Targeted product design: Locating inside the Salop circle[1]

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Abstract

Product design is a key choice for firms. We consider the trade-off associated with well-targeted designs that are much more suitable for some types of consumers against more generic designs that are unremarkable and inoffensive to all types. We introduce a model that adapts the familiar Salop circle model (1979) by allowing firms to locate on the interior of the circle. Thereby we allow for continuous design choices between the extremes of fully targeted and fully generic designs. We provide simple sufficient conditions that ensure extreme or intermediate design choices. Further, we show that firms with higher marginal cost of production choose more targeted designs.

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1 Introduction

Firms constantly make decisions not only about prices and quantities, but also regarding the kind of goods that they produce. Even though some choices of product characteristics may be costless to the firm, these are non-trivial decisions, as making a product more attractive to some consumers may make it less attractive to others.

Our focus in this paper is the trade-off inherent in the targeting decision associated with product design. A more targeted design satisfies consumers to whom it is directed but at the cost of alienating others. Instead, more generic products might alienate few consumers but are unlikely to excite the passions of any. Examples of this trade-off in the choice between more targeted and more generic designs are wide-ranging. Restaurants can choose very authentic tailored cuisines or offer more bland or less daring offerings. Software designers might choose to design very slick clean programs to address specific needs, or slower more cumbersome designs that can handle many uses. Even in the choice of color, a fashion or product designer might choose a specific bright color that may appeal to some, or a more neutral palette that may not thrill any consumer, but is less likely to offend anyone.

To address the issue of how much to target a design rather than choose more generic designs that are neither loved nor loathed, we introduce a new model. In our model designs lead to demand rotations (discussed in particular in Johnson and Myatt, 2006). A relatively more generic design leads to a rotation of a firm's demand curve, whereby the consumer who enjoys the good most gains less utility from a more generic design, but the consumer who enjoys it the least gains more utility.[2] This design decision thus contrasts from standard models of horizontal differentiation, where the concern is which consumers to satisfy rather than how much to satisfy segments of the population, and models of vertical differentiation where designs are commonly ranked in consumers' preferences.

As an example, consider a new Persian restaurant. It is naturally limited

[2] Formally a rotation imposes a little more structure by requiring that the demand curves associated with different designs cross only once.

in the range that it can offer, and so must choose between menu items that are designed with broader audiences in mind (for example, offering French fries instead of rice), or items that might appeal only to more refined palettes (such as kalleh pacheh—a traditional broth prepared with lamb's head and trotters). This kind of design choice creates an interesting trade-off since a blander, more conventional menu might appeal to a broader audience but at the same time means that no individual diner is likely to be so enamored with the cuisine that the restaurateur can charge a very high price and still make sales. In seeking to attract a wider range of horizontal preferences through the design, there is a sense in which there is a vertical quality drop through the loss of authenticity. Indeed, Kovács et al (2013) provide empirical support for this effect by highlighting that patrons perceive targeted (single-category) restaurants as more authentic and of higher quality. As an alternative example, a software designer may decide to broaden the appeal of its product by adding new features, but this might create a slower running program or a more complex, less intuitive and bloated interface. In both examples, these two effects (broader appeal, loss in vertical quality) appear in combination and result in a reduction in the overall dispersion of consumers' valuations.

In considering design, the restaurateur, software designer, or firm, more generally, must consider the underlying consumer preferences. In particular, a key determinant of design will be the extent to which the breadth of appeal increases while the product suffers some fall in vertical quality for the aficionado who most appreciates the product or service. If this customer cares a great deal for authenticity but is relatively insensitive once moving away from a genuinely authentic cuisine, then the restaurateur will do best by choosing an extreme offering—either as bland and generic as he can be to cater to a wide audience, or as authentic as possible to target the extreme tastes. Instead if, the aficionado very much dislikes bland generic offerings but is relatively insensitive across offerings that are somewhat authentic, then the restaurateur optimizes with an intermediate menu that balances between the aficionado's tastes and those of the broader population. Similarly, if adding features degrades quality or slows down software to a greater extent when there are few features than many, the software firm optimizes by offering either a very stripped down or a very broad program. Instead, in the opposite case when the effect of extra features in terms of slowing down the program or making the interface more complicated gets worse at an accelerating rate, then the most profitable software design might be an intermediate one.

