Selecting a Customization Strategy Under Competition: Mass Customization, Targeted Mass Customization, and Product Proliferation

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Abstract—**Customization requires not only an implementation of proper manufacturing systems but also a proper strategy regarding when firms should offer customized products and what the nature of customization should be. This paper questions 1) whether customization is better than no customization, and, if so, 2) what kind of customization strategy firms should adopt under competition. We find that customization is not optimal when the cost of soliciting customer preference information is sufficiently high. When competing firms choose to customize, we show that firms target only certain customer segments with customized products. We also find that the optimal customization strategy may require firms to offer only a few discrete product varieties. Despite the concern that customization may initiate price wars because customization reduces product differentiation, we find that customization does not escalate the price competition, because aggressive price competition exacerbates cannibalization. Although customers within the product line of a firm are charged higher prices, we show that on average customers are better off when firms adopt customization. However, unless the customization is quite cheap, when firms choose to customize, we find that firms cannot generate more profits than when firms offer only a single product.**

Index Terms—**Cannibalization, competition, customization, differentiation, flexible manufacturing systems, mass customization, operational flexibility cost, price competition.**

I. Introduction

MASS production enables manufacturing of standard products in large quantities at low unit costs. Customization, on the other hand, enables firms to provide goods and services that match individual customers' needs. Customization is often achieved by changing, assembling, or modifying standard products according to customers' desires [48]. Conventional manufacturing technologies typically serve one of these two production choices [19]. Dedicated machines in assembly lines achieve mass production of a standard product with high efficiency (or low marginal production cost) while inhibiting flexibility, whereas flexible machines in job shops facilitate production of different varieties of a product in batches while sacrificing efficiency. The advances in manufacturing technologies, such as flexible manufacturing systems (FMS), computer-aided design/manufacturing (CAD/CAM), and just-in-time (JIT), have changed the ways organizations produce and market consumer goods. Manufacturers no longer need to trade the efficiency of mass production for the flexibility of customization. These new technologies have improved the manufacturer's ability to produce customized products without a significant increase in marginal production cost.

These new dynamics of manufacturing have enabled firms to offer a large number of varieties in almost every conceivable product category. A study by Federal Reserve Bank of Dallas [14] reports that since the 1970s, the number of product varieties has increased dramatically: Frito-Lay chips from 10 to 78, personal computer models from 0 to 400, car models from 140 to 260, and car styles from 654 to 1212. The same study found that the average number of varieties offered by a single firm increased as well. Many firms offer multiple varieties tailored to meet diverse customer tastes, partly to target market segments unserved or poorly served by existing products. Customization also allows firms to charge higher prices for their offerings. Customers are frequently willing to pay a premium that reflects the added value of satisfaction that arises from individualized solutions [10]. Although firms take advantage of new capabilities of flexible manufacturing systems, they follow different product variety (customization) strategies. While some firms offer two or more discrete product varieties to serve their customer bases (i.e., *product proliferation*), others offer every possible variant of the product within their customization scope (i.e., *mass customization*) [49].[1] For example, a firm adopting the product proliferation strategy may offer a product in two colors- say, yellow and red- but a firm adopting the mass customization strategy may customize the product to any shade of color within the yellow-red band. In spite of advances in manufacturing technologies that enable various forms of customization, it is not clear whether firms can benefit from customization in the face of competition since rival firms can also adopt similar customization strategies. Besides, increasing the number of product varieties can have undesirable impacts on cost, quality, and responsiveness in a manufacturing environment [42], [58]. Therefore, firms should carefully assess the cost and benefit of customization over no

Manuscript received September 1, 2004; revised April 1, 2005 and May 1, 2005. Review of this manuscript was arranged by Special Issue Department Editor, T. Blecker.

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Digital Object Identifier 10.1109/TEM.2006.889064

[1]Both mass customization and product proliferation deliver goods and services that fit the needs of individual customers with a production efficiency that almost equals that of mass production [55].

customization before investing in customization technologies. Another issue confronting firms today is the design of an effective and profitable customization strategy. There are several customization strategies from which firms can choose. The selection of an appropriate customization strategy becomes even more critical in today's competitive markets because each customization strategy can affect competition differently. Therefore, a firm designing its customization strategy must answer several questions, including the following:

1) Should the firm choose product proliferation, mass customization, or a hybrid strategy? Or is it better for the firm not to customize at all?
2) How should the products be positioned within the firm's product line?
3) What should be the price of each product variety offered?

These decisions, of course, are influenced by both operational factors and market characteristics. Operational factors include the cost associated with investment in customization technologies that provide flexible manufacturing capabilities and/or the cost of obtaining customer preferences before manufacturing customized products, depending on the firm's choice of customization level. Market factors include competition, the extent to which a firm's decisions affect competing firms; segmentation, the extent to which a product variety extracts surplus from customer(s) to whom it is targeted; and cannibalization, the extent to which a product variety reduces a firm's profits from the other varieties it produces. This paper integrates these factors into a model for designing a firm's optimal customization strategy.

As mentioned above, moving from a single variety to customization requires a firm to acquire unique operational characteristics [58]. Firms have to be flexible enough to manufacture and distribute different varieties without significantly increasing the cost [58]. Depending on the requirements of the products, firms may gain flexibility through various manufacturing techniques, such as modular design, platform commonality, postponement, and configuration and/or logistics techniques to achieve integration, coordination, and transparency in the supply chain. Although these techniques help firms increase efficiency in customization, introducing flexibility requires a considerable initial investment that we call *operational flexibility cost* [28]. Production economics is such that firms incur an increasing marginal cost to acquire additional flexibility in manufacturing and logistics to offer a larger set of products that are tailored to heterogeneous consumer tastes [3]. Serving consumers with customized products first requires identifying their unique needs [48]. In addition to operational flexibility cost, firms incur *information elicitation cost*, which is the cost of interacting with customers to obtain specific information about their preference structure [58]. This cost increases at the same marginal rate with the number of customers for whom customized products are offered, because gathering and processing customer information is similar for each additional customer, irrespective of the collection method used [20].

Despite the promise of customization to produce anything that a customer wants, diversity in customer tastes, in addition to customization costs, hinders offering customized products to every customer. In reality, firms often customize according to a limited set of attributes along which customers' preferences vary. Following the convention in customization literature, we analyze firms' customization strategies by assuming that products are customized based on an attribute, which is either a single attribute or an aggregate attribute weighted over multiple attributes. Customization literature often uses a linear [32] or a circular [52] model of unit length to represent products that differ on the customization attribute. A point in the line or in the circle is considered to be a product variety. Customer preferences, or their ideal products, are assumed to be uniformly distributed along the unit line or circle. In this model, no customization strategy is represented as a point corresponding to a single product offered by the firm, whereas product proliferation strategy is captured by a set of discrete points corresponding to the product varieties offered by the firm. Mass customization strategy is represented by one continuous segment along the line or the circle. The firm adopting mass customization offers every product variety within this segment, known as the customization scope of the firm [46]. Though customization for the entire product space may be impossible to achieve, a firm may be able to achieve customization in more than one segment of the product space. That is, a firm may have multiple customization scopes, each representing a range of customized products, instead of product varieties in one continuous customization segment. We denote this hybrid strategy as *targeted mass customization*. Analysis of targeted mass customization is new to the customization literature and may explain why, in some markets, firms produce ranges of customized product varieties whereas in other markets firms only produce a number of discrete product varieties when they customize.

Our analysis of customization strategies under competition offers several insights into when firms should offer customized products, what the nature of customization should be, and how the selected strategy affects product line design, price competition, rent extraction, and social welfare. We find that the availability of flexible manufacturing systems is not a sufficient reason for firms to adopt customization. Customization is suboptimal when the cost of soliciting customer preference information is very high. Contrary to popular belief that firms will extend their product offerings as customization gets cheaper, we find that firms do not increase their customization scopes beyond a certain level even when the cost of customization does decrease. While consumers always benefit from customization, we find that, unless the cost of customization is sufficiently low, firms are worse off when they offer customized products instead of a single product. Competition between firms is the reason firms end up with such an inferior outcome even if firms adopt the optimal level of customization. When firms can aim customization at specific consumer segments, we show that offering a single customization scope may not be optimal. Firms offer either several customization scopes or several discrete products, depending on the cost of obtaining customer preferences *vis-à-vis* the price premiums associated with customized products. Compared to mass customization, targeted mass customization allows firms to lock in some customers between their customization scopes. This, in turn, enables firms to enjoy local monopolies within their product lines. Firms also save on customization cost by not offering customized product varieties to those customers. We find that firms always accommodate some noncustomization segments- those who are served with standard product varieties- in their product lines so long as customization is not absolutely free. Customization reduces differentiation between firms' product lines. However, this does not exacerbate the price competition.

Our paper contributes to the extant literature in several ways. First, we show that customization is not always the optimal choice for competing firms. Second, we find that firms may be better off by focusing on several discontinuous segments of the market instead of one continuous segment when customizing. Third, we show that the optimal customization strategy may be to introduce several product varieties instead of a range of products within a segment or multiple segments.

In Section II and III, we first summarize the relevant literature. Then, we describe our model and analyze the first model that compares customization with no customization to answer whether customization is better than none. Next, to find the best customization strategy, we analyze a second model that captures several customization strategies as special cases. After that, we compare customization strategies along several dimensions, such as price competition, rent extraction, and consumer welfare. We end the paper with some concluding remarks, managerial implications, limitations, and future research directions.

II. Literature Review

Our work on customization is related to the product line design studies that examine the breadth and positioning of product lines of competing firms. Since product line design strategies affect firms' decisions on production and marketing-mix elements, such as pricing and distribution channels, management of product variety has received great emphasis in the marketing, economics, and operations literature [31], [34]. The following paragraphs summarize the existing literature from these streams.

