Mass Customization: An Economic Analysis *

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Abstract

“Virtually all managers are keenly aware that the key to winning in market after market today is excelling in tailoring one’s offerings to the specific needs of each customer while still maintaining low costs and prices.” - Anderson and Narus(1995).

More and more firms have lately been trying to both lower costs and improve their ability to provide goods and services that are customized to individual buyer needs. This is reflected for example in the growing adoption of mass customization - the ability to provide customized goods or services to individual consumers while producing high volumes and at low costs - by firms in recent years in a variety of industries and in different countries. However, economists have so far not looked at the interrelationship between these two choices and their relationship with other economic variables. This paper takes a first step in that direction.

I first consider a monopolistic firm in a discrete time, infinite horizon set-up. The firm can try to both lower its costs and increase its ability to customize its product in each period. The outcomes of these efforts add up over time. I use a modified version of the standard Hotelling(1929) location framework to model consumer preferences and solve the dynamic optimization problem of the firm. I find that the two choices are complementary to each other. However, I also find an economic distinction between these two choices based on their relationship to consumer preferences. I develop several predictions - both over time and across firms in a cross-section - regarding these choices. I also analyze the social optimality or lack thereof of the choices made by the firm.

Next, I consider a duopoly set-up with Cournot and with Bertrand product market competition. Further, in each duopoly scenario, I consider the case when the firms’ products are substitutes and when they are complements. I find that the difference found in the monopolistic set-up between lowering cost and improving ability to customize remains qualitatively the same in either duopoly scenario for both the cases. Further, the predictions obtained in the monopolistic set-up continue to hold qualitatively in either duopoly scenario. I also develop some predictions about the interrelationship between the two choices and the form of product market competition.

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1 Introduction

“Virtually all managers are keenly aware that the key to winning in market after market today is excelling in tailoring one’s offerings to the specific needs of each customer while still maintaining low costs and prices.” - Anderson and Narus(1995).

For a long time, quality and low cost were considered to be trade-offs. Similarly, customization and low cost were considered to be trade-offs as well. However since the late 1980’s, firms have started to recognize the possibility of gaining the ability to produce goods of high quality at a low cost that are also at least to a large extent made-to-order as per the wishes of the customer and are starting to do so. Thus, more and more firms are now increasingly trying both to lower their production costs and to improve their ability to customize their products according to the needs of their buyers. Examples of such firms include the likes of Motorola, United Services Automobile Association (USSA) and Hallmark to name a few. In fact, there has been a rapid increase in the number of firms in a variety of industries and in different countries that are trying to adopt the practice of mass customization - namely, the ability to provide customized goods or services to individual consumers while producing high volumes and at low costs. However to the best of my knowledge, the economic determinants of firms’ decisions regarding efforts to lower costs and improve customization abilities and the interrelationship of these choices with each other as well as with other economic variables have not been studied till date. This paper takes a first step in that direction and in doing so provides an understanding of the phenomenon of mass customization from an economic perspective.

\[\text{\textsuperscript{1}}\text{See Gillmore and Pine(1997) or Da-Silveira et. al (2001) for a discussion about the concept of mass customization. Pine et.al(1993) has examples of several firms that have undertaken this practice.}\]

\[\text{\textsuperscript{2}}\text{There are many articles and even several books on mass customization in the marketing/management literature - see for example, the survey article by Da-Silveira et. al (2001) and references therein. However, these focus mainly on its organizational aspects.}\]
Before I start to describe the framework that I use, I would like to briefly describe some stylized features of mass customization. First of all, it is of utmost importance to recognize that mass customization is not the same as producing many different variants of some standard product. In fact, such an approach can lead to disastrous consequences. Mass customization involves gaining the ability to meet any requests that consumers may come up with. As Pine et. al(1993) put it -

“In a true mass-customization environment, no one knows exactly what the next customer will want, and, therefore no one knows what product the company will be creating next.”

Further, for each buyer that a mass-customizing firm sells to, it makes the product in consultation with the buyer and tries to customize the product according to the buyer’s needs. However, it is able to satisfy individual customer needs to different extents for different buyers. Such firms also typically try to continually improve the efficiency as well as the flexibility of their production processes - i.e. to lower costs and to enhance their customization abilities respectively.

I first consider a monopolistic firm. The firm’s clientele consists of consumers, each of whom buys either one unit of the firm’s product or nothing at all from the firm. All consumers receive the same utility from the firm’s product if the product is customized exactly to their needs. However, the firm is able to satisfy individual customer needs to

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3 See Pine et.al(1993) and Pine(1993) for further discussion and illustrative examples in this regard.
4 Mass customizing firms typically have production processes that are highly modular. The modules in such a production process can be linked in various ways to meet different customer needs at little or no extra cost. Thus, production processes of such firms have two aspects - efficiency and flexibility. The level of flexibility reflects the range of customer needs that can be met while the level of efficiency reflects the cost of making any of the customized products that the process can handle. In terms of what happens to the production process, improving flexibility typically involves making the process more modular and improving the links between various modules while improving efficiency involves improving the various modules.
different extents for different buyers. As a result, different consumers get different levels of utility from the customized products that the firm is able to make for them which I model using a framework analogous to the standard Hotelling(1929) location framework. In my framework, the equivalent of the unit transportation cost is an endogenous variable and can be lowered through efforts by the firm. Note that a lower value of the equivalent of the unit transportation cost means that a greater number of consumers receive a utility higher than any given fraction of that received from an “exactly-customized” product - i.e. the firm is able to better customize its product and thus meet individual needs of its customers to a greater extent. Further, the per-unit cost of producing the good is also endogenous in my model and can be lowered through efforts by the firm. I consider a dynamic set-up with discrete time and an infinite horizon and solve the dynamic optimization problem of the firm. In my framework, before undertaking production in any period, the firm can try to both lower its per-unit production cost and to increase its customization ability. Further, the outcome of these efforts accumulate over time.

The first question that probably comes to mind here is whether there is any economic distinction and any interrelationship between these two choices. I find that at the margin, a reduction in the per-unit output cost of a firm by say a dollar always means that the firm saves a dollar on every unit of output that it produces. On the other hand, the per-unit output benefit at the margin to a firm from an improvement in its customization ability by say one unit is the corresponding increase in the price of the firm’s product. This increase in price depends on how much the marginal buyer values this increase in the firm’s customization ability. Thus the two choices are economically distinct in that the per-unit output benefit from a lower cost is independent of while that from improved customization ability depends on which consumers buy the product. I also find that for both cost reductions and improvements in customization ability, a higher output means a larger total benefit from
any such outcome - i.e. there are scale effects in returns to either effort. A greater effort at cost reduction leads to a lower per-unit cost. This in turn means that the monopolist sells more. Consequently, it puts in a greater effort at enhancing its customization ability due to the associated scale effects. A similar effect works the other way as well. Thus, the two choices are interrelated in that they are complementary to each other.

Given the findings above, the next question most likely would be as to what one may expect to see regarding these two choices both for an individual firm over time and across firms in a cross-section at any given point of time. In my framework, the firm has an opportunity to lower cost and to increase its customization ability in each period and does so. Hence, its per-unit cost decreases while its customization ability increases over time. As a result, the firm sells more over time. Hence, due to the scale effects in returns to both lower costs and improvements in customization ability discussed earlier, the firm would in general have a tendency to do more of both over time. Since I have a discrete choice model of consumer demand, in my framework selling more means that the firm has to sell to more people. This in turn means it has to sell to people whose customization needs it is able to meet to a lesser extent. Also, these are people who would benefit more from an enhancement in the monopolist’s customization ability.\(^5\) Hence, the economic distinction between the two choices discussed earlier leads to the prediction that a monopolistic firm will devote relatively more of its effort to enhancing its customization ability over time.