We model design choices as an intuitive trade off between conventional representations of horizontal and vertical differentiation. Formally, we adapt the Salop (1979) model where consumers are located on the circumference of a circle to allow firms to locate on the interior rather than only on the edge of the circle. Locations closer to the center of the circle correspond to more generic offerings that appeal to a broad base and locations close to the circumference are targeted niche offerings. Consumer preferences are reflected in horizontal costs associated with moving around the circle and vertical costs associated with moving to the interior, thus a generic offering involves relatively high vertical costs for all consumers, but also lower horizontal costs. We abstract from production costs associated with different designs, although these can be incorporated in the model in a straightforward way.

We establish the following results and show that they hold both for the monopoly case and for various forms of competition. First, we find sufficient conditions that ensure extreme product offerings—that is, offerings that are either as generic or as targeted as possible. As suggested above, these key conditions are related to the relative speed by which horizontal and vertical cost vary. Second, we show that the higher the marginal cost of production, the more targeted the offering. The intuition is a familiar one—a firm with a very high marginal cost must charge a relatively high price and so it values variance in consumer valuations in the hope of finding some consumers willing to buy. On the contrary, a firm charging a relatively low price expects most consumers would be willing to purchase unless the good is a very poor match, so that the firm benefits from reducing variance by choosing to be more generic. This result is of particular interest in the context of the search model of monopolistic competition analyzed in Section 4, as it shows how different rich market configurations in terms of product design arise through the interplay of firms' marginal cost heterogeneity and the trade off between vertical and horizontal quality.

Related Literature

In identifying circumstances in which firms choose extreme designs, our analysis is reminiscent of Porter's (1998) notion of firms "stuck in the middle". Note that our focus though is at the level of product design, rather than the more comprehensive notion of the overall "firm strategy" contemplated in Porter's work. The empirical validity of Porter's conjecture has found mixed support (see Campbell-Hunt, 2000, for a meta-analysis of empirical studies). Our model provides theoretical foundations for when extreme design strategies are to be expected. In particular, firms do not gain from intermediate design strategies when consumers care a great deal for having their precise needs met and are relatively insensitive to customization once a product is generic enough.

In analyzing demand rotations, this paper is related to a recent literature in economics and marketing that has explored information disclosure in monopoly and competitive settings. Anand and Shachar (2011), for example, demonstrate that when television networks advertise their own shows they face a trade-off . This provision of information results in a reduction in the demand for some consumers, but an increase for others. Earlier theoretical work by Lewis and Sappington (1991, 1994) considers firms' incentives to provide consumers (of two possible types) with private information. More recently, Johnson and Myatt (2006) provide a general treatment allowing for a continuum of consumer types and introducing demand rotations—that is, families of demand curves where any pair of demand curves cross only once—and consider several examples that ensure an ordering of demand curves that leads a monopolist to an extremal choice.[3] Kuksov and Lin (2010), Gu and Xie (2013), Sun (2010) and Sun and Tyagi (2012) consider the incentives of different types of firms to provide different kinds of information (for example, on vertical product quality as opposed to information on individual product fit). Similar to our result on product design, high marginal cost firms often have greater incentives to provide more (idiosyncratic) product

[3] See also Ganuza and Penalva (2010) who provide an ordering of informative signals.

fit information.

While the literature has tended to focus on information provision, the work on the role of product design in inducing demand rotations is more limited. In particular, Kuksov (2004) considers a binary design choice, and Johnson and Myatt (2006), Larson (2011), and Bar-Isaac, Caruana and Cuñat (2012) make assumptions that ensure only two designs (the extreme generic or niche designs) arise. In a framework more closely related to ours, von Ungern-Sternberg (1988) instead imposes conditions that ensure an interior solution, and analyses a symmetric free-entry equilibrium, where the "vertical" cost that leads to a trade-off is not one that affects consumer utility directly but instead raises the firm's cost of production. The present work can be seen as complementary to this earlier in work in several respects. First, instead of exogenously choosing whether to analyze extreme or intermediate decisions, we provide the conditions (in terms of the horizontal-vertical trade-off) for either case to arise. Second, we show that even when these conditions fail, many qualitative features of the recent extreme-design approach remain valid. In particular, we show that high cost firms choose more targeted designs, and that reductions in consumer search costs can lead to increased market shares for both the highest and lowest cost firms.

