) = \sqrt{\lambda_j\left(\frac{2S}{h} + [(1+k^2)(1-\Phi(k)) - k\phi(k)]l\right)}. \tag{11.7}$$

We make a few parametric assumptions in order to focus on more interesting scenarios. We continue to assume that the customers' reservation values w_i are high enough so the market is covered in equilibrium. In addition, we assume that the unit margin differential between standard and customized products $|m_t - m_c|$ is sufficiently small so both standard and customized products are offered in equilibrium, that is, customized products always have a positive market share and there is at least one standard product variant. This is determined by unit costs and reservation values since $m_i = w_i - c_i$. Specifically, we consider the case of $\underline{m} < m_t - m_c < \overline{m}$, where

$$\underline{m} = \left(2\gamma - \frac{1}{2}\right)r - \frac{v(\mu - \gamma\lambda)}{(\mu - \lambda(1-\gamma))^2} \text{ and } \overline{m} = \frac{3\gamma r}{2} - \frac{v(\mu - \lambda)}{\mu^2}, \tag{11.8}$$

where

$$\gamma = \sqrt[3]{\frac{h}{\lambda r^2}\left(\frac{2S + l(v/2+h)[(1+k^2)(1-\Phi(k)) - k\phi(k)]}{\sqrt{2S + lh[(1+k^2)(1-\Phi(k)) - k\phi(k)]}} + k\sqrt{lh}\right)^2}, \tag{11.9}$$

which happens to be optimal market share for a standard product variant as shown in Proposition 4 in the following.

The firms simultaneously determine their competitive product offerings to maximize their expected profits. They set prices p_t and p_c and the traditional firm also determines the number of its product variants n and their configurations $\zeta_j \in [0,1]$ for $j: 1,\ldots,n$.[10] As they arrive, customers choose from the product offerings to maximize their utility. The following proposition characterizes the equilibrium.

Proposition 4. *When traditional Firm t competes with customizing Firm c, the firms set prices*

$$p_c = c_c + \frac{v\lambda_c}{(\mu - \lambda_c)^2} + \frac{\lambda_c\gamma r}{2(\lambda - \lambda_c)} \quad \textit{and}$$
$$p_t = p_c - (w_c - w_t) + \frac{v}{\mu - \lambda_c} - \frac{\gamma r}{2} - \frac{lv[(1+k^2)(1-\Phi(k)) - k\phi(k)]}{2Q^*(\gamma\lambda)},$$

[10] In addition, the traditional firm also determines the optimal replenishment batch size Q_j for each product variant j, where its optimal batch size is specified in (11.7).

where $Q^*(\cdot)$ is given by (11.7) and λ_c is given by the solution of

$$\frac{v(\mu+\lambda_c-\lambda)}{(\mu-\lambda_c)^2}+\frac{\lambda_c\gamma r}{2(\lambda-\lambda_c)}=\frac{3\gamma r}{2}-(m_t-m_c). \tag{11.10}$$

The traditional firm offers

$$n=(1-\lambda_c/\lambda)/\gamma \tag{11.11}$$

product variants, and chooses their positions $(\zeta_1,\zeta_2,\ldots,\zeta_n)$ so each has an equal market share. These result in profit rates

$$\Pi_t=\frac{v(\lambda-\lambda_c)^2}{(\mu-\lambda_c)^2}\ \text{and}\ \Pi_c=\frac{v\lambda_c^2}{(\mu-\lambda_c)^2}+\frac{\lambda_c^2\gamma r}{2(\lambda-\lambda_c)}. \tag{11.12}$$

An explicit solution for λ_c in (11.10) is provided in Mendelson and Parlaktürk (2008b).

In the following section we discuss the effect of some operational and market parameters on the profitability of MC and traditional approach studying their impacts on the equilibrium profits stated in Proposition 4.

11.6 Comparative Statics: Conditions Favoring MC

Table 11.1 shows comparative statics for the effects of various market and operating characteristics in monopoly and duopoly. These help us understand how competitive considerations affect the attractiveness of MC. The table shows that in some cases competition can entirely reverse the monopoly results. For example, the changes in customization rate and market size can affect the customizing firm in diametrically opposite directions in monopoly and under competition. Similarly, improving the unit holding cost is always beneficial for a monopoly, whereas it may be harmful for a traditional firm under competition. Likewise, the changes in customers' preference intensity r and replenishment lead time of standard products l can have opposite effects in monopoly and duopoly. These are derived and discussed in Mendelson and Parlaktürk (2008b). Overall, it was shown that the margin differential m_c-m_t

Table 11.1 Comparative statics in monopoly and duopoly of traditional vs. customizing firms.