Further, the presence of scale effects for both choices and the economic distinction be-

\(^5\)In the real world, it would be natural to expect a positive correlation between the total willingness of a buyer to pay for a firm’s product and the extent to which the firm is able to meet the buyer’s individual needs. One would also expect a buyer whose individual needs have been met to a large extent to benefit less from any improvement in the firm’s customization ability than a buyer whose individual needs have been met to a lesser extent. Together, these would imply a positive relationship between quantity sold and the amount by which the marginal buyer benefits from an improvement in a firm’s customization ability.
between them also lead to the prediction that amongst two monopolistic firms in an industry with structure as in the Independent Submarkets with Single Products of Sut- ton(1998), ceteris paribus a larger firm will in absolute terms do more of both cost reduction and customization enhancement while in relative terms, it will devote relatively more of its effort to enhancing its customization ability. I also come up with predictions about how these two choices would differ across monopolistic firms that are of the same size but differ in features like the size of their markets or the distribution of consumer preferences or the importance that they attach to short-term results.\(^6\) Thus, this paper provides some guidelines as to what patterns one can expect to see in cross-sectional studies of firms regarding their choices of cost reduction and customization enhancement.

I further consider whether the choices made by a profit-maximizing firm are socially optimal or not. Considering the case where both a profit-maximizing monopolist and a welfare-maximizing monopolist produce the same sequence of outputs,\(^7\) I find that the profit-maximizing monopolist does less of customization enhancement than is socially optimal.

It is natural to ask to what extent findings from the monopolistic set-up hold in a scenario with more than one firm and strategic interactions between firms. In order to answer this question, I also consider duopoly scenarios with Cournot as well as with Bertrand product market competition. I find that the economic distinction between the choices of trying to lower cost and to improve customization ability remain qualitatively unchanged in either

\(^6\)One would expect to see such differences across firms that are in the same industry but in different countries. There is for example, evidence that Japanese firms are typically more far-sighted than US firms and of a similar difference between British and Japanese firms as well - see for example, Jacobson and Aaker(1993), Ito(1992) for the former and Becchetti(1995) for the latter.

\(^7\)I impose this restriction because otherwise, ceteris paribus the two firms will choose different outputs which will also contribute to a difference in their choices of cost reduction and improvement in customization ability.
duopoly. Other predictions found in the monopolistic set-up continue to hold qualitatively in either duopoly as well. I also analyze how the choices by a firm of cost reduction and improvement in customization ability and the form of product market competition are interrelated.

This paper is related to the small body of work that looks at the relationship of pricing or variety choices by firms and market structure with the efficiency and flexibility of the production process - see for example Brander and Eaton(1984), Klemperer(1992), Eaton and Schmitt(1994) and references therein. However, these papers take the production process to be exogenously given. It is also related to again a small body of work regarding endogenous choice of only the amount of flexibility of the production process - see for example von Ungern-Sternberg(1988) and Weitzman(1994). In contrast to the literature discussed above, this paper considers the endogenous choice of both the efficiency and flexibility aspects of the production process and their relationship to various economic variables within such a context.

The rest of the paper is as follows. Section 2 lays down the basic model for the monopolistic set-up. Section 3 develops results for monopolistic firms. Section 4 considers duopoly scenarios. Section 5 concludes. All proofs are in the appendix.

2 Monopolistic set-up

Here, I consider the case where there is a single firm selling a non-durable product. Time is discrete and denoted by $t$ where $t \in \{0, 1, 2, \ldots \}$. All variables in period $t$ will have the subscript $t$. Also, price, revenue, costs, expenditure incurred to lower per-unit cost or improve customization ability and utility that a buyer receives from the firm’s product are

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8Further, in both these papers, more flexibility means a higher production cost. Thus they model the earlier paradigm discussed at the beginning in which production flexibility and efficiency were considered to be substitutes.
all measured in terms of some numeraire good.

The firm’s clientele consists of a mass $M_t$ of potential buyers in period $t$ where $\{M_t\}_{t\geq 0}$ is exogenously given and known to the firm. The firm’s product at the end of period $t$ is characterized by the vector $(v, c_{t+1}, d_{t+1})$. Here, $c_{t+1}$ is the per-unit production cost for the firm, $v$ is the utility that any buyer gets from the product if the product is exactly customized to the buyer’s preferences while $d_{t+1}$ as we will see below is a measure of the firm’s ability to customize its product in period $t$. Buyers are characterized by their value of a variable $D$ where $D \in [D_1, D_2]$, $0 \leq D_1 < D_2$ and $D_2$ is finite. Each buyer buys one or zero units of the product from the firm in any given period. For each individual buyer, the firm in consultation with the buyer customizes its product as per the buyer’s individual needs to the extent possible. If a buyer with say $D = \hat{D} \in [D_1, D_2]$ buys one unit of the product in period $t$ at a price of say $p_t$, then the buyer receives a utility of $(v - d_{t+1}\hat{D} - p_t)$ and buys the product provided this utility is non-negative. Here, $D$ is a measure of the customization needs of a buyer with a higher value of $D$ indicating greater customization needs. $dD$ is a measure of the extent to which the firm is unable to meet the customization needs of the buyer. Note that a lower value of $d$ means that the firm is better able to meet customization needs of all buyers - i.e. it has a higher customization ability. The distribution of $D$ across consumers is exogenously given, time-invariant and known to the firm. The value of $D$ for any individual buyer however is private information and known only to the buyer.$^9$ \begin{align*}
F(\cdot) & \text{ }
\end{align*}

$^9$Since the firm customizes its product, one may expect it to know individual values of $D$ for at least all its actual buyers through its discussions with them. In fact, if $d$ was unobservable to individual buyers unless they discussed their needs with the firm, then by the same logic, one may expect this to be true with respect to all buyers. What I am assuming is that the firm gets to know the extent to which it is able to meet each buyer’s needs or requests but not the values that individual buyers attach to different needs. Hence, the firm does not know the value of $dD$ for individual buyers. However, the firm knows the extent to which it is overall able to satisfy customization needs of its buyers given its customization ability - equivalently, the
denotes the cumulative distribution function of $D$ across the potential buyers. I assume that $F(\cdot)$ is continuously differentiable in $D$ with a corresponding density function $f(\cdot)$ where $f(D) > 0, \forall D \in [D_1, D_2]$.