Because the idea of product variety conflicted with the concept of mass production, the main focus in the early days of manufacturing was on producing a single product. Correspondingly, much of the economics literature investigated monopolistic competition in which each firm offers one variety in the product space [21], [36], [57]. As competition intensified in many industries, and manufacturing technologies made it possible to increase variety without losing efficiency, the marketing and economics literature started to focus on the effect of product variety strategies on competition and how firms should cope with the adverse effects of competition by managing their customization strategies. Lancaster [37] reviewed possible product variety strategies. Brander and Eaton [7] analyzed the competition in product positioning between multiproduct firms by assuming that each firm in a duopoly produces two products. They showed that firms could tailor products for different market segments and accordingly charge higher prices. However, Martinez-Giralt and Neven [44] showed that, when faced with the choice of offering either one or two products, firms would choose one product because price competition outweighs the benefits of market segmentation when each firm offers two products. Recently, Cavusoglu and Raghunathan [9] concluded that the result in [44] is mainly driven by the specific functional form chosen for transportation cost and that product proliferation in fact can be the optimal strategy. The above studies focus on the customization strategies whereby firms can produce only distinct product varieties in the product space. Another stream of research investigates customization strategies in which firms offer all possible varieties within their customization scopes [5], [54]. Beckman [5] and Thisse and Vives [54] analyze the strategy by which firms customize by redesigning a basic product to suit consumer tastes. Since, in this case, customization is achieved through reconfiguring finished products, their models do not consider any ramification of customization in manufacturing environments. The extent of product customization is contingent upon a firm's flexibility to reconfigure its manufacturing resources, not its ability to reconfigure the finished products. This manufacturing flexibility can be measured as the range of product varieties offered by the firms. Mussa and Rosen [46] represent customization as a continuous spectrum of product characteristics. Although their model allows the firm to produce a range of product varieties, it ignores the cost of customization. In a later study, Dewan *et al.* [20] incorporate the missing cost of customization and analyze single-scope product customization. However, the single customization region that was exogenously imposed in [20], [46] does not allow firms to customize in some niche segments of the market. In this paper, unlike early studies, we relax the single-scope assumption and allow firms to focus on multiple niche scopes. This setup also enables firms to adopt product proliferation, which is to produce multiple discrete products. Our multiscope customization framework allows firms to trade off the cost of improving flexibility of production against the setup cost to accommodate multiscope customization. In fact, we show that firms may be better off by adopting targeted mass customization.

In marketing, product line design studies have focused on the number of products to be introduced, their positions, and their prices [27], [33], [37]. The customers were assumed to be differentiated either vertically or horizontally based on product attributes [2], [8], [12], [18], [29], [45], [56]. Customers are *vertically differentiated* if all customers agree that the attribute of differentiation is the quality, and that customers differ in their willingness to pay more for higher quality. However, customers are *horizontally differentiated* if the differentiation occurs based on product attributes other than product quality. For example, customers are said to be horizontally differentiated if their preferences change with respect to the size of the back-pockets of a pair of jeans. In other words, the size of the pocket is not regarded as a determinant of quality. Following the seminal work of Hotelling [32], many studies in the product variety literature have considered horizontal differentiation. In this paper, we also characterize customization in a horizontally differentiated market. Prior studies have generally assumed customer self-selection [45]. That is, each customer is entitled to choose the product variety that gives the highest utility. Since a customer can choose to purchase a product intended for a different customer segment if he/she gets a higher utility from it, cannibalization- competition between product varieties offered by the same firm- can pose challenges to firms offering multiple varieties. Hence, because customization requires careful pricing and location decisions, when we analyze customization strategies among competing firms, we explicitly consider cannibalization and eliminate it by using an appropriate pricing scheme.

Since customers can have diverse valuations for the same product, offering a standard product with a customized price has recently been discussed as an effective way to sustain competitiveness in some markets. Today, firms such as direct marketing firms, catalog retailers, credit card companies, and long-distance phone companies, can determine how much each customer is willing to pay and, in response, offer their products at an individual price that extracts the highest rent from each customer [11]. However, such a strategy only offers a customized price without a customized product. In this paper, firms not only produce customized varieties but also charge customized prices. Therefore, because customization strategies are production driven, they take into account both cost elements and price premiums associated with customization.

Much of the work in the operations management area has focused on manufacturing strategies (techniques and methods) that support a high product variety [22], [38], [40], [41]. Krishnan and Ulrich [35] review product development and design literature. Lee [39] proposes postponement as a strategy to alleviate prohibitive costs of producing large product varieties. Desai *et al.* [17] propose a modular design that enables sharing components to maintain quality. Netessine and Rudi [47] examine the tradeoff between production and supply chain costs in decisions on product variety. Smith and Agrawal [53] consider joint inventory and product line design. In this paper, instead of analyzing a specific technique or method to support customization, we incorporate the cost of customization into our model regardless of techniques used to support customization. This level of abstraction allows us to simultaneously capture marketing and manufacturing aspects of customization to determine the optimal customization strategy.

Empirical studies on product variety aim mainly at determining external and internal factors that influence firms' product variety strategies. In one group of studies, market forces and industry structure are used to explain firms' decisions on product variety. Connor [13] concludes that imperfect market structures lead to higher levels of product proliferation in many food categories. Bayus and Putsis [4] find that the extent of product variety in the computer industry depends on the firm's market share and the costs of supplies. In a later paper, Putsis and Bayus [50] find that firms increase product varieties when industry barriers are low and market opportunities are perceived to exist. In the other group of studies, the focus is on identifying and measuring the variety-related product losses. Fisher *et al.* [24] observe that greater product variety causes an increase in overhead cost, quality problems, the risk of stockouts, and the need for rework in the automobile industry. They suggest that firms need to commit more resources to support smooth operations as they increase the number of product varieties. MacDuffie *et al.* [43] discover that labor productivity decreases as the mean option content per vehicle increases. Fisher and Ittner [23] find that the greater day-to-day variability in option content, but not the mean option content per car, significantly increases total labor hours per car, overhead hour per car, assembly line downtime, and inventory level. They also show that bundling options improves performance as it reduces the random variability in options included in the cars manufactured. Randall and Ulrich [51], using data from the U.S. bicycle industry, show that a firm's product variety strategy depends on its supply chain cost, which comprises production cost and cost of reaching the target market successfully. However, they find no evidence to suggest that offering multiple varieties through strategies such as customization or variety postponement results in higher firm performance. Another study also finds that increasing variety using platform approach does not always increase the profitability of product line [30]. Given our finding on profitability of customization, we might speculate that firms in those industries did incur high customization costs that prevented them from enjoying the benefits of customization, compared to the single product case.

III. Model

We consider two symmetric firms that are determining their customization and pricing strategies. We model the product space, which represents all possible variations of a specific product, and uniform distribution of customer preferences,[2] along a unit circle. The circular model of product space was first introduced by Salop [52] to eliminate the end point difficulties of Hotelling's linear model [32].[3] In our circular model, firms are located at the opposite ends. Each firm can offer one or more products within its product space. We model the competition between firms as a two-stage game. In the first stage, firms simultaneously choose their customization strategies. They simultaneously determine their prices in the second stage. In Section III, we first analyze whether customization is preferred over no customization when customization technologies are readily available to both firms. If customization is an optimal strategy when there is competition, we next address what kind of customization strategy—namely, mass customization, targeted mass customization, or product proliferation—firms should adopt. Finally we compare various customization strategies to analyze their effects on product line design, price competition, rent extraction, and consumer welfare.

A. *Should a Firm Customize at All?: Customization Versus No Customization*

In this section we capture customization within a single scope. When a firm chooses to customize, it offers every customer within its *customization scope* (customization segment) a product that perfectly fits his/her preference. We capture the customization scope of a firm as a continuous arc along the circle that represents its product space. The length of customization scope determines the cost of customization. For a customization scope of length x, firms incur a cost of $ax^2 + bx$.[4] The first term is associated with *operational flexibility* that encompasses manufacturing, distribution, and customer service

[2]This is a standard assumption in product variety literature in economics. Although some operations literature uses a beta distribution to represent customer preference, it has been used only in a monopolistic setting.

[3]Our results also apply to the linear model of product space.

[4]There may also be a fixed production cost that is independent of x. However, this can be normalized to zero.

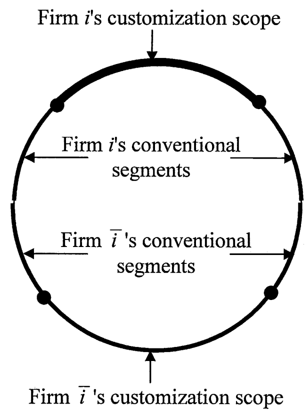

Fig. 1. Conventional and Customization Segments in Duopoly.

costs [28]. The second term models the *information elicitation* cost of obtaining customer preferences [58]. A customer located y distance away from the location of a product, which is priced at p, receives a utility of $r - p - ty$, where r is the reservation price that a customer is willing to pay and t is the misfit cost per unit distance.[5] Each customer in the market who has a unitary demand chooses the product that gives him/her the highest utility. A customer located in a firm's customization scope can purchase a product variety that perfectly fits his/her preference, but a customer who is located outside the firm's customization scope cannot. Customer segments served by the firm but not covered by the customization scope are often denoted as *conventional segments*, as depicted in Fig. 1. Note that no customization is a special case of the customization model depicted in this section. If the firm's optimal customization scope is zero, it implies that the firm prefers no customization over customization, because customization scope of zero length effectively means that the firm offers only a single product variety.