2 A Model of Design: Monopoly

We adapt the well-known Salop (1979) circular model of horizontal differentiation to consider product design. As in Salop's model, we assume that consumers are uniformly distributed on a circle of radius 1. It is convenient and without loss of generality to suppose that there is a mass 2π of consumers. However, we break with the standard model in supposing that firms can locate not only on the circumference of this circle, but also on the interior of a ring. The outer-edge of the ring is a circle of radius 1, corresponding to consumer locations, and the inner edge is a circle with inner radius B, where $1 > B > 0$. Locations anywhere in this ring correspond to different possible designs.[4]

In this section we consider a monopoly firm (and extend to models of competition in later sections). The monopolist has a constant per unit marginal cost m and can locate anywhere within the ring. Thus, a firm's location is determined by the angle and the distance to the center. In the example of the restaurant, a location consists of the type of cuisine (Italian, Persian etc.) corresponding to an angle of the circle, in addition to a choice of how authentic (further out towards the outer-edge of the ring) or bland/generic (towards the inner-edge of the ring) is the restaurant.

If the firm locates exactly at the location of a consumer, this consumer's value for the product is V. Otherwise, the consumer must incur travel costs to reach the firm. She first travels along a radius towards the center of the ring and, only then, travels along the arc.[5] If she travels a distance y along the radius and x along the arc, the travel costs are assumed to be $c(y) + x$ with $c(\cdot)$ twice continuously differentiable and $c'(\cdot) > 0$. That is, we assume linear unit travel costs along the arc, but allow any increasing shape for the cost of travelling along a radius.[6] By construction, the cost of traveling along a radius is common to all consumers and can be interpreted as vertical differentiation. Meanwhile, the cost of traveling along the arc varies across consumers depending on their locations. Thus, a change in this transport cost can be interpreted as a change in horizontal differentiation. Throughout the paper we refer to the cost of traveling along the arc as a horizontal cost and the cost of traveling along a radius as a vertical cost. A central element of the model is that firm strategies always involve a trade-off between these

[4] For convenience, the algebra in this paper is written for $B > 0$. The results for $B = 0$ do not change, and coincide with those obtained for the case limit when B tends to 0.

[5] We assume that the consumer travels towards the center and along a ring independently, and allow for different costs. Hence these dimensions are better suited for two different characteristics of a good (such as the brightness and hue of its colour) rather than dimensions in a physical space.

[6] Linear costs along the arc deliver linear demand functions, while unit costs are without loss of generality.

two costs. This framework is illustrated in the figure below:

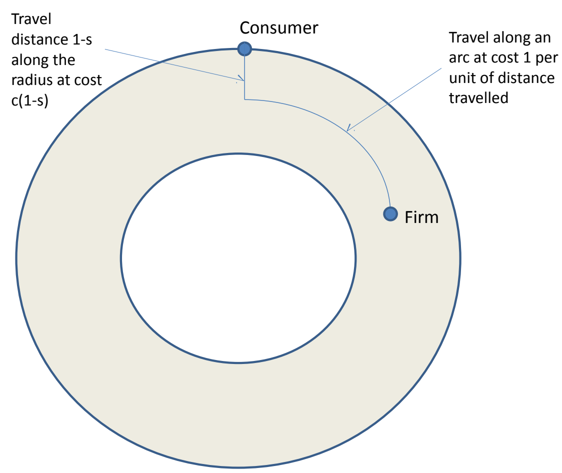

Figure 1: Design and consumer travel costs.

Without loss of generality the firm is located at angle 0. Thus, the location decision boils down to choosing how far inside the ring it wants to be, which we capture by $s \in [B, 1]$. Locating at $s = 1$ corresponds to a fully tailored design in which the firm aims for a niche consumer base. Such a design maximizes the valuation of the consumer located at angle 0, but it also maximizes the dispersion of valuations and, in particular, it minimizes the appeal of the product for the consumer located at angle π. Locating closer to the centre, reduces the heterogeneity of consumer valuations and has a similar effect to a reduction of horizontal transport costs in a standard circular setting. However, moving towards the center also reduces the vertical quality of the good by imposing a common additional cost on all consumers.

If a monopolist chooses a price p and a design s, the marginal consumers who are indifferent between purchasing or not are located at angles x and $-x$, where x satisfies:

$$V - c(1 - s) - sx - p = 0.$$

Thus, the demand for a monopoly who chooses price p and design s is given by:

$$q(p,s) = \max(0, \min(2\pi, \frac{2}{s}\left(V - c\left(1-s\right) - p\right))).$$

2.1 Optimal Design

For simplicity, we assume that optimal choices lead to a demand that is in the interval $(0, 2