As far as product characteristics are concerned, $v$ is exogenously given, time-invariant and known to the firm.\textsuperscript{10} Let $c_t$ and $d_t$ denote the values of $c$ and $d$ respectively that the firm starts off with in period $t$ with $(c_0, d_0)$ being exogenously given. In each period $t$, the firm can invest in efforts to lower both $c$ and $d$ - i.e to improve the efficiency and flexibility of its production process as discussed earlier in footnote 4 and related discussion. The outcomes of these efforts are deterministic. Suppose, the firm spends $\bar{r}_c^t$ and $\bar{r}_d^t$ in period $t$ in efforts to lower $c$ and $d$ respectively. Then, $c_{t+1} = c_t - A_c^t g(\bar{r}_c^t)$ while $d_{t+1} = d_t - A_d^t g(\bar{r}_d^t)$. Here $g(\cdot)$ is of the form $g(r) = r^\lambda$ where $\lambda \in (0, 1)$ and is exogenously given. $\{A_c^t\}_{t \geq 0}$ and $\{A_d^t\}_{t \geq 0}$ are exogenously given and known to the firm. Note that efforts to lower $c$ and $d$ are analogous to doing R&D. $\{A_c^t\}_{t \geq 0}$ and $\{A_d^t\}_{t \geq 0}$ measure the productivity of the firm in its efforts to lower its per-unit cost and to improve its customization ability. The outcomes of these two efforts that I have assumed here are analogous to assumptions regarding outcomes of R&D that have been made elsewhere in the R&D literature - see for example Klepper(1996), Sutton(1998). I further assume that reductions in per-unit cost and improvements in customization ability add up over time.

Events unfold as follows. At the beginning of any period $t$, the firm decides how much to spend in that period to lower its per-unit cost and to improve its customization ability. I assume that the firm can spend any amount that it wants to in any period on these two efforts. Then, outcomes of these efforts are realized as per the earlier description. Following

\textsuperscript{10}Note that here an increase in the value of $v$ by any amount has the same effect as and is thus equivalent to a decrease in $c$ by the same amount.
this, production takes place and the firm sells its product to buyers in the market. Since the firm knows only the distribution of $D$ but not the value of $D$ for individual buyers, the firm cannot price discriminate and charges the same price to everyone. It has a discount factor $\beta$ where $\beta \in [0, 1]$ and acts so as to maximize the sum of its discounted profits over the entire time horizon.

I use the following definition and notation.

**Definition:** Throughout this paper, *degree of market penetration* by a firm will denote the ratio of output sold by the firm to the mass of potential buyers for the firm’s product.

**Notation:** With a monopolistic firm,

**N.i.i)** $x$ will denote the fraction of the total mass of potential buyers to whom the firm sells its product while $x_t$ will denote the profit-maximizing choice of $x$ for the firm in period $t$,

**N.i.ii)** $p(x, d_{t+1})$ will denote the resultant price if the firm decides to sell to a fraction $x$ of its buyers in period $t$, while

**N.i.iii)** $MR(x, d_{t+1})$ will denote the marginal revenue of the firm with respect to $x$ in period $t$.

**N.ii)** For any $t \geq 0$, $\bar{r}_t^c$ and $\bar{r}_t^d$ will denote spending by the firm in period $t$ on lowering its per-unit cost and on improving its customization ability respectively while $\{r_t^c\}_{t \geq 0}$ and $\{r_t^d\}_{t \geq 0}$ will denote optimal choices for spending by the firm on lowering cost and improving customization ability respectively over the entire horizon.

**Preliminary results:** Since each buyer buys one unit of the product or nothing, if the firm decides to sell to a fraction $x$ of its potential buyers in period $t$, then total quantity sold by the firm in period $t$ is $xM_t$. Thus, $x_t$ is the degree of market penetration by the firm in period $t$. Further, $x_t$ solves

$$Max_{x \in [0,1]}[v - d_{t+1}F^{-1}(x) - c_{t+1}]xM_t$$

(1)

Note that solving for the profit-maximizing choice of $x$ and solving for the profit-maximizing choice of quantity for the firm are equivalent. Also, given my assumptions regarding $F(.)$, 

$F^{-1}$ is well-defined and unique for all $x \in [0, 1]$. Further, \( \{r^c_t\}_{t \geq 0} \) and \( \{r^d_t\}_{t \geq 0} \) solve

$$Max_{\{r^c_t\}_{t \geq 0}, \{r^d_t\}_{t \geq 0}} \sum_{t \geq 0} \beta^t [\pi_t(v, c_{t+1}, d_{t+1}) - \bar{r}^c_t - \bar{r}^d_t]$$

where $\forall t \geq 0$, $c_{t+1} = c_t - A^c_t g(\bar{r}^c_t)$, $d_{t+1} = d_t - A^d_t g(\bar{r}^d_t)$ and $\pi_t(v, c_{t+1}, d_{t+1})$ is the solution to (1) above with the $\{c_{t+1}\}_{t \geq 0}$ and $\{d_{t+1}\}_{t \geq 0}$ that results from $\{\bar{r}^c_t\}_{t \geq 0}$ and $\{\bar{r}^d_t\}_{t \geq 0}$.

I make the following assumptions.

**Assumptions:**

**A1:** $\frac{d^2[x F^{-1}(x)]}{dx^2} > 0$, $\forall x \in (0, 1)$.

**A2:** i) $\sum_{t \geq 0} \beta^t M_t$ is finite, ii) $c_0 - \sum_{t \geq 0}(A^c_t)^{1/\lambda} \{\lambda[\sum_{k \geq t} \beta^{k-t} M_k]\}^{\lambda/\lambda}(x) \geq 0$, and

iii) $d_0 - \sum_{t \geq 0}(A^d_t)^{1/\lambda} \{\lambda D_2[\sum_{k \geq t} \beta^{k-t} M_k]\}^{\lambda/\lambda}(x) \geq 0$.

**A3:** i) \( argmax_{x \in [0,1]} [v - d_0 F^{-1}(x) - c_0] x > 0 \), while ii) \( argmax_{x \in [0,1]} [v - d^* F^{-1}(x) - c^*] x < 1 \)

where $c^* = c_0 - \sum_{t \geq 0}(A^c_t)^{1/\lambda} \{\lambda[\sum_{k \geq t} \beta^{k-t} M_k]\}^{\lambda/\lambda}(x)$ and $d^* = d_0 - \sum_{t \geq 0}(A^d_t)^{1/\lambda} \{\lambda D_2[\sum_{k \geq t} \beta^{k-t} M_k]\}^{\lambda/\lambda}(x)$.

A1 ensures that the firm always faces a downward-sloping marginal revenue curve in the product market. A2 ensures that $r^c_t$ and $r^d_t$ are finite in all periods, the firm’s dynamic optimization problem is well-defined and that the firm always has a non-negative per-unit cost as well as a non-negative value of $d$ - i.e. is unable to perfectly mass customize its product. A3 ensures that the firm sells a positive amount in each period but the entire market is never covered. These together with the assumptions regarding consumer preferences and returns to spending on lowering cost and on improving ability to customize lead to the following characterization.

**Properties of improving ability to customize:** $\forall x \in (0, 1)$, (i) $\frac{\partial(p(x,d_{t+1}))}{\partial d_{t+1}} < 0$, (ii) $\frac{\partial^2 p(x,d_{t+1})}{\partial x \partial d_{t+1}} < 0$, (iii) $\frac{\partial MR(x,d_{t+1})}{\partial d_{t+1}} < 0$ and (iv) $\frac{\partial^2 MR(x,d_{t+1})}{\partial x \partial d_{t+1}} < 0$.

Thus, an improvement in the ability to customize shifts out both the inverse demand and the marginal revenue curve. Further, the amount of shift in both cases is increasing in the degree of market penetration - i.e. geometrically speaking, an improvement in the ability to customize makes both the inverse demand and the marginal revenue curve flatter. Further, **Lemma 1:** (i) The firm spends a positive amount in each period to both lower its per-unit
cost and to improve its customization ability. Thus, both $c$ and $d$ decrease over time.

(ii) The firm’s dynamic optimization problem [see (2) above] is well-defined.