Firm i charges p_i for *standard products*, which are the products positioned at the edges of its customization scope. It charges $p_i(z)$ for the product located z (where $z < x/2$) units of distance away from the standard product within the customization scope. A firm's profit expression under mass customization can be specified as

$$\pi_i = 2\left\{p_i\left[\frac{p_{\bar{i}} - p_i}{2t} + \frac{1 - x_i - x_{\bar{i}}}{4}\right] + \int_0^{x_i/2} p_i(z)dz\right\} - ax_i^2 - bx_i \quad \forall\, i \neq \bar{i} \in \{1,2\}. \tag{1}$$

Intuitively, a firm can charge higher prices for product varieties within its customization scope than for its standard products. We can show that the firm chooses a linear discriminatory pricing scheme $p_i(z) = p_i + tz$ for the product varieties within its customization scope. This pricing scheme follows from the observation that firm i can extract as much as the disutility that a customer would suffer if he/she were to purchase a standard product.[6] The term tz represents the price premium associated with customization, because a customer who is located z distance away from the standard product is willing to pay this much more to get his/her ideal product.

In the first stage, firms choose the sizes of their customization scopes simultaneously by maximizing their respective profits.

$$\max_{x_i} \pi_i \quad \forall\, i \in \{1,2\}. \tag{2}$$

In the second stage, they determine prices for their products simultaneously

$$\max_{p_i} \pi_i \quad \forall\, i \in \{1,2\}. \tag{3}$$

We solve the problem using backward induction. Solving optimization problems given in (3) simultaneously with respect to prices leads to the pricing of standard products as

$$p_i = t\left(\frac{1}{2} + \frac{x_i - x_{\bar{i}}}{6}\right) \quad \forall\, i \neq \bar{i} \in \{1,2\}. \tag{4}$$

Before moving to the first stage, we need to ensure that the pricing strategy profile in (4) is subgame perfect. For a strategy profile in a multistage game to be subgame perfect, no player should gain by deviating from the action prescribed in the strategy profile at any stage of the game (Fudenberg and Tirole [25, p. 108]). The price expressions in (4) characterize the pure strategy equilibrium in the price subgame if and only if neither firm can be better off by charging a different price. Since the customization problem is a two-stage game, to verify subgame perfectness, we need to check whether any choice of customization scope sizes in the first stage would lead one of the competing firms to deviate from the stated equilibrium pricing strategy. D'Aspremont and Gabszewicz [16] show, in the context of single product case, that if the firms' products are closely located, then there is no pure strategy equilibrium in the price subgame. In our single scope customization model, we need to check if attaining equilibrium in the price subgame

[5]Misfit cost captures how sensitive the customer is to product differences. Through customization, firms charge more for customized products than standard products. As we show later in the paper, misfit cost corresponds to price premium associated with customized products.

[6]If firm i charges higher than the price shown in the linear pricing scheme, the customer will choose to purchase the standard product. If it charges a lower price, the firm will not extract the whole rent. Therefore, the linear discriminatory pricing scheme is optimal.

$$\pi_i = \begin{cases} p_i\left(\frac{p_{\bar{i}} - p_i}{t} + \frac{(1 - x_i - x_{\bar{i}})}{2}\right) + p_i x_i + \frac{t x_i^2}{4} - a x_i^2 - b x_i & \text{if } |p_i - p_{\bar{i}}| \le \frac{t}{2}(1 - x_i - x_{\bar{i}}) \\ p_i(1 - x_i) + p_i x_i + \frac{t x_i^2}{4} - a x_i^2 - b x_i & \text{if } p_i < p_{\bar{i}} - \frac{t}{2}(1 - x_i - x_{\bar{i}}) \\ -a x_i^2 - b x_i & \text{if } p_i > p_{\bar{i}} - \frac{t}{2}(1 - x_i - x_{\bar{i}}) \end{cases} \tag{5}$$

$$p_i^*(p_{\bar{i}}) = \begin{cases} \frac{p_{\bar{i}}}{2} + \frac{t}{4}(1 + x_i - x_{\bar{i}}), & \text{if } |p_i^* - p_{\bar{i}}| \le \frac{t}{2}(1 - x_i - x_{\bar{i}}) \\ p_{\bar{i}}^* - \frac{t}{2}(1 - x_i - x_{\bar{i}}) - \xi, & \text{otherwise} \end{cases} \tag{6}$$

can be an issue. Formally, given the customization strategy, for p_i to be a pure strategy equilibrium for firm i, we must have $\pi_i(p_i) \ge \pi_i(p_i - \xi)$, for any $\xi > 0$. The profit expression given in (1) assumes that the subgame perfection is not violated. By considering deviations in the pricing stage, the complete characterization of the profit for firm i can be written in terms of firms' scope sizes and prices as shown in (5) at the bottom of the previous page.

It is clear that the profit function exhibits two discontinuities. Therefore, the optimal price reaction can be expressed as shown in (6) at the top of the page.

If $p_i = p_{\bar{i}}^* - (t/2)(1 - x_i - x_{\bar{i}}) - \xi$, the customers in the market segment that firm $\bar{i}$ is supposed to serve would prefer to buy from firm i. Hence, firm i captures the entire market. The price expression in (4) is the equilibrium if and only if firm i's profit under these prices is not less than the profit when it captures the entire market by deviating from the price equilibrium. For a given customization scope, the profit of firm i under the price equilibrium is

$$\begin{aligned} \pi_i^1 &= \pi_i\left(p_i^* = t\left(\frac{1}{2} + \frac{x_i - x_{\bar{i}}}{6}\right), p_{\bar{i}}^* = t\left(\frac{1}{2} + \frac{x_{\bar{i}} - x_i}{6}\right)\right) \\ &= \frac{t}{36}\left(10x_i^2 - 2x_i(x_{\bar{i}} - 3) + (x_{\bar{i}} - 3)^2\right) - ax_i^2 - bx_i. \end{aligned}$$

If firm i chooses to charge $p_i = p_{\bar{i}}^* - (t/2)(1 - x_i - x_{\bar{i}}) - \xi$ when the firm $\bar{i}$ chooses the optimum price of $p_{\bar{i}} = t\left((1/2) + (x_{\bar{i}} - x_i/6)\right)$, the profit of firm i for a given customization scope is

$$\begin{aligned} \pi_i^2 &= \pi_i\Bigg(p_i^* = p_{\bar{i}}^* - \frac{t}{2}(1 - x_i - x_{\bar{i}}) - \xi, p_{\bar{i}}^* \\ &\qquad = t\left(\frac{1}{2} + \frac{x_{\bar{i}} - x_i}{6}\right)\Bigg) \\ &= \frac{t}{12}\left(4x_i - 3x_i^2 + 8x_{\bar{i}}\right) - ax_i^2 - bx_i. \end{aligned}$$

A quick comparison of π_i^1 and π_i^2 reveals that any deviation from the pricing equilibrium for firm i is not profitable (i.e., $\pi_i(p_i) \ge \pi_i(p_i - \varepsilon)$) under the following condition:

$$\left(\frac{1}{2} + \frac{x_i - x_{\bar{i}}}{6}\right)^2 \ge \frac{1}{3}(x_i + 2x_{\bar{i}}). \tag{7}$$

A similar condition can be obtained for firm $\bar{i}$ as

$$\left(\frac{1}{2} + \frac{x_{\bar{i}} - x_i}{6}\right)^2 \ge \frac{1}{3}(x_{\bar{i}} + 2x_i). \tag{8}$$

Thus, when either (7) or (8) is not satisfied, then at least one firm has an incentive to deviate from the pricing strategy given in (4). It is clear that the price equilibrium is stable when conditions (7) and (8) are satisfied. Further, firms have to ensure that customization scopes are nonnegative. In other words

$$x_i \ge 0 \quad \forall\, i \in \{1, 2\}. \tag{9}$$

When (7)–(9) are satisfied, the pricing game is subgame perfect. Thus, to ensure the stability of pure strategy price equilibrium, firms should solve the following constrained optimization problem simultaneously

$$\begin{aligned} &\max_{x_i} \pi_i \quad \forall\, i \in \{1, 2\} \\ &\text{s.t. } (7),\ (8),\ \text{and } (9). \end{aligned} \tag{10}$$

The optimal solution to the single scope customization problem is given in Proposition 1.

Proposition 1: The two-stage game in customization scopes and conventional market prices has a unique subgame perfect equilibrium in pure strategies of

$$\langle x_1, x_2, p_1, p_2 \rangle = \begin{cases} \left\langle \frac{1}{4}, \frac{1}{4}, \frac{t}{2}, \frac{t}{2} \right\rangle, & \text{if } a \le \frac{7t}{12} - 2b \;\&\; b \le \frac{t}{6} \\ \left\langle \frac{t-6b}{12a-3t}, \frac{t-6b}{12a-3t}, \frac{t}{2}, \frac{t}{2} \right\rangle, & \text{if } a > \frac{7t}{12} - 2b \;\&\; b \le \frac{t}{6} \\ \left\langle 0, 0, \frac{t}{2}, \frac{t}{2} \right\rangle, & \text{if } b > \frac{t}{6} \end{cases}. \tag{11}$$

Proof: Refer to the Appendix.