	Traditional monopoly	Traditional firm in duopoly	MC monopoly	MC firm in duopoly
$d\Pi/d\lambda$	+	+	+ or 0	+ or −
$d\Pi/dr$	−	+ or −	0	+
$d\Pi/d\mu$	N/A	−	+	+ or −
$d\Pi/dh$	−	+ or −	N/A	+
$d\Pi/dl$	−	+ or −	N/A	+

plays a critical role in determining the outcome of these changes.

In this section, we focus on the effects of market size λ and customization rate μ.

11.6.1 Market Size λ

An increase in market size has two effects. It increases the size of the "pie," so each firms worries less about its market share and more about its profit margin, potentially softening the competition. But it also helps the traditional competitor decrease its unit fulfillment cost as a result of scale economies that characterize its operations. Both effects favor the traditional firm, therefore its profit always increases in market size. On the other hand, they affect the customizing firm in opposite directions, and the following proposition shows that either effect can dominate and an increase in market size may increase or decrease the customizing firm's profit.

Proposition 5. *(i)* $d\Pi_t/d\lambda > 0$.
(ii.a) If $\gamma r \leq 2v\lambda/\mu^2$ *then* $d\Pi_c/d\lambda > 0$.
(ii.b) If $\gamma r > 2v\lambda/\mu^2$*, there exists* $m^* \in (\underline{m}, \overline{m})$ *such that* $d\Pi_c/d\lambda < 0$ *for* $m_t - m_c > m^*$.

One can show that the traditional firm's unit fulfillment cost (holding + ordering) is equal to γr and the Proposition shows that when this is small, there is not much to be gained from economies of scale, hence the larger pie effect dominates. However, when γr is large, the customizing firm's profit decreases in market size if its margin disadvantage $m_t - m_c$ is above a threshold (e.g., due to high cost or low quality). Figure 11.1(a) shows the regions in which the profit of the customizing firm increases or decreases due to a larger market size, and Figure 11.1(b) shows the firm's profit rate for various margin differentials. The figure shows that the customizing firm has an ideal market size when its margin disadvantage is large either due to high cost or

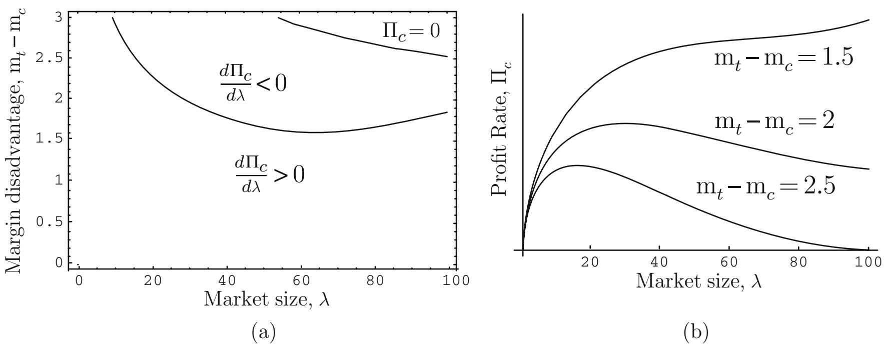

Fig. 11.1 Effect of market size ($S = 3$, $h = 0.15$, $k = 0.75$, $l = 6$, $v = 20$, $r = 80$, $\mu = 100$). (a) The regions in which the customizing firm's profit increases or decreases in market size. (b) The customizing firm's profit rate as a function of market size at various margin differentials.

low quality (recall that $m_t - m_c = w_t - w_c - (c_t - c_c)$). Furthermore, Figure 11.1(a) shows that this ideal market size decreases in the firm's margin disadvantage. This is because the traditional opponent cannot compete effectively in a small market due to its high unit holding and ordering cost. On the other hand, when the customizing firm's margin disadvantage is small, it can compete with the traditional firm head to head and it always prefers a larger market. Finally, when the customizing firm's margin disadvantage is in the middle in Figure 11.1(a), its profit decreases in market size unless the market is either sufficiently small or sufficiently large. This is because the traditional opponent cannot effectively compete in a small market, and the competition is mild in a large market.

11.6.2 Customization Rate μ

We now discuss the effect of improving the expected time needed to customize each unit, $1/\mu$, which reflects the capacity of the customizing firm as well as the difficulty or complexity of customization. Intuition suggests that customization should be more attractive when it takes less time. While this always holds for a monopoly, increasing μ may actually adversely affect the customizing firm in duopoly. The following proposition shows that the outcome critically depends on the firm's competitive position which is determined by the margin differential.

Proposition 6. *(i)* $d\Pi_t/d\mu < 0$.
(ii.a) If $\mu \geq 2\lambda$ *then* $d\Pi_c/d\mu > 0$.
(ii.b) If $\lambda < \mu < 2\lambda$ *then there exist* $m^* \in (\underline{m}, \overline{m})$ *such that* $d\Pi_c/d\mu < 0$ *for* $m_t - m_c > m^*$.