(iii) The firm sells to a larger fraction of its potential buyers - i.e. $x_t$ increases - over time.

3 Lowering cost and improving customization ability

In this section, I characterize a monopolistic firm’s choices to invest in lowering per-unit cost and in improving the ability to customize its product.

3.1 Difference and interrelationship between lowering cost and improving customization ability

I begin by considering the economic difference and interrelationship if any between the two choices. From equation (2) and using the envelope theorem, it follows that in each period $t$, $r^c_t$ and $r^d_t$ satisfy the following first-order necessary conditions.

\[
\text{FONC for } r^c_t: \left\{ \sum_{k \geq t} [\beta^{k-t} x_k M_k] A^c_t g'(r^c_t) \right\} = 1 \quad (3)
\]

\[
\text{FONC for } r^d_t: \left\{ \sum_{k \geq t} [\beta^{k-t} \{F^{-1}(x_k)\} x_k M_k] A^d_t g'(r^d_t) \right\} = 1 \quad (4)
\]

From (3) and (4), it follows that

**Proposition 1:** (i) Returns to investing in lowering cost in any period depend on the associated productivity in that period and output produced in that and subsequent periods while returns to improving customization ability depend on that and also on the willingness of the buyers in that and subsequent periods to pay for improved customization ability. In this sense, the two choices differ from each other.

(ii) Consider two scenarios, 1 and 2. In each scenario, (a) the firm starts off in period $t$ with per-unit cost $c_t$ and customization ability $d_t$, (b) it can only choose $r^X_t$ and (c) \{$\bar{r}^X_k\}_{k > t}$ and \{$\bar{r}^Y_k\}_{k \geq t}$ are exogenously given, where both $X$ and $Y \in \{c, d\}$ and $X \neq Y$. Further, suppose that $\bar{r}^X_k$ is the same in both scenarios $\forall k > t$ while $\bar{r}^Y_k$ is at least weakly higher in scenario
∀k ≥ t with strict inequality for some k. Then, the firm chooses a higher value of \( r_t^X \) in scenario 1. In this sense, the two choices are complementary to each other.

The intuition behind Proposition 1(i) is simple. Reductions in cost and improvements in customization ability are cumulative over time. Equation (3) shows that at the margin, the benefit from further cost reduction in any period is the discounted sum of corresponding savings in that and subsequent periods with the non-discounted, per-unit output saving in that or any subsequent period being equal simply to the reduction in per-unit cost and thus independent of the degree of market penetration. Equation (4) on the other hand shows that at the margin, the benefit from further improvement in customization ability in any period is the discounted sum of corresponding benefits in that and subsequent periods with the non-discounted, per-unit output benefit in that or any subsequent period being equal to the improvement in customization ability times what the marginal buyer is willing to pay for such an improvement which is positively related to the degree of market penetration. In this sense, the two choices are different.

Regarding Proposition 1(ii), consider the case where \( X = c \) and \( Y = d \). Then, the same choice of \( r_t^c \) in both scenarios would mean higher market penetration from period \( t \) onwards (at least weakly with strict inequality in some period) in scenario 1. This in turn implies a greater incentive for cost reduction in period \( t \) [follows from (3)]. Equation (4), the positive correlation between the degree of market penetration and the willingness of the marginal buyer to pay for improvements in customization ability and a similar logic leads to the result in the other case. Further, an analogous reasoning shows that spending on cost reduction across time periods are also complementary to each other and similarly for spending on improving customizing ability. This is stated formally in the corollary below.

**Corollary to Proposition 1 (ii):** Consider two scenarios, 1 and 2. In each scenario, (a) the firm starts off in period \( t \) with per-unit cost \( c_t \) and customization ability \( d_t \), (b) it can
only choose \( r^X_t \) and \( (c) \{ \bar{r}^X_k \}_{k>t} \) and \( \{ \bar{r}^Y_{k} \}_{k \geq t} \) are exogenously given, where both \( X \) and \( Y \in \{ c, d \} \) and \( X \neq Y \). Further, suppose that \( \bar{r}^Y_k \) is the same in both scenarios \( \forall k \geq t \) while \( \bar{r}^X_k \) is at least weakly higher in scenario 1 \( \forall k > t \) with strict inequality for some \( k \). Then, the firm chooses a higher value of \( r^X_t \) in scenario 1.

3.2 Evolution of the two choices over time

Comparing the FONC’s for \( r^c_t \) and \( r^d_t \) over time leads to the following result.

**Proposition 2:** Suppose the mass of potential buyers and the productivity of lowering per-unit cost and of improving ability to customize are time-invariant. Then, the firm spends more on both lowering per-unit cost and on improving ability to customize over time.

Clearly, an increase(decrease) in the productivity of lowering cost or of improving ability to customize would lead to an increase(decrease) in the incentive for such spending. Also, the earlier finding of a positive relationship between returns to lowering costs or improving ability to customize in any period and total output in that and subsequent periods implies that an increase(decrease) in the mass of potential buyers over time would lead to an increase(decrease) in the incentive for either spending. Proposition 2 shows that in addition to these effects, the firm would have a tendency to spend more on either effort over time. This is due to the increase over time in the degree of market penetration by the firm which is brought about by the continuous reduction in per-unit cost and improvement in customizing ability and the consequent increase in total output holding the mass of potential buyers constant.

It would be natural to ask whether there is any change at all and if so in which direction in the relative choice by the firm between the two efforts over time. I find that

**Proposition 3:** Suppose the productivity associated with lowering per-unit cost relative to that associated with improving ability to customize is constant over time - i.e. \( \text{A}^c_t / \text{A}^d_t \) is time-
invariant. Then, over time the firm devotes relatively more effort to improve its ability to customize - i.e. \( r^c_t / r^d_t \) is decreasing over time.

Thus, Proposition 3 shows that net of the effect of any change over time in the relative opportunities for lowering cost and for improving customization ability, the firm would have a tendency of spending relatively more on improving customization ability over time. This is due to the increase over time in the degree of market penetration by the firm and the fact [follows from equations (3) and (4)] that the benefit to the firm from an improvement in customization ability relative to that from a reduction in per-unit cost depends on the willingness of the marginal buyer to pay for improvements in customization ability which is positively related to the degree of market penetration. Further note that Proposition 3 holds regardless of how the absolute magnitudes of the productivity of lowering cost and of improving ability to customize or the mass of potential buyers change over time.

### 3.3 Social optimality

Consider two firms - Firm \( S \) and Firm \( P \). Firm \( S \) tries to maximize welfare while Firm \( P \) tries to maximize profit. Further, both firms produce the same exogenously given sequence of outputs \( \{Q_t\}_{t \geq 0} \) where \( Q_t \) is the output produced in period \( t \). Everything else is as in Section 2. All parameter values are the same across the two firms. Then I find that

**Proposition 4:** In any period \( t \),

(i) both firms devote the same effort to lowering cost while

(ii) Firm \( S \) devotes more effort to improving ability to customize than Firm \( P \).

The economic intuition underlying Proposition 4 is as follows. For a given sequence of outputs, both the social benefit and the private benefit to a firm from any cost reduction is the corresponding savings in production costs. This in turn depends only on the sequence

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11 One way to interpret this assumption is that the relative opportunity for the two avenues to improve the production process is time-invariant. Note that the opportunities in absolute terms may vary over time.
of outputs and the amount of cost reduction. Hence, both firms spend the same amount on cost reduction. Regarding spending to improve customization ability, since Firm $P$ cannot price discriminate, it is unable to extract the entire social benefit from any improvement in its customization ability and a part of the benefit accrues to consumers as an increase in their surplus. Hence, the profit-maximizing firm spends less on improving customization ability than a welfare-maximizing firm.