From (11), the equilibrium profit of firm i can be found as

$$\pi_i = \begin{cases} \frac{17t-4a-16b}{64}, & \text{if } a \le \frac{7t}{12} - 2b \;\&\; b \le \frac{t}{6} \\ \frac{18b^2+18at-5t^2}{72a-18t}, & \text{if } a > \frac{7t}{12} - 2b \;\&\; b \le \frac{t}{6} \\ \frac{t}{4}, & \text{if } b > \frac{t}{6} \end{cases}. \tag{12}$$

Fig. 2 illustrates Proposition 1. As can be seen from the figure, firms' customization cost (a and b) relative to customers' misfit cost (t) determines whether firms choose customization over no customization, and if they do, the extent of customization. Proposition 1 offers several insights. First, customization is optimal only when gathering customer preferences is relatively cheap compared to customers' marginal disutility associated with buying a nonideal product. That is, if it is too costly to elicit customer preference information, it is worthwhile not to adopt customization. In such a case, each firm is better off by offering a standard product. However, Internet technologies, such as online registration, cookies, and filtering tools, enable firms to understand customer preferences at low costs (b can be actually very small). Therefore, we can say that if firms use these technologies effectively, they will find customization a reality in many product categories, irrespective of how expensive it is to produce customized products. The cost of flexible manufacturing (a) will only affect the extent of customization. Second, we show that the common belief that "with more advanced customization technologies available, the firms will expand their customization scopes" [20] might not be always

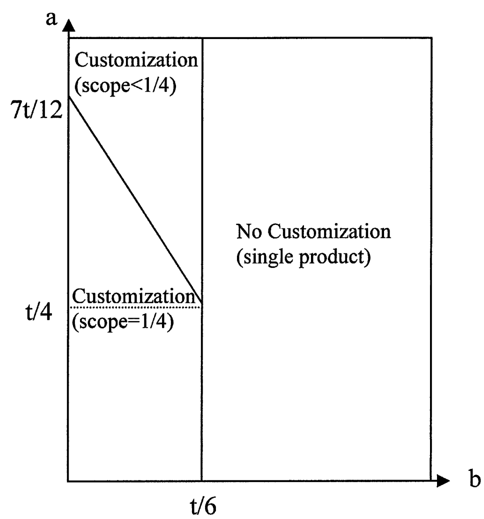

Fig. 2. Equilibrium Regions with Respect to Cost Parameters.

true. Customization scope of firms does not keep increasing as a decreases. In fact, once the customization scope reaches 1/4, a further decrease in a does not change the customization scope. Our results show that with customization in duopolistic competition, a maximum of fifty percent of customers are offered customized products and the other fifty percent buy standard products, irrespective of the cost of customization.[7] Third, when firms prefer customization (i.e., $b \leq t/6$), a decline in the cost of customization (the cost of operational flexibility or the cost of eliciting customer information) does not always lead to more competition between firms and lower profits for firms. Although a reduction in a or b first leads to a decrease in the firms' profits, we find that the decrease in the firms' profits may not be indefinite. Indeed, once the customization scope reaches its maximum limit (because of a drop in a or b or both), a further decrease in flexibility cost and/or elicitation cost always results in an increase in profits. This is because a decrease in the cost of customization increases competition between firms and results in more customization. However, since firms do not extend their customization scopes indefinitely, after reaching the maximum customization level, firms start enjoying the positive effect of cost savings on their bottom lines. The above results are the direct interpretation of partial derivatives of a firm's profit and customization scope size with respect to customization cost parameters (a and b).

One can measure the value of customization over no customization in terms of additional profit that it generates for firms. The value of customization can be obtained by comparing profits of firms when they adopt customization with profits when they offer only a single product. The following proposition summarizes this comparison.

Proposition 2: Relative to the case in which both firms offer a single product, firms are 1) always worse off when they adopt customization with less than the maximum customization scope, and 2) better off when they adopt customization with the maximum customization scope if and only if firms can recover the cost of customization through price premiums (i.e., $a + 4b < (t/4)$).

This result does not imply that firms do not adopt customization unless it is more profitable than no customization. Customization is the outcome of simultaneous decisions made by the firms under competition. Competition leads firms to customize when $b < (t/6)$. It is easy to show that each firm prefers to customize if its rival customizes. Proposition 2 implies that firms are not always better off with customization. This unintuitive result can be explained by analyzing the forces that affect profit expressions of firms. When firms customize with a scope of size less than 1/4, although they get additional rent from customers who purchase customized products, the additional revenue through price premiums is not enough to cover the cost of customization. The additional revenue required to offset the cost of customization is generated only when firms customize at the maximum extent and the cost of customization is sufficiently small, as specified in Proposition 2. Hence, customization in the duopoly case can lead competing firms to the Prisoner's dilemma.[8]

In this section we assume that each firm offers a single customization scope. However, offering a single customization scope, even if it turns out to be better than no customization, may not be the optimal customization strategy. The optimal customization strategy may require firms to produce multiple discrete products or to customize with multiple customization scopes. In Section III-B we formulate and solve the customization problem with a more general model that endogenizes the number of customization scopes to accommodate various customization strategies.

B. Selecting the Optimal Customization Strategy

In this model, we assume that firm j introduces N_j customization scopes on each semi-circle,[9] as shown in Fig. 3. Each customization scope is represented with an arc in the unit circle. The size of customization scope i of firm j is denoted as x_{ij}.[10] As in Section III-A, the products at the boundary of each customization scope are referred to as conventional products. Between the conventional products in each customization scope, firms produce customized products. Competing firms locate their closest conventional product varieties y distance away from each other. Firm j leaves $y_{(i+1)j} - x_{ij}$ distance between its ith and $(i+1)$th customization scopes. Customers in these segments are not offered customized products.

[7]In this paper, we assume that operational flexibility cost is a quadratic function of the customization scope. This form implies that marginal cost of customization increases as the scope of customization increases (i.e., $\partial^2(\text{operational flexibility cost})/\partial x^2 > 0$). However, any functional form with increasing marginal cost, such as e^x, is sufficient to get the same qualitative results. The function form of operational flexibility cost only affects the value of the maximum customization scope.

[8]Prisoner's Dilemma is a famous game in game theory to explain a conflict between individual and group rationality and to show how a group whose members pursue rational self-interest may all end up worse off than a group whose members act contrary to rational self-interest. The game gets its name from a hypothetical situation where two criminals arrested under the suspicion of having committed a crime together. Each prisoner has only two choices: *cooperate* (i.e., not confessing to the police) or *defect* (i.e., confessing to the police). Since neither prisoner knows what the other prisoner would choose, even each prisoner gets more jail time when both defect than that when neither defects, each prisoner prefers to defect in the equilibrium. The payoff structure of customization in duopoly resembles the classical prisoner's dilemma game in some cases. Since the profit when neither firm customizes is less than the profit of the customizing firm whose competitor chooses not to customize, each firm is "tempted" to customize in those cases. Hence, in the equilibrium, both firms customize and end up with less profit than the profit they would have gained had both chosen not to customize.

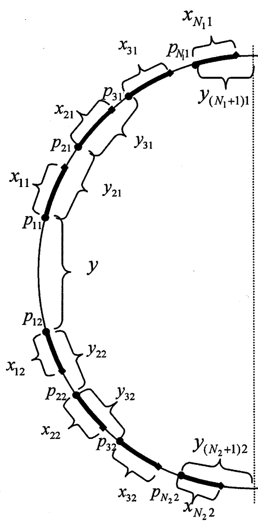

Fig. 3. Customization Structure.

Firm j charges p_{ij} and p'_{ij} for its conventional products located at the boundaries of its customization scope i. The price of a customized product located at a distance z from the conventional product priced at p_{ij} is given by $p_{ij}(z)$. Similar to the setup in Section III-A, firm j incurs a cost of $ax_{ij}^2 + bx_{ij}$ for offering customization scope i. Compared to a manufacturing environment that enables customization with the single scope of size x, a manufacturing environment enabling customization with multiple scopes of *total* size x is less flexible. This is because a manufacturing plant achieving multiple-scope customization cannot readily move from producing product varieties in one customization scope to producing product varieties of the others. To do so, the firm has to incur a *setup cost* to accommodate multiscope customization in a semi-flexible environment, such as cost associated with model changeover, changing fixtures, or underutilization of machinery [1, p. 58]. For example, as the number of body styles increases within an automobile plant, higher setup costs are incurred at the body framing area due to switching between body styles [43, p. 353]. We assume that firm j incurs a setup cost of $f(N_j)$. We do not impose any functional form for f. Our results work with any $f(N_j)$ that increases in N_j. Then the profit of firm j can be written as[11]

$$\begin{aligned}\pi_j =& p_{1j}\left(\frac{p_{1\bar{j}} - p_{1j}}{2t} + \frac{y}{2}\right)\\ &+ \int_0^{x_{1j}} p_{1j}(z)dz + p'_{1j}\left(\frac{p_{2j} - p'_{1j}}{2t} + \frac{y_{2j} - x_{1j}}{2}\right)\\ &+ \sum_{i=2}^{N_j}\left(p_{ij}\left(\frac{p'_{(i-1)j} - p_{ij}}{2t} + \frac{y_{ij} - x_{(i-1)j}}{2}\right)\right.\\ &\qquad + \int_0^{x_{ij}} p_{ij}(z)dz\\ &\qquad \left. + p'_{ij}\left(\frac{p_{(i+1)j} - p'_{ij}}{2t} + \frac{y_{(i+1)j} - x_{ij}}{2}\right)\right)\\ &- \sum_{i=1}^{N_j}\left(ax_{ij}^2 + bx_{ij}\right) - f(N_j). \qquad (13)\end{aligned}$$

This customization model incorporates various customization strategies speculated in previous sections as special cases. For instance, when the optimal customization strategy requires a firm to place its customization scopes adjacent to each other without any noncustomization segment between them (i.e., $\sum_{i=1}^{N_j} x_{ij} > 0$ and $\sum_{i=1}^{N_j} y_{(i+1)j} - x_{ij} = 0$), this model reduces to the single-scope (mass) customization. If the placement of customization scopes is such that there is at least one noncustomization segment between adjacent customization scopes (i.e., $\sum_{i=1}^{N_j} x_{ij} > 0$ and $\sum_{i=1}^{N_j} y_{(i+1)j} - x_{ij} \neq 0$), then multiple-scope (targeted mass) customization is the optimal customization strategy. Finally, when the optimal customization strategy leads to multiple discrete product varieties (i.e., $\sum_{i=1}^{N_j} x_{ij} = 0$), then the model reduces to product proliferation. Hence, these three customization strategies- mass customization, targeted mass customization, and product proliferation- collectively cover all possibilities.