As might be expected, a shorter customization time always hurts the traditional firm. However, this can also be detrimental to the customizing firm itself. Specifically, when customization is not very fast and the customizing firm's margin advantage is below a threshold, improving its customization time hurts the customizing firm. Intuitively, longer customization delays create a degree of separation between customized and standard products, which softens the competition. When the customizing firm has a weak competitive position, it is not in its best interest to undermine this differentiation by speeding customization up through capacity expansion or design improvements even when these are free. Overall, the firm is more likely to benefit from a capacity expansion when it has a stronger competitive position.

11.7 Concluding Remarks

With this chapter we aim to contribute to the growing literature on the value and adoption of MC (Ahlström and Westbrook 1999; Agrawal et al. 2001; Zipkin 2001; Piller et al. 2004), studying how it relates to the firm's competitive position. 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. In our base model, the firms compete in a two-stage game: Firms first make their production technology decisions (i.e., whether to adopt MC) and then compete in prices. We consider two alternatives with regard to the customizing firms' price policies: When they can set a price menu for each configuration and when they have to set a uniform price. We solve for the resulting equilibrium and characterize when firms invest in MC under competition.

We find that the value of MC critically depends on the firm's competitive position. Ignoring competitive forces can lead to critically incorrect decisions for firms considering MC. While adopting MC always helps a monopolist extract more surplus from its customers, it may lead to a negative return (even before paying back the investment cost) in duopoly when the firm does not have a sufficiently strong competitive position. This is due to the adverse effect of MC on price competition. We show that a firm with an overall quality/cost disadvantage never adopts MC in equilibrium. Our results suggest that MC would be more suitable only for firms with sufficiently large quality or efficiency advantage. Furthermore, we find that ability to customize prices in conjunction with product customization would lead to a broader adoption of MC in the marketplace.

We then extend our base model to capture some key differences in the operations of a firm that follow MC: A customizing firm does not carry finished good inventories and it customizes to order resulting in customer waits. In contrast, a traditional firm usually fulfills customer demand using its inventories and it can provide instant availability from inventory. When the traditional firm backorders demand, this also results in customer waits. In our extended model, we assume that production technology decisions are already made and we study the competition between a customizing firm and a traditional firm.

Our results are useful for identifying how some market and operating characteristics affect profitability of MC when competing against a traditional firm. We find that a larger customization capacity does not always translate into higher profits under competition while it is always beneficial for a monopoly. Specifically, a larger capacity decreases the customizing firm's profit when the firm has a large margin disadvantage (either due to high cost or low quality). Intuitively, customization delays create a degree of separation between customized and standard products, which softens the price competition. When the firm has a weak competitive position, it is better off maintaining this separation. In addition, we show that a larger market does not necessarily increase the customizing firm's profit: When the customizing firm has a sufficiently large margin disadvantage, a larger market can hurt its profit. We find that in this case the customizing firm will be better off in a smaller market where the traditional competitor cannot compete effectively due to its scale economies. Overall, we find that the effects of both market size and customization rate on the profitability of the customizing firm are non-monotonic and their desirable levels depend on the firm's competitive position.

Our results may be extended in a number of ways. As is common in the literature that study MC (e.g., Mendelson and Parlaktürk 2008a; Alptekinoğlu and Corbett 2008; Syam and Kumar 2006; Jiang et al. 2006; Dewan et al. 2003), our product space is restricted to a single attribute. So adopting MC enables a firm offer product types same as or similar to that of its competitor which in turn intensifies the price competition. In contrast to our model, in a model with multiple product attributes a firm may benefit from adopting MC even with a margin disadvantage by customizing those attributes that will help distance itself from its competitor.

In practice, the firms not only decide whether to customize their products, but they also decide the degree of customization they will provide. For example, NikeID provides only style customization for its sneakers letting customers choose colors and imprint their names on the shoe, however it does not offer customized fit, whereas mi adidas offers customized fit in addition to customized colors and imprinted names. In Mendelson and Parlaktürk (2008b), the firms competitively choose their customization levels where a higher customization level requires a larger investment.

Allowing customers customize the product to their liking may have additional benefits beyond what is captured in our model, which would be fruitful to incorporate in further studies of MC. For example, MC may help a firm gain a better understanding of customer preferences and trends in the marketplace. The firm can then also improve configuration of its standard product offerings. For P&G, Reflect.com was reported to be one of its most efficient market research tools. Shoppers could create custom cosmetic products through Reflect.com. Data gathered provided valuable insights on customer needs and it also helped P&G improve its standard product line. Furthermore, offering a custom product allows a firm establish stronger ties with its customers. The customer invests in the customization process to communicate her preferences and that leads to higher switching cost. For example, in the case of Lands'End, the customer needs to provide numerous measurements for custom fit in addition to choosing her favorite style options. Lands'End stores this information making the repeat purchase more convenient for the customer compared to the hassle of describing her preferences again to another firm.

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