3.4 Cross-sectional implications

In this subsection, I consider industries consisting of submarkets where there is at most one firm in each submarket and any decision by a firm in one submarket has no effect whatsoever on any other firm in any other submarket - see Sutton(1998). Within each submarket, the structure is as described in Section 2. Also, throughout this subsection, size of a firm refers to the amount of output that it produces. Thus, two firms are of the same size if they produce the same amount of output while one firm is larger than another if it produces a greater amount of output than the other firm. One question that would arise would be as to how firms in the same industry but differing in their size would differ in their choices regarding the two efforts. It would be natural to expect firms in the same industry to have the same $\{M_t, A^c_t, A^d_t\}_{t \geq 0}, D_1, D_2, F(\cdot), \lambda$ and $g(\cdot)$. Considering two such firms, Firm 1 and Firm 2 that differ only in size, I find that

**Proposition 5:** Suppose, both firms have $\beta = 0$ - i.e. the firms are myopic - and the same $\{M_t, A^c_t, A^d_t\}_{t \geq 0}, D_1, D_2, F(\cdot), \lambda$ and $g(\cdot)$. Further, Firm 1 is larger than Firm 2 in some period $t$ in the sense that it sells a larger output in that period. Then, in that period

(i) Firm 1 spends more on lowering per-unit cost and improving ability to customize than Firm 2.

(ii) In relative terms, Firm 1 spends more on improving its ability to customize than Firm 2.

(iii) Firm 1 has a lower return - amount of improvement per unit spending - than Firm 2 in
both its efforts at lowering cost and improving ability to customize.

The underlying intuition is as follows. A larger firm spends more on both lowering per-unit cost and on improving ability to customize due to the scale effects associated with the two. Also, selling more means having greater market penetration which means selling to people who attach a higher value to improvements in ability to customize. Hence, in relative terms, the larger firm spends more on improving its ability to customize. There are diminishing marginal returns to both lowering per-unit cost and to improving ability to customize. The larger firm spreads its spending on these two efforts over a larger output and hence does more of both but due to diminishing marginal returns ends up with a lower return to both in terms of improvement per-unit spending.

Further, in general, differences have often been observed along many different aspects in the behavior of firms that are in the same industry but from different countries. Firms from different countries are likely to differ in the values of their discount factor, market size as measured by the mass of potential buyers and the distribution of buyers with respect to their valuation of firms’ ability to customize. It would be natural to ask how we might expect the choices of firms of the same size regarding efforts to lower costs and to improve ability to customize to differ in such cases. Analyzing the choices of two such firms, Firm 1 and Firm 2 that are of the same size, I find that

**Proposition 6:** [Scenario (a):] Suppose, both firms have the same \( \{M_t, A_t/A_t^1 \}_{t \geq 0}, D_1, D_2, F(\cdot), \lambda \text{ and } g(\cdot) \) Further, Firm 1 and Firm 2 are of the same size in the sense of producing the same amount of output in some period \( t \). They differ only in that for Firm 1, \( \beta = 0 \) while for Firm 2, \( \beta > 0 \) - i.e. Firm 1 is myopic while Firm 2 is non-myopic.

[Scenario (b):] Everything is as in Scenario (a) except that \( \beta = 0 \) for both firms while \( M_t \)

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\(^{12}\)For example, there is an extensive literature on differences in the behavior and practices of US and Japanese firms.
is smaller for Firm 2 than for Firm 1.

[Scenario (c):] Everything is as in Scenario (a) except that $\beta = 0$ for both firms while $F^{-1}(x)$ is greater for Firm 2 than for Firm 1 for all $x$ in $[0,1]$. Then in each of these three scenarios, in relative terms Firm 2 spends more on improving its ability to customize than Firm 1.

Here, since I am considering two firms in the same industry, it seems natural to expect relative productivities of lowering per-unit cost and improving ability to customize to be the same for the two firms though their absolute magnitudes may differ due to country-specific factors. In scenario (a), Firm 2 takes into account that over time it will have higher market penetration and thus sell to people who attach more value to its ability to customize. As a result, in relative terms it spends more on improving its ability to customize. In scenario (b), Firm 2 has a smaller market than Firm 1. Hence, both firms being of the same size means Firm 2 has a higher degree of market penetration and thus sells to people who attach higher value to its ability to customize. In scenario (c), for the same degree of market penetration, buyers of Firm 2 always attach a higher value to the firm’s ability to customize than buyers for Firm 1. Also, in this case, both firms have the same degree of market penetration. Hence, in both these scenarios, Firm 2 in relative terms spends more on improving its ability to customize. Further, even if (i) in scenario (a), Firm 1 has a positive discount factor that is lower than that of Firm 2 while (ii) in scenarios (b) and (c), both firms have the same positive discount factor, it can be shown that the reasoning discussed above works in qualitatively the same way. Also, if $A^c_t$ and $A^d_t$ are the same for both firms for all $t$, then in both scenarios (b) and (c) both firms spend the same amount in lowering per-unit cost but Firm 2 spends more to improve its ability to customize while in scenario (a), Firm 2 would spend more than Firm 1 in both efforts.
4 Duopoly

I again consider a non-durable product. Time is discrete - \( t = 0, 1, 2, \ldots \) - with an infinite horizon. Prices, utility, revenues, costs and all spending are all in terms of a numeraire good.

Here, two firms - Firm 1 and Firm 2 - with discount factors \( \beta_i \in [0, 1], i \in \{1, 2\} \) - produce the product. There is a mass \( M_t \) of potential buyers in period \( t \). Period 0 is the first period when the product is commercially introduced by at least one of these firms. Firm \( i \) if in operation is characterized by its characteristic vector \( \{d_i, c_i, (a_i, b_i)\} \). \( d_i \) as we will see below denotes its ability to customize with a lower value of \( d_i \) implying better ability to customize. \( c_i \) is its per-unit production cost. There are no fixed costs of production. \( (a_i, b_i) \) is the own product preference vector for Firm \( i \)'s product. \( a_i \) is time-invariant and exogenously given. The values of \( b_i \) and \( d_i \) are positively related. If Firm \( i \) can exactly customize its product as per consumer needs, then \( b_i = 0 \), otherwise, \( b_i > 0 \). \( \{d_{i,t}, c_{i,t}, (a_i, b_{i,t})\} \) denotes the characteristic vector that Firm \( i \) if in operation starts off with in period \( t \). It can try to both lower its cost and to improve its ability to customize its product in such a case with \( r^c_{i,t} \) and \( r^d_{i,t} \) denoting its spending in these two efforts respectively in period \( t \). The outcome of these efforts is deterministic and at the end of period \( t \), Firm \( i \) has the characteristic vector
\[
\{d_{i,t+1}, c_{i,t+1}, (a_i, b_{i,t+1})\} = \{d_t - A^d_{i,t} g_i(r^d_{i,t}), c_{i,t} - A^c_{i,t} g_i(r^c_{i,t}), (a_i, b_{i,t} - A^d_{i,t} g_i(r^d_{i,t}))\}.
\]
Here \( g_i() \) is of the form: \( g(r) = r^{\lambda_i}; \lambda_i \in (0, 1) \). \( (A^d_{1,t}, A^c_{1,t}) \) has the same interpretation as before.\( M_t, A^d_{i,t} \) and \( A^c_{i,t} \) are all positive but finite \( \forall t \geq 0 \). \( \{M_t, (A^d_{1,t}, A^c_{1,t})\}_{t \geq 0} \) and \( \lambda_i \) are exogenously given and common knowledge; \( \lambda_i \) is time-invariant while \( M_t, A^d_{i,t} \) and \( A^c_{i,t} \) can vary over time. Reductions in production cost and improvements in ability to customize are cumulative over time.