The game is played in two stages. In the first stage, firms simultaneously determine the numbers, locations, and sizes of customization scopes to maximize their profits

$$\max_{N_j, \forall\, x_{ij}, \forall\, y_{ij}} \pi_j \quad \forall\, j \in \{1,2\}. \qquad (14)$$

In the second stage, they simultaneously choose the prices of their products

$$\max_{\forall\, p_{ij}} \pi_j \quad \forall\, j \in \{1,2\}. \qquad (15)$$

We first solve the pricing problem given in (15) and then the customization problem given in (14). The pricing problem for the multiple-scope customization is similar to that for the single-scope customization. Therefore, we just present the solution to the pricing problem. To extract the maximum rent possible, firm j sets the price of the conventional product in customization scope i using the following scheme:

$$p_{ij} = p_{(i-1)j} + ty_{ij}. \qquad (16)$$

Similarly, the price of a customized product located at distance z away from a conventional product in scope i of firm j is set at

$$p_{ij}(z) = p_{ij} + tz. \qquad (17)$$

Therefore, the conventional product at the other end in scope i of firm j (i.e., the one located further from the competitor) is priced at

$$p'_{ij} = p_{ij} + tx_{ij}. \qquad (18)$$

[9]Because of the symmetric arrangements of products on each half of the circle, firm j has a total of $2N_j$ customization scopes.

[10]Index i starts with the scope closest to competitor's product line and increases as we move to the center of the firm's product line.

[11]π_j represents the profit generated from the half of firm j's market segment and $j \neq \bar{j} \in \{1,2\}$.

When we substitute (16)–(18) into (13) and solve the problem given in (15), we find the optimal prices as

$$p_{1j} = t\left(\frac{1}{2} + \frac{Y_j - Y_{\bar{j}}}{3}\right) \quad \forall j \in \{1,2\} \tag{19}$$

where $Y_j = \sum_{i=2}^{N_j+1} y_{ij}$.

In order to ensure stability of the price equilibrium, we have to impose some conditions on Y_j. Following the steps described earlier in Section III-A, we obtain the following constraints:

$$t\left(\frac{1}{2} + \frac{Y_1 - Y_2}{3}\right)^2 \geq \frac{2t}{3}(Y_1 + 2Y_2) \tag{20}$$

$$t\left(\frac{1}{2} + \frac{Y_2 - Y_1}{3}\right)^2 \geq \frac{2t}{3}(Y_2 + 2Y_1). \tag{21}$$

We also know that each scope has a nonnegative size. In other words,

$$x_{ij} \geq 0 \quad \forall i, j. \tag{22}$$

In the first stage, firms solve the optimization problem in (14) such that (20)–(22) are satisfied. The solution to this problem is summarized in Proposition 3.

Proposition 3: Optimal customization strategy requires that 1) each firm introduces $2 * N$ number of scopes where $N = \arg\min_{N_j}\{\mathcal{L}_j\}$. 2) The location of each scope is $y_{ij} = 1/8N$. 3) The sizes of the scopes are

$$x_{ij} = \begin{cases} \frac{t-8bN}{8N(t+2a)}, & \text{if } \frac{1}{8N} \geq \frac{b}{t} \\ 0, & \text{if } \frac{1}{8N} < \frac{b}{t}. \end{cases} \tag{23}$$

We see from Proposition 3 that when $b > t/8N$, firms offer only discrete products. Specifically, each firm offers $2N$ conventional products with no customization scope around them. This result contradicts the belief that a firm always prefers having customization with scopes [20]. When firms choose to introduce standard products, they prefer to attain neither maximum differentiation nor minimum differentiation, but a certain level of differentiation. This result is analogous with the findings in [16]. When $b \leq t/8N$, each firm offers $2N$ customization scopes. Each customization scope has the same length, and is separated at an equal distance from the edges of two of the firm's adjacent customization scopes.

Fig. 4 illustrates Proposition 4 for the case in which $N = 1$. We can see that when firms prefer customization with scopes, each firm introduces customization regions at the boundaries of its product line and does not introduce any customization region at the center of its product line. When firms prefer product proliferation, each firm introduces only two conventional products at its boundaries.

Corollary 1: When demand is inelastic (i.e., t is high) and/or eliciting customer preference information is not costly (i.e., b is low), firms choose to implement customization with multiple scopes. However, when demand is elastic and/or eliciting customer information is costly, firms choose to introduce a set of conventional product varieties.

This corollary describes the relationship between operational and market characteristics in choosing the optimal customization strategy. The demand elasticity, a market characteristic, or the cost of eliciting customer information, an operational characteristic, can be enough to determine whether the firm is better off with customization with multiple scopes (mass or targeted mass) or product proliferation. If firms serve customers who are not sensitive to price changes or have access to inexpensive technology to collect customer preference information, they should implement customization with multiple scopes. Otherwise, firms should adopt product proliferation as a customization strategy.

Customization in some industries confirms our finding in Corollary 1. In the breakfast cereal industry, although customer tastes are heterogeneous, customers are not sensitive to changes in ingredients. For instance, although they may prefer wheat over corn, they may not choose cereal based on Vitamin B6 content (i.e., t is low). This argument is consistent with the empirical finding that consumers are sensitive to price change in cereals [26]. As a result, as predicted in our model, firms produce various breakfast cereal brands (varieties) for different grain types. Corollary 1 also explains why traditional footwear manufacturers produce shoe pairs based only on foot length since it is very costly to obtain exact fit characteristics of each customer (i.e., b is high). Although 3-D foot scanning systems can obtain these fit measures, it is prohibitively costly to install such systems. If customers themselves knew their fit measures and revealed them to manufacturers, manufacturers could adopt (mass or targeted mass) customization. Given that multiple-scope customization is optimal (i.e., b is low or t is high), the following corollary shows when a firm should prefer mass customization over targeted mass customization.

Corollary 2: Unless operational flexibility cost and cost of eliciting customer information are both zero (i.e., $a \rightarrow 0$ and $b \rightarrow 0$), firms will always have customers between their customization segments who will be served with conventional products.

This is because the size of each customization segment is equal to the distance between the edges of two adjacent segments (i.e., $x_{ij} = y_{ij}$) only when both a and b are zero. This implies that mass customization is the optimal customization strategy only when customization is costless. Otherwise (i.e., when either a or b is not zero) each firm prefers targeted mass customization over mass customization and offers customized product varieties to $2\sum_{i=1}^{N_j} x_{ij} = ((t - 8bN)/4(t + 2a))$ fraction of customers. The remaining customers are served with the conventional products. Most firms offering customized products today do not produce every possible variety that customers prefer to buy. Consider Factory 121, a Switch watch maker, as an example. The company allows a customer to design a watch for his/her unique taste by choosing among available alternatives for each component such as case, bezel, crown, dial, and strap. The combinations offered are almost infinite [48]. However, not all combinations are allowed. Factory 121 eliminates the cost of eliciting customer information by using an interactive website. It also reduces operational flexibility cost considerably by starting the design process with a partially assembled watch. Since cost of customization is not exactly zero, our model may explain why not all combinations are allowed and

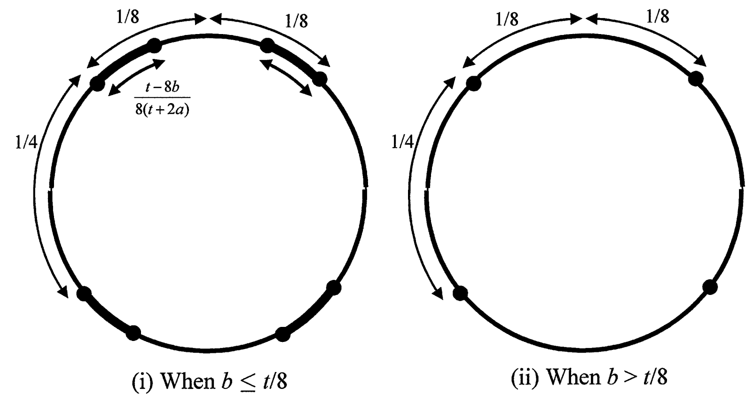

Fig. 4. Locations of Products Along the Unit Circle When $N = 1$.

customers who prefer those combinations can only purchase the variety which is closest to their ideal product variety. The result in Corollary 2 is very important since it implies that, although the mass customization can be better than no customization as described in Section III-A, mass customization cannot be better than targeted mass customization if customization is not costless.

Corollary 2 provides important insights for customization of digital goods.[12] Unlike traditional (nondigital) goods, once a digital product is ready, it is easy to modify it to meet the needs of various customer types. Therefore, in the case of customization of digital goods, a is negligible. In addition, widespread availability of personalization services on the Internet makes collecting customer preferences almost costless. By creating personal profiles, customers reveal their preferences to manufacturers. So b can be zero for some digital goods[13]. Thus, we can conclude that mass customization is the best strategy for customization of digital goods as long as eliciting preference structure of customers and delivering digital goods for individual tastes are costless. For instance, many financial portals, such as Yahoo Finance, can be personalized based on consumers' preference to see stock prices, market announcements, performance ratings, and expert recommendations regarding their portfolios. With the help of its sophisticated web technologies, Yahoo is able to deliver mass customized contents satisfying diverse needs of customers. Mass customization can also be the best strategy for some nondigital goods. Customers can design their own products by interacting with online design sites. For instance, Reflect.com sells customized cosmetic products [15]. The bases for customization of many cosmetic products are color and shininess. Because a system that can produce red-shiny lipsticks is flexible enough to produce pink-matte lipsticks, and because customers reveal their preferences directly through the site, customization for Reflect.com is almost costless. Therefore, Reflect.com adopts a mass customization strategy as predicted by our model.

[12]We thank the reviewers for bringing this issue to our attention. In this paper, we use the term "digital goods" to refer to products and services whose content is primarily information.

[13]Not every digital product can be mass customized. For example, the use of the Internet may not be enough to get customer preferences for complex software without incurring any cost, such as operating system software. Therefore, as predicted by our model, operating system software vendors prefer product proliferation, i.e., having multiple versions: home-user version and professional-user version, to mass customization.