I assume all potential buyers have the same utility function. Let \( x_{i,t} \equiv \) the number of units of output that each person buys from Firm \( i \) in period \( t \); \( x_{i,t} \) a continuous variable, \( x_{i,t} \in \mathbb{R}_+ \). Thus, total output sold by Firm \( i \) in period \( t \) is \( x_{i,t} M_t \) and \( x_{i,t} \) is the degree of
market penetration by Firm $i$ in period $t$. Further, in any period, I assume that buying $x_i$ units from Firm $i$ at a per-unit price of $P_i$, where Firm $i$ has the own product preference vector $(a_i, b_i)$, $i \in \{1, 2\}$, gives a consumer a utility of

$$U(x_1, x_2) = a_1 x_1 + a_2 x_2 - (b_1 x_1^2 + 2 \gamma x_1 x_2 + b_2 x_2^2)/2 - P_1 x_1 - P_2 x_2$$

(5)

where $\gamma$ is an exogenously given constant, $\gamma > 0$. Thus as in Dixit(1979), the two firms sell differentiated products that are substitutes except that $b_1$ and $b_2$ are endogenous.

Note that returns to spending on lowering per-unit cost here are as in the monopolistic set-up. Regarding consumer preferences, here I am using a non-discrete model of consumer demand. So, it is natural to expect that here as a consumer buys more of a firm’s product, the consumer would use the product for purposes for which the product is less suited. If a firm, say Firm $i$ is able to exactly customize its product to the consumer’s needs, then given the amount of output bought from the other firm, the consumer’s marginal utility from Firm $i$’s product should be the same for all $x_i$. Otherwise, with imperfect customization and given $x_j$, (i) the consumer’s marginal utility should be decreasing in $x_i$; (ii) an increase in Firm $i$’s ability to customize its product should lead to higher marginal utility from Firm $i$’s product for all $x_i$ and (iii) the amount of increase in marginal utility should be increasing in $x_i$ - this is because higher $x_i$ means the consumer uses the product for purposes for which Firm $i$ is able to meet its customization needs to a lesser extent and hence the consumer benefits more from an increase in Firm $i$’s ability to customize in such cases. From equation (5), note that given $x_j$, $a_i - \gamma x_j$ is the marginal utility here from the output of Firm $i$ for all $x_i$ if Firm $i$ can exactly customize its product to the consumer’s needs. Also, properties (i)-(iii) above hold here. Thus, from an economic perspective, my modelling of mass customization here in a duopoly scenario conceptually makes sense.

Further, note that properties (i)-(iii) above hold in the earlier monopolistic set-up with respect to degree of market penetration there. Also, here given $x_j$, $a_i - \gamma x_j$ is playing the
role for Firm $i$ of $v$ in the earlier monopolistic set-up. Further, the effects in the earlier monopolistic set-up of an improvement in the ability to customize for a firm on its marginal revenue hold in this set-up with respect to the expression for marginal revenue here. Thus, the modelling of consumer preferences here is in the same spirit as in and in that sense an extension of the earlier monopolistic set-up.

Throughout this section, size of a firm will continue to denote total output sold by the firm. Here, events occur as follows. At the start of a period, firm $i$, $i \in \{1, 2\}$ if in operation chooses its spending on lowering cost and on improving its ability to customize for that period. It has no financial constraints in this regard. Then the outcomes of these efforts are realized after which production occurs. Let, $P_{i,t} \equiv$ price per-unit output for firm $i$ in period $t$. Thus, if both firms operate in period $t$, for $i, j \in \{1, 2\}, i \neq j$, we have

**Inverse demands:**
$$P_{i,t}(x_{i,t}, x_{j,t}, d_{i,t+1}, d_{j,t+1}) = a_i - b_{i,t+1}x_{i,t} - \gamma x_{j,t};$$

**Direct demands:**
$$x_{i,t}(P_{i,t}, P_{j,t}, d_{i,t+1}, d_{j,t+1}) = \frac{(a_i-P_{i,t})b_{i,t+1} - \gamma (a_j-P_{j,t})}{b_1 t+1 + b_2 t+1 - \gamma^2};$$

(6)

where $b_{i,t+1}$ and $b_{j,t+1}$ are the values of $b_i$ and $b_j$ corresponding to $d_{i,t+1}$ and $d_{j,t+1}$ respectively.

The two firms might enter the industry in different periods. A firm when making its choice of spending on cost reduction and on improving ability to customize in a period knows if it will be in a monopoly or a duopoly scenario in that and subsequent periods. Further, its spending choices have no effect in this regard. Also, with both firms operating, they make their spending choices simultaneously. However, $\{d_{i,t+1}, c_{i,t+1}, (a_i, b_{i,t+1})\}, i \in \{1, 2\}$ is common knowledge when the firms make their output or pricing decisions. Thus, choices of spending on cost reduction and improving ability to customize by say Firm 1 in period $t$ do not affect corresponding choices of Firm 2 but does affect the output or price decision of Firm 2 in period $t$. The initial characteristic vector that each firm starts out with is exogenously given and common knowledge. Also, either firm when in operation cannot price discriminate and has no capacity constraints.
The initial values of $d_i$ (and the corresponding value of $b_i$) and $c_i$ for Firm $i$ are exogenously given. For analytical simplicity, I assume $\beta_1 = \beta_2 = 0$. I also assume parameter values are such that $\forall t$, $c_{i,t+1} \geq 0$, $b_{i,t+1} \geq 0$, $b_{1,t+1} b_{2,t+1} > \gamma$ and the profit-maximization problem is well-defined for both firms.$^{13}$

Here, Firm $i$ if it is a monopolist in period $t$ solves:

$$\max_{[r^d_i, r^c_i]} [a_i - (b_{i,t} - A^d_{i,t} g_i(r^d_i))] x^\text{mon}_{i,t} - (c_{i,t} - A^c_{i,t} g_i(r^c_i))] x^\text{mon}_{i,t} M_t - r^d_i - r^c_i,$$

where $x^\text{mon}_{i,t} \equiv \arg\max_{x_{i,t} \geq 0} [a_i - (b_{i,t} - A^d_{i,t} g_i(r^d_i))] x_{i,t} - (c_{i,t} - A^c_{i,t} g_i(r^c_i))] x_{i,t} M_t$.

With Cournot duopoly in period $t$, $(r^d_{1,t}, r^c_{1,t})$ solves:

$$\max_{[r^d_1, r^c_1]} [a_1 - (b_{1,t} - A^d_{1,t} g_1(r^d_1)) x^C_{1,t} - (c_{1,t} - A^c_{1,t} g_1(r^c_1))] x^C_{1,t} M_t - r^d_1 - r^c_1$$

where $x^C_{1,t}$ and $x^C_{2,t}$ are the resulting choices of $x_1$ and $x_2$ by Firms 1 and 2 respectively if Firm 1 chooses $(r^d_1, r^c_1)$ given that Firm 2 is choosing $(r^d_2, r^c_2)$; similarly for $(r^d_2, r^c_2)$.

On the other hand, with Bertrand competition in the product market, $(r^d_{1,t}, r^c_{1,t})$ solves

$$\max_{[r^d_1, r^c_1]} [P^B_{1,t} - (c_{1,t} - A^c_{1,t} g_1(r^c_1))] [\{ (a_1 - P^B_{1,t}) b_{2,t+1} - \gamma (a_2 - P^B_{2,t}) \} / (b_{1,t} - A^d_{1,t} g_1(r^d_1)) b_{2,t+1} - \gamma^2] M_t - r^d_1 - r^c_1$$

where $P^B_{1,t}$ and $P^B_{2,t}$ are the resulting choices of prices by Firms 1 and 2 respectively if Firm 1 chooses $(r^d_1, r^c_1)$ given that Firm 2 is choosing $(r^d_2, r^c_2)$, with $(b_{2,t+1})$ the resultant value of $b_2$ for Firm 2; similarly for $(r^d_{2,t}, r^c_{2,t})$.

From the discussion above and using the envelope theorem at the product market stage, it follows that with $\beta_1 = \beta_2 = 0$, $r^c_{i,t}$ and $r^d_{i,t}$, $i, j \in \{1, 2\}$, $i \neq j$, satisfy the following FONC’s:

**Monopoly:** $r^c_{i,t} : (x^\text{mon}_{i,t} M_t) A^c_{i,t} g'_i(r^c_{i,t}) = 1$; $r^d_{i,t} : [x^\text{mon}_{i,t}] (x^\text{mon}_{i,t} M_t) A^d_{i,t} g'_i(r^d_{i,t}) = 1$ (7)

**Cournot duopoly:**

$$r^c_{i,t} : [A^c_{i,t} g'_i(r^c_{i,t}) - \gamma (\partial x^C_{j,t} / \partial r^c_{i,t})] (x^C_{i,t} M_t) = 1$$

$$r^d_{i,t} : [(x^C_{i,t}) A^d_{i,t} g'_i(r^d_{i,t}) - \gamma (\partial x^C_{j,t} / \partial r^d_{i,t})] (x^C_{i,t} M_t) = 1$$ (8)

**Bertrand duopoly:**

$$r^c_{i,t} : [A^c_{i,t} g'_i(r^c_{i,t}) + (\gamma / b_{j,t+1}) (\partial P^B_{j,t} / \partial r^c_{i,t})] (x^B_{i,t} M_t) = 1$$

$$r^d_{i,t} : [x^B_{i,t} A^d_{i,t} g'_i(r^d_{i,t}) + (\gamma / b_{j,t+1}) (\partial P^B_{j,t} / \partial r^d_{i,t})] (x^B_{i,t} M_t) = 1$$ (9)

$^{13}$In upcoming versions of this paper, I will put in corresponding assumptions regarding parameter values as in the earlier monopolistic set-up.
In (8) (and (10) below), $x^C_{i,t}$ and $x^C_{j,t}$, $i, j \in \{1, 2\}, i \neq j$, are equilibrium values of $x_{i,t}$ and $x_{j,t}$ with Cournot while in (9) (and (10) below), $P^B_{i,t}$ and $P^B_{j,t}$ are equilibrium price choices and $x^B_{i,t}$ and $x^B_{j,t}$, the corresponding $x_{i,t}$ and $x_{j,t}$ with Bertrand product market competition. Also, in (8)-(10), $b_{.,t+1}$ and $c_{.,t+1}$ are equilibrium values. Note that in both Cournot and Bertrand duopoly, spending by a firm, say Firm $i$, on both lowering cost and on improving ability to customize have a per-unit output (i) “direct effect” - effect on its profit holding product market decisions of Firm $j$ constant - which is as in monopoly, (ii) “strategic effect” - effect on its profit through its effect on product market decisions of Firm $j$; $[-\gamma(\partial x^C_{j,t}/\partial r^C_{i,t})]$ for spending on lowering cost and $[-\gamma(\partial x^C_{j,t}/\partial r^d_{i,t})]$ for spending on improving ability to customize in Cournot, $[(\gamma/b_{j,t+1})(\partial P^B_{j,t}/\partial r^C_{i,t})]$ for spending on lowering cost and $[(\gamma/b_{j,t+1})(\partial P^B_{j,t}/\partial r^d_{i,t})]$ for spending on improving ability to customize in Bertrand. I use the following notation.

\[
\omega_t \equiv \frac{\gamma^2}{b_{1,t+1}b_{2,t+1}-\gamma^2}, \forall t \geq 0.
\]

The effect of choices of Firm $i$ about spending to lower cost and to improve ability to customize on product market decisions of Firm $j$, $i, j \in \{1, 2\}, i \neq j$, are as shown in (10). (7)-(10) lead to the results below.

\[
\frac{\partial x^C_{j,t}}{\partial r^C_{i,t}} = -\frac{\omega_t g'(r^C_{i,t})}{\gamma}, \quad \frac{\partial x^C_{j,t}}{\partial r^d_{i,t}} = -\frac{\omega_t 2x^C_{i,t}g'(r^d_{i,t})}{\gamma};
\]

\[
\frac{\partial P^B_{j,t}}{\partial r^C_{i,t}} = -\frac{\omega_t b_{j,t+1}g'(r^C_{i,t})}{\gamma}, \quad \frac{\partial P^B_{j,t}}{\partial r^d_{i,t}} = \frac{\omega_t b_{j,t+1}g'(r^d_{i,t})}{\gamma} [-2\gamma(a_j - c_{j,t+1}) - 4b_{j,t+1}(a_i - c_{i,t+1})] (10)
\]

**Proposition 7:** Difference between lowering cost and improving ability to customize

With both Cournot as well as Bertrand duopoly, returns to a firm to lowering costs depends only on demand parameters, productivity in lowering cost and quantity sold while returns to improving ability to customize depend on demand parameters, productivity in improving ability to customize, demand parameters and also positively on the degree of market penetration by the firm.

Thus, the difference between the two choices with both Cournot and Bertrand duopoly
is as in the earlier monopolistic set-up. The underlying intuition is as follows. With both Cournot and Bertrand duopoly, the direct effect of spending to improve ability to customize as well as of spending to lower per-unit cost here (i) are and (ii) differ from each other, as in the monopolistic set-up. Now, consider the strategic effects. Let $BR^C_{i,t}(x_{j,t})$ and $BR^B_{i,t}(P_{j,t})$ be optimal choice for Firm $i$ in period $t$ of $x_i$ and $P_i$ in the product market stage given the corresponding choice by Firm $j$ in a Cournot and in a Bertrand duopoly respectively. At any interior point on the reaction functions

$$BR^C_{i,t}(x_{j,t}) = \frac{a_i - \gamma x_{j,t} - c_{i,t+1}}{2b_{i,t+1}}; BR^B_{i,t}(P_{j,t}) = \left[\frac{a_i + c_{i,t+1}}{2} - \frac{\gamma a_j}{2b_{j,t+1}}\right] + \frac{\gamma P_{j,t}}{2b_{j,t+1}}.$$

First, consider Cournot competition. An increase in $r^c_{i,t}$ lowers the marginal cost of Firm $i$ but leaves both $P_i(x_i,x_j)$ and $P_j(x_i,x_j)$ unchanged. As a result, $BR^C_i(x_j)$ shifts out (higher $x_i$ for each $x_j$) in a parallel fashion while $BR^C_j(x_i)$ is unchanged. So, the consequent decrease in equilibrium $x_j$ and the resultant benefit to Firm $i$ - the strategic benefit from spending on lowering per-unit cost - are independent of equilibrium $x_i$. An increase in $r^d_{i,t}$ raises $P_i(x_i,x_j)$ and the corresponding marginal revenue - as discussed earlier, the amount of increase in both are increasing in $x_i$ - but leaves $P_j(x_i,x_j)$ unchanged. Hence, $BR^C_i(x_j)$ shifts out in a non-parallel fashion (amount of shift is increasing in $x_i$) while $BR^C_j(x_i)$ is unchanged. Hence, the consequent decrease in equilibrium $x_j$ and the corresponding benefit to Firm $i$ - the strategic benefit from spending on improving ability to customize - are increasing in equilibrium $x_i$.