C. *Comparison of Customization Strategies*

The difference between single-scope (mass) customization (as described in Section III-A) and multiple-scope (targeted mass) customization (as described in Section III-B) has to do with a firm's ability to customize in certain ranges of its product line. If operational capabilities enable a firm to apply its customization efforts to several specific niches, the firm, in general, is strictly better off adopting multiple-scope customization instead of single-scope customization, since single-scope customization is a special case of multiple-scope customization. In this section we specifically compare mass customization and targeted mass customization. Our purpose is to see how the ability to target certain niches affects the extent of product line, price competition, rent extraction, and consumer welfare.

Since firms are identical, it is not surprising that each firm serves half of the market, whether firms adopt mass customization or targeted mass customization. We know that the number of customers that a firm serves with customized products is not more than 1/4 of the total market in any customization scheme. However, different from mass customization, a firm's product line always covers 1/4 of the total market in targeted mass customization. The reason is that firms in targeted mass customization can lock in some customers within their product line, thereby creating local monopolies and charging more than what they would have charged if they had served these customers in mass customization. Therefore, each firm has a tendency to locate its customization segments (multiple scopes) in such a way that the noncustomization segments between them are maximized. Since competing firms cannot locate their products closer than 1/4 of the attribute space, the product line always covers 1/4 of the market in the targeted mass customization. However, in mass customization, since there is only one customization segment (single scope), firms cannot have customer segments served with standard products within their customization scope. The decision to expand a product line is made based purely on the tradeoff between the marginal cost of expanding this single customization scope and the marginal revenue that the firm gets by offering customized products to additional customers. Hence, a firm's product line in mass customization covers always less than or equal to 1/4 of the total market.

Since a larger product line decreases differentiation between competing products, one would expect that expanding the

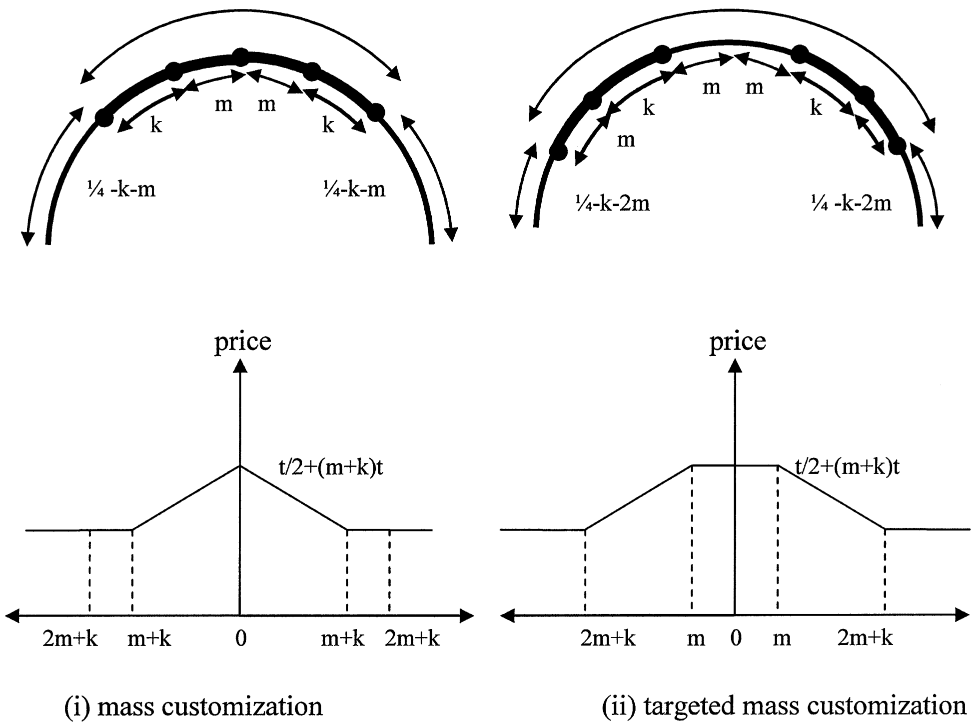

Fig. 5. Pricing Under (i) Mass Customization and (ii) Targeted Mass Customization.

product line intensifies the price competition. However, we know that the prices of the closest conventional products of competing firms are $t/2$ in both mass customization and targeted mass customization. This is also the price if firms were to offer only one standard product without engaging in any form of customization.

Corollary 3: Neither mass customization nor targeted mass customization intensifies the price competition between the competing firms.

The intuition behind this result is as follows. Since firms can charge higher prices to those customers who lie within their product lines, they do not compete aggressively for the marginal customers who are located between their product lines. If firms get into price competition, then the ensuing competition affects not only the prices of varieties produced by competing firms-those standard varieties that compete directly against each other-but also the prices of other customized varieties produced by the same firm because of cannibalization problem. Overall, the firm has more incentive to prevent cannibalization than to escalate the price competition. Therefore, customization in both forms does not intensify the price competition.

Mass customization is also different from targeted mass customization in terms of the amount of total rent extracted from customers. In mass customization, because the firm provides product varieties in its product line that exactly fit each customer's taste, the firm can appropriate maximum rent from customers within its customization segment. However, the firm cannot extract the maximum rent from customers who are outside of the firm's product line since they only get conventional products. Similar to mass customization, in targeted mass customization, the firm can extract the maximum rent from customers who are provided customized products within its product line. However, because some segments within the firm's product line are offered conventional products, targeted mass customization also cannot appropriate the maximum rent from those customers. But, the rent that is extracted from customers who get conventional products in targeted mass customization is higher than the rent that is extracted from customers who get conventional products in mass customization. Customers who purchase conventional products in mass customization are charged $t/2$ due to competition from the rival firm, while customers who purchase conventional products in targeted mass customization are charged higher than $t/2$ due to local monopolies. Hence, the firm extracts higher rent in targeted mass customization than in mass customization.

Corollary 4: Assuming the same extent of customization scope, a firm adopted targeted mass customization extracts more rent than that a firm adopted (single-scope) mass customization.

Fig. 5 shows the locations and prices of product varieties in mass and targeted mass customization, assuming that both customization strategies have the same extent of customization segment (i.e., $2(k + m)$). Note that the area under price figure represents the total rent extracted in each customization strategy. Hence, it is easy to see from Fig. 5 that a firm extracts higher total rent in targeted customization compared to mass customization.

We know that customization may not result in any additional profit to competing firms. Does this finding imply that customers accrue the benefit of customization? Irrespective of customization strategy, customers who are located between the product varieties of competing firms enjoy additional surplus with customization since they get to purchase a product which is closer to their preferences at the same price that would be charged if both firms were introduce a single product in no customization case. However, this is not the case for all customers within a firm's product line. Those customers who are closer to the corner than to the center of a firm's product line accrue greater surplus with customization than in the single product case. On

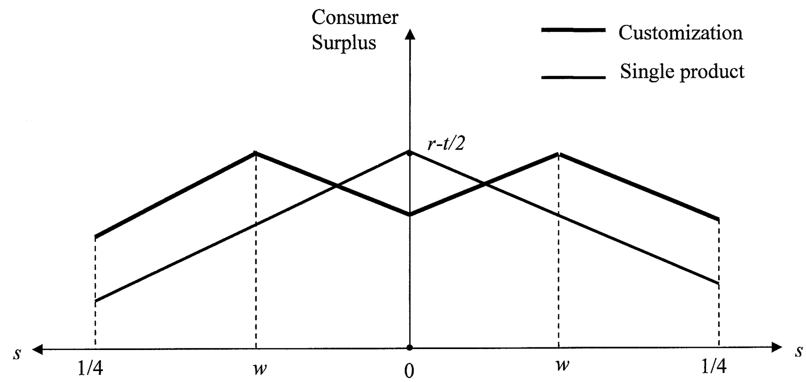

Fig. 6. Consumer Surplus Based on Location from the Center of a Firm's Product.

the other hand, those customers who are closer to the center than to the corner of a firm's product line incur greater disutility with customization than in the single product case. The following result summarizes the comparison of customization with no customization in terms of consumer surplus.

Corollary 5: 1) The average consumer surplus under targeted mass customization is higher than or equal to the average consumer surplus under mass customization. 2) However, the average consumer surplus when any type of customization is offered is higher than the average consumer surplus when both firms offer only a single product.

Corollary 5 can be easily proven by referring to Fig. 6. Assume that each firm locates its product variety which is the closest to its competitor's product line at w distance away from the center of its own product line. A customer who is located s distance away from the center of a firm's product line gets $r - [(t/2) + t|w - s|]$ utility when firms customize, regardless of the type of the customization. Because w is always 1/8 under targeted mass customization and less than or equal to 1/8 under mass customization, the average consumer surplus under mass customization cannot be greater than that under targeted mass customization. This proves the first part of Corollary 4. On the other hand, the customer who is located s distance away from the center gets $r - [(t/2) + ts]$ utility when neither firm customizes. By comparing these two expressions, one can show that customers located at most $w/2$ distance away from the center of a firm's product line get higher surplus under no customization than under customization. Yet, customers located more than $w/2$ distance away from the center of a firm's product line get higher surplus under customization than under no customization. Since customers are located uniformly, the total surplus gain with customization for customers who are located at s where $s \in [(w/2), w]$ is equal to the total surplus loss with customization for customers who are located at s where $s \in [0, (w/2)]$. Hence, there is no change in the total surplus within the product line. However, customers located at s where $s \in [w, (1/4)]$ get more surplus under customization than under no customization. Consequently, we can conclude that customization increases the average consumer surplus.

IV. Conclusion, Discussions and Limitatitons

Improvements in manufacturing technologies have made it possible to customize almost every conceivable product. However it is not clear how competing firms should approach customization. In this paper we first analyze whether customization is a preferred choice when customization technologies are readily available to every firm, or whether firms are better off with no customization. Once we define conditions under which customization is the optimal strategy when there is competition, we next address what kind of customization strategy- mass customization, targeted mass customization or product proliferation- firms should adopt in a competitive setting.

Our analysis of customization strategies versus no customization has led to several interesting and new findings. Using a model that compares no customization with mass customization to address the first question, we find that mass customization is not always the best strategy even if customization technology is very cheap. We show that whether competing firms choose mass customization over no customization depends upon firms' cost of obtaining customer preferences *vis-à-vis* the price premiums associated with customized products. No matter how cheap it is to invest in the customization technologies, firms choose to offer a single product variety instead of mass customization when the cost of soliciting customer preference information is relatively high compared to customers' willingness to pay for customized products. When firms adopt mass customization, the extent of the customization scope depends on the cost of customization technology. If customization technology is sufficiently inexpensive, each firm offers customized products to 1/4 of the market. Otherwise, each firm's customization scope covers less than 1/4 of the market. A surprising result of our analysis is that even if customization technology is inexpensive, not every customer is offered a customized product. The reason is that extending customization beyond a certain limit triggers a hostile price war, which in turn hurts the competing firms. Another surprising result is that the optimality of mass customization does not necessarily mean that mass customization generates more profit for firms than no customization. A firm's profit is greater under mass customization than under no customization only when the cost of customization is significantly small. When customization costs are high, the additional rent that firms can extract from customers does not offset the cost of customization. This result implies that adoption of customization can result from competition, not from customization's positive effect on firms' bottom lines. We also find that when customization gets cheaper, firms' profits may decline. The intuition behind this result is that firms, in such cases, aggressively extend their customization scopes, thereby leading to a more severe competition, which in turn results in a marginal return that is less than the marginal cost.

Given that customization can be the optimal strategy for competing firms, we address the second question using a more general model that allows firms to target customization to specific customer points or segments. We show that mass customization may not be the optimal customization strategy unless customization is costless (i.e., operational flexibility cost and cost of eliciting customer information are zero). Instead of mass customization, firms choose to adopt targeted mass customization as a customization strategy and offer multiple customization scopes. Targeted mass customization also leads to a larger product line than mass customization. Firms even offer multiple discrete products without any customization segment when the cost of learning customer preference structure is expensive compared to price premiums resulting from customization. Analogous to no customization versus mass customization, we find that firms do not consider the cost of operational flexibility when choosing between targeted mass customization and product proliferation.

Contrary to the expectation that customization reduces product differentiation and, therefore, leads to price wars among competing firms, we show that neither mass customization nor targeted mass customization intensifies the price competition. The reason for this counter-intuitive result is that price competition escalates cannibalization among a firm's own product varieties. Each firm has more incentive to reduce cannibalization than to extend its market reach through price competition.

We show that targeted mass customization extracts larger customer rent than mass customization. The reason is that, in targeted mass customization, each firm has an ability to place conventional (noncustomization) segments into its product line to prevent competition from the rival firm in those segments. However, in mass customization, conventional segments of a firm are open to direct competition from the rival firm. We finally show that customers are the primary beneficiaries of any form of customization, because both mass customization and targeted mass customization result in an average consumer surplus that is higher than the average consumer surplus in case of no customization.

Our paper presents a theoretical framework to validate some observations made by academics and practitioners alike. For example, Zipkin [58], when arguing about the limits of mass customization, highlights that firms should "carefully assess the technology and the market demand before committing" to mass customization. Our paper provides a systematic analysis of those operational and market factors to which Zipkin alludes. From a marketing and operations management perspective, our analysis suggests that firms may be better off concentrating on one or more niche regions within the product space when adopting a customization strategy. For instance, Billington [6], in describing the customization strategy adopted by Hewlett Packard for its printers, claims "you (firms) can mass customize effectively for only about 20% of the customers." Our finding on the limit of customization can be interpreted as a more general version of this early quantification.

A. Discussion and Managerial Implications

Customization is a reality in today's manufacturing environments. An important question within this context is to define an appropriate customization strategy. Our results provide useful insights to managers who are considering offering customized products. We summarize our model implications for practice below.

Customization is not only a technological problem but also a strategic one. Firms carefully assess the cost of customization against its benefits before investing in customization technologies. Firms should know that they cannot customize to all customers. This is especially true in traditional goods markets. If gathering customer preferences is costly, firms should not even consider customization, no matter how cheap the technology that enables it. However, Internet technologies have drastically changed the way firms learn customer preferences. Widespread availability of personalization services makes getting customer preferences almost costless for firms. By creating personal profiles, customers reveal their preferences to manufacturers. Customers also design their own products by interacting with online design sites. For example, Land's End provides design-to-fit solutions to address its customers' tastes and needs. In addition to customizing an item on several dimensions using a software-based product configurator, customers can make an item uniquely theirs with monograms. So firms should try, as much as possible, to use the technologies that permit customers to reveal their preferences directly rather than through traditional methods, such as market surveys. Once firms have systems in place to get customer tastes, they should determine the level of customization purely based on the cost of manufacturing technologies that provide flexibility for customization. If customization is not free, firms should target their customization efforts only to some niche segments and serve other customer segments with standard products. An untargeted customization strategy cannot be the best strategy. Therefore, firms should define their niche segments before investing in customization technologies. However, if price premiums associated with customized offerings are not large enough to cover the cost of customization, firms should consider offering just a few discrete product varieties.

Unlike traditional (nondigital) goods, once a digital product is ready, it is easy to modify it to meet the needs of various customer types. Firms do not have to spend extra money on customization technologies to produce customized digital goods. Further, firms can harness the power of the Internet to learn customer needs and deliver the customized digital content easily. Essentially, firms may not incur any cost for customization of digital goods on the Internet. For example, many news sites on the Internet allow their readers to have personalized newsletters or personalized news pages. There is no need for targeted customization in this case (i.e., allowing only some readers to customize the appearance of the news pages). Therefore, firms should engage in mass customization for customization of digital goods as long as eliciting customer preferences is almost costless.

B. Limitations and Future Research Directions

Our paper has several limitations. Some of these limitations are direct results of modeling assumptions. First, we assume that a firm's product line consists of one or more segments. However, optimal product line found in this paper cannot be directly mapped to product characteristics to operationalize customization choices since distribution of customer preferences can be different for different products. Second, we assume that each product variety within a product space costs the same. Therefore, the unit cost of production was normalized to zero in the model. This is a reasonable assumption given that customization technologies today enable production of varieties at the same marginal cost. However, firms need to obtain customization capabilities by investing in customization technologies to offer customized product varieties. This cost obviously depends on the extent of the customization scope, as captured in the model. Third, we assume that operational flexibility cost is a quadratic function of the customization scope. Quadratic cost function captures the fact that marginal cost of customization flexibility increases as the scope of customization increases. Further, this cost function has been used in prior studies [20]. However, any functional form with increasing marginal cost, such as exponential cost function, is sufficient to get the same qualitative results presented in this study. The issue of whether quadratic or exponential form captures the true nature of the customization flexibility is an empirical one, and can be different for different products. The functional form of operational flexibility cost may only affect the size of customization scope(s). Fourth, we assume that firms compete in a duopoly market. The analysis of customization strategies when more than two firms compete in the market can provide further insights into the extent of competition. Future research should address the above-mentioned limitations of this paper.

Notwithstanding these potentially attractive avenues for further research, the present study, which we believe is the first to investigate various customization strategies, provides useful insights into the value of customization under competition. Our findings justify the common belief that customization is not only a technological problem, but also a strategic one. To benefit from customization, firms have to address both of these problems.

APPENDIX

Proposition 1: The Lagrangian for the constrained optimization problem can be written as follows:

$$\begin{aligned}\mathcal{L}_i &= \frac{t}{36}\left(10x_i^2 - 2x_i(x_{\bar{i}}-3) + (x_{\bar{i}}-3)^2\right) - ax_i^2 - bx_i\\ &\quad + \lambda\left(\left(\frac{1}{2}+\frac{x_i - x_{\bar{i}}}{6}\right)^2 - \frac{1}{3}(x_i + 2x_{\bar{i}})\right)\\ &\quad + \mu\left(\left(\frac{1}{2}+\frac{x_{\bar{i}} - x_i}{6}\right)^2 - \frac{1}{3}(x_{\bar{i}} + 2x_i)\right)\\ &\quad + \varepsilon_i x_i + \varepsilon_{\bar{i}} x_{\bar{i}} \quad \forall\, i \neq \bar{i} \in \{1,2\}.\end{aligned}$$

The Kuhn-Tucker conditions are

$$\begin{aligned}\frac{\partial\mathcal{L}_1}{\partial x_1} &= \frac{t}{36}(20x_1 - 2(x_2-3)) - 2ax_1 - b\\ &\quad + \lambda\left(\frac{2}{6}\left(\frac{1}{2}+\frac{x_1-x_2}{6}\right) - \frac{2}{6}\right)\\ &\quad + \mu\left(-\frac{2}{6}\left(\frac{1}{2}+\frac{x_2-x_1}{6}\right) - \frac{4}{6}\right) + \varepsilon_1\\ \frac{\partial\mathcal{L}_2}{\partial x_2} &= \frac{t}{36}(20x_2 - 2(x_1-3)) - 2ax_2 - b\\ &\quad + \lambda\left(-\frac{2}{6}\left(\frac{1}{2}+\frac{x_1-x_2}{6}\right) - \frac{4}{6}\right)\\ &\quad + \mu\left(\frac{2}{6}\left(\frac{1}{2}+\frac{x_2-x_1}{6}\right) - \frac{2}{6}\right) + \varepsilon_2\\ &\lambda\left(\left(\frac{1}{2}+\frac{x_1-x_2}{6}\right)^2 - \frac{1}{3}(x_1+2x_2)\right) = 0\\ &\mu\left(\left(\frac{1}{2}+\frac{x_2-x_1}{6}\right)^2 - \frac{1}{3}(x_2+2x_1)\right) = 0\\ &\varepsilon_1 x_1 = 0\\ &\varepsilon_2 x_2 = 0.\end{aligned}$$

The Kuhn-Tucker conditions are satisfied in three regions with different customization scopes.

a) When $a < (7t/12) - 2b : x_1 = x_2 = (1/4), \lambda = \mu = (7t/12) - 2b - a, \varepsilon_1 = \varepsilon_2 = 0$.

b) When $(1/4) > (t-6b)/(12a-3t) > 0$: $x_1 = x_2 = (t-6b)/(12a-3t), \lambda = \mu = \varepsilon_1 = \varepsilon_2 = 0$.

c) When $6b > t : x_1 = x_2 = 0, \lambda = \mu = 0, \varepsilon_1 = \varepsilon_2 = b - (t/6)$.