With Bertrand, an increase in $r^c_{i,t}$ lowers the per-unit cost of Firm $i$ but does not change $x_i(P_i,P_j) \text{ or } x_j(P_i,P_j)$. Hence, $BR^B_j(P_i)$ is unchanged while $BR^B_i(P_j)$ shifts in a parallel fashion (lower $P_i$ for each $P_j$). So, the consequent decrease in equilibrium $P_j$ (with Bertrand, lower price by one firm leads to a lower price by the other, hence the strategic effect of spending to lower per-unit cost is negative) and the corresponding effect on Firm $i$ - the strategic effect of spending to lower per-unit cost - are independent of equilibrium $P_i$ and $x_i$. An increase in $r^d_{i,t}$ leaves $BR^B_i(P_j)$ unchanged. However, it lowers the intercept term but
increases the slope of $BR_j^B(P_i)$. The former provides a push towards a lower $P_j$ for all $P_i$ while the later provides a push towards a larger $P_j$ for all $P_i$. Thus, the two effects work in opposite directions. Hence, the sign of the net strategic effect of spending to improve ability to customize is ambiguous with Bertrand duopoly but it’s magnitude is turns out to be increasing in $x_i$. Thus, with both Cournot and Bertrand duopoly, the strategic effects reinforce the difference between the direct effects of spending to improve ability to customize and spending to lower per-unit cost leading to Proposition 7.

Proposition 8 below characterizes both for Cournot and for Bertrand product market duopoly, how the two choices by a firm evolve over time as well as how they differ across firms of different sizes at any given point in time. The basic intuition underlying Proposition 8 is similar to the corresponding results in the monopolistic set-up.

**Proposition 8**: (i) With Cournot duopoly, a) ceteris paribus, a larger firm spends more both on lowering cost and improving ability to customize and also spends relatively more on increasing its ability to customize than a smaller firm; b) if a firm achieves a greater degree of market penetration over time, then ceteris paribus, it spends more on lowering cost as well as on improving ability to customize and relatively more on improving its ability to customize over time.

(ii) With Bertrand duopoly, a) ceteris paribus, a larger firm spends more both on lowering cost and improving ability to customize and also spends relatively more on increasing its ability to customize than a smaller firm provided the difference in size between the two firms is large enough; b) if a firm achieves a sufficiently greater degree of market penetration over time, then ceteris paribus, it spends more on lowering cost as well as on improving ability to customize and relatively more on improving its ability to customize over time.

Further, comparing the two choices at any given point of time by firms of the same size but in a monopolistic, Cournot or Bertrand set-up, I find the following.
Proposition 9: Consider two firms of the same size. Then, (i) if one firm is in a Cournot duopoly while the other is in a monopolistic set-up, ceteris paribus, the firm in a Cournot duopoly spends more on lowering cost, more on improving its ability to customize and relatively more on its effort to improve its ability to customize than the firm in a monopolistic set-up;

(ii) if one firm is in a Bertrand duopoly while the other is in a monopolistic set-up, ceteris paribus, the firm in a Bertrand duopoly spends less on lowering cost and for a range of parameter values relatively less on its effort to improve its ability to customize than the firm in a monopolistic set-up.

Thus, Proposition 9 provides a ranking in terms of the relative effort at trying to improve ability to customize amongst firms of the same size but differing in the form of product market competition. The underlying intuition is as follows. Ceteris paribus, the direct effect for both spending to lower per-unit cost and to improve ability to customize are the same across a monopolistic firm, a firm in a Cournot and a firm in a Bertrand duopoly. In a Cournot duopoly, the strategic effect for both spending to lower per-unit cost and to improve ability to customize are positive. Hence, a firm in a Cournot duopoly does more of both than a monopolistic firm. Further, the magnitude of the strategic effect relative to the direct effect is larger for spending on improving ability to customize. Hence, a firm in a Cournot duopoly spends relatively more on improving ability to customize than a monopolistic firm. In a Bertrand duopoly, the strategic effect for spending to lower per-unit cost is always negative while that for spending to improve ability to customize could be either negative or positive. However, for a range of parameter values, the strategic effect for spending to improve ability to customize is negative; further it is of a larger magnitude relative to its direct effect than that for spending to lower per-unit cost. Hence, we get Proposition 9(ii).

Further, all of the results with duopoly hold even with $\gamma < 0$. Thus, these results hold
both when the products of the two firms are substitutes as well as when they are complements of each other.

5 Concluding Remarks

In this paper, I have provided an analysis of the phenomenon of mass customization from an economic perspective. It is worth pointing out that all my results here depend on three simple assumptions. One is regarding consumer preferences, namely that there is a negative relationship between total willingness to pay for a firm’s product and the willingness to pay for improvements in the firm’s ability to customize. The other two assumptions are regarding returns from spending to lower per-unit cost and that from spending to improve ability to customize, namely diminishing marginal returns to both and an inverse relationship between ratio of marginal return from spending on lowering per-unit cost to that from spending on improving ability to customize and ratio of amount spent on lowering per-unit cost to amount spent to improve ability to customize. As long as these three assumptions hold, all my results should qualitatively remain the same though getting them analytically may become more difficult. A careful and thorough empirical test of the predictions found here seems to be the next obvious step. However, this is beyond the scope of this paper and is left for future research.

6 Appendix

Proof of Lemma 1: (i) follows from the fact that $g'(r)$ tends towards infinity as $r$ tends towards zero and A4. The other parts follow from the discussion preceding Lemma 1.

Proof of Proposition 1: Follows from (3) and (4).

Proof of Proposition 2: Follows from (3) and (4) and the fact that $g'(r)$ is decreasing in $r$.

My assumption of the functional form for $g(.)$ is a sufficient condition to guarantee an inverse relationship between $\frac{\Delta^c g'(r_c)}{\Delta^d g'(r_d)}$ and $\frac{r_c}{r_d}$ for all values of $r_c$ and $r_d$. 

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Proof of Proposition 3: Follows from (3) and (4) and the fact that the functional form of $g(.)$ implies an inverse relationship between $\frac{g'(r^c)}{g'(r^d)}$ and $\frac{r^c}{r^d}$.

Proof of Proposition 4: Follows from (3) and (4) replacing $x_t$ by $\frac{Q}{M_t}$ and noting that Firm $S$ takes into account benefits to consumers from increasing customization ability.

Proof of Propositions 5 and 6: Follow from comparing (3) and (4) for the two firms obtained after incorporating the assumptions made in the Propositions.

Proof of Propositions 7-9: To be included.

References