These regions overlap only when $6b > t$ and $a < (7t/12) - 2b$ are satisfied. Therefore, in the overlapped region, whichever customization alternative gives the higher payoff is the optimum strategy. Because $\pi(x = (1/4)) = ((17t/12) - (a/16) - (b/4)) < \pi(x = (t-6b)/(12a-3t)) = (18b^2 + 18at - 5t^2)/(72a - 18t) < \pi(x = 0) = (t/4)$, the optimal strategy in the overlapped region is alternative c).

Proposition 2: The difference between each firm's profit when both customize and that when neither customizes can be obtained with simple algebra from (12)

$$\begin{aligned}\Delta\pi_i &= \pi_i\Big|_{\substack{\text{both}\\ \text{customize}}} - \pi_i\Big|_{\substack{\text{neither}\\ \text{customizes}}}\\ &= \begin{cases}\frac{t-4a-16b}{64} & a \le \frac{7t}{12} - 2b \;\&\; b \le \frac{t}{6}\\ \frac{t^2-36b^2}{36(t-4a)} & a > \frac{7t}{12} - 2b \;\&\; b \le \frac{t}{6}.\end{cases}\end{aligned}$$

When $a > (7t/12) - 2b$ and $b \le (t/6)$, $\Delta\pi_i$ is always negative. However, when $a \le (7t/12) - 2b$ and $b \le (t/6)$, $\Delta\pi_i$ is positive if $a < (t/4) - 4b$.

Solution to Pricing Problem in Customization With Multiple Scopes: After (16)–(18) are substituted in (15), the following first-order conditions are obtained

$$\begin{aligned}\frac{\partial\pi_1}{\partial p_{11}} &= \frac{p_{12}}{2t} - \frac{p_{11}}{t} + \frac{1}{4} + \frac{Y_1}{2} - \frac{Y_2}{2} = 0\\ \frac{\partial\pi_2}{\partial p_{12}} &= \frac{p_{11}}{2t} - \frac{p_{12}}{t} + \frac{1}{4} + \frac{Y_2}{2} - \frac{Y_1}{2} = 0.\end{aligned}$$

$$\left[\begin{array}{c|c} B.1_{NxN}+(A'-B)I_{NxN} & C.1_{NxN} \\ \hline C.1_{NxN} & B.1_{NxN}+(A'-B)I_{NxN} \end{array}\right]\begin{bmatrix}\bar{Y}_1\\ -\\ \bar{Y}_2\end{bmatrix}=\begin{bmatrix}D'.1_{Nx1}\\ \hline E'.1_{Nx1},\end{bmatrix}$$

Solving these equalities simultaneously leads to pricing given in (19).

Proposition 3: The Lagrangian for the problem given in (14) such that (20)–(22) are satisfied is as follows.

$$\begin{aligned}
\mathcal{L}_j =\, & t\left(\frac{1}{2}+\frac{Y_j-Y_{\bar{j}}}{3}\right)\left(\frac{1}{4}-\frac{5Y_j}{6}-\frac{Y_{\bar{j}}}{6}\right)\\
& + \frac{t}{2}x_{1j}^2 + y_{2j}t\left(\frac{1}{2}+\frac{Y_j-Y_{\bar{j}}}{3}\right)+(y_{2j}-x_{1j})tx_{1j}\\
& + \frac{t}{2}x_{2j}^2 + y_{3j}t\left(\frac{1}{2}+\frac{Y_j-Y_{\bar{j}}}{3}+y_{2j}\right)\\
& + (y_{3j}-x_{2j})tx_{2j}\\
& + \frac{t}{2}x_{3j}^2 + y_{4j}t\left(\frac{1}{2}+\frac{Y_j-Y_{\bar{j}}}{3}+y_{2j}+y_{3j}\right)\\
& + (y_{4j}-x_{3j})tx_{3j} + \cdot + \frac{t}{2}x_{N_jj}^2 + y_{(N_j+1)j}t\\
& \times\left(\frac{1}{2}+\frac{Y_j-Y_{\bar{j}}}{3}+y_{2j}+y_{3j}+\cdots+y_{N_jj}\right)\\
& + (y_{(N_j+1)j}-x_{N_jj})tx_{N_jj}\\
& - \sum_{i=1}^{N_j}\left(ax_{ij}^2+bx_{ij}\right)-f(N_j)\\
& + \lambda\left(t\left(\frac{1}{2}+\frac{Y_1-Y_2}{3}\right)^2-\frac{2t}{3}(Y_1+2Y_2)\right)\\
& + \mu\left(t\left(\frac{1}{2}+\frac{Y_2-Y_1}{3}\right)^2\geq\frac{2t}{3}(Y_2+2Y_1)\right)\\
& + \sum_{i=1}^{N_j}\varepsilon_{ij}x_{ij}\\
& + \sum_{i=1}^{N_{\bar{j}}}\varepsilon_{i\bar{j}}x_{i\bar{j}}.
\end{aligned}$$

By using the Lagrangian above, we can obtain the Kuhn-Tucker conditions as

$$\begin{aligned}
&\frac{\partial\mathcal{L}_j}{\partial N_j}=0 \quad \forall\, j\in\{1,2\}\\
&\frac{\partial\mathcal{L}_j}{\partial x_{ij}}=0 \quad \forall\, j\in\{1,2\},\quad \forall\, i\in\{1,2,\ldots,N_j\}\\
&\frac{\partial\mathcal{L}_j}{\partial y_{(i+1)j}}=0 \quad \forall\, j\in\{1,2\},\quad \forall\, i\in\{1,2,\ldots,N_j\}\\
&\lambda\left(t\left(\frac{1}{2}+\frac{Y_1-Y_2}{3}\right)^2-\frac{2t}{3}(Y_1+2Y_2)\right)=0\\
&\mu\left(t\left(\frac{1}{2}+\frac{Y_2-Y_1}{3}\right)^2\geq\frac{2t}{3}(Y_2+2Y_1)\right)=0\\
&\varepsilon_{ij}x_{ij}=0 \quad \forall\, j\in\{1,2\},\quad \forall\, i\in\{1,2,\ldots,N_j\}.
\end{aligned}$$

Since firms are identical, the number of scopes should be identical and equal to $N=\arg\min_{N_j}\{\mathcal{L}_j\}$. The critical points that satisfy the above K-T conditions.

1) When $\lambda>0$, $\mu>0$ and $\forall\,\varepsilon_{ij}=0$.
   From the second set of the K-T conditions, we can get $x_{ij}=((ty_{(i+1)j}-b)/(t+2a))$. After substituting these into the third set of the K-T conditions, we obtain the set of equalities, shown in the equation at the bottom of the page, where 1_{mxn} is an m by n matrix whose all elements are 1, I_{mxm} is an m by m identity matrix, and $\bar{Y}_j$ is N by 1 vector whose elements are $y_{2j},y_{3j},\ldots,y_{(N_j+1)j}$, $A=(1/9)+t/(t+2a)+(2/9)(\lambda+\mu)$, $B=(10/9)+(2/9)(\lambda+\mu)$, $C=(-1/9)-(2/9)(\lambda+\mu)$, $D=(b/(t+2a)-(1/6)+(\lambda/3)-\mu$, and $E=b/(t+2a)-(1/6)+(\mu/3)-\lambda$. Then, the difference between the two rows of the matrix above implies that y_{ij}'s are equal. By solving fourth and fifth K-T conditions, we obtain $Y_1=Y_2=(1/8)$. Therefore, $y_{ij}=(1/8N)$. Substituting y_{ij} into x_{ij}, we get $x_{ij}=(t-8bN)/(8N(t+2a))$. Also note that $t-8bN$ has to be greater than zero to ensure feasibility.
2) When $\lambda>0$, $\mu>0$ and $\forall\,\varepsilon_{ij}>0$.
   From the second set of the K-T conditions, we can get $x_{ij}=0$. After substituting these into the third set of the K-T conditions, we obtain the set of equalities, shown in the equation at the top of the page, where $A'=(1/9)+(2/9)(\lambda+\mu)$, $D'=-(1/6)+(\lambda/3)-\mu$, and $E'=-(1/6)+(\mu/3)-\lambda$. As in 1), the difference between the two rows of the matrix above implies that y_{ij}'s are equal.

$$\left[\begin{array}{c|c} B.1_{NxN}+(A-B)I_{NxN} & C.1_{NxN} \\ \hline C.1_{NxN} & B.1_{NxN}+(A-B)I_{NxN} \end{array}\right]\begin{bmatrix}\bar{Y}_1\\ -\\ \bar{Y}_2\end{bmatrix}=\begin{bmatrix}D.1_{Nx1}\\ \hline E.1_{Nx1}\end{bmatrix}$$

By solving fourth and fifth K-T conditions, we obtain $Y_1 = Y_2 = (1/8)$. Therefore, $y_{ij} = (1/8N)$. From the first set of K-T conditions, we get $\varepsilon_{ij} = b - (t/8N)$. To ensure that it is nonnegative, we need to satisfy $t - 8bN \leq 0$. Combining the results in 1) and 3) leads to Proposition 2.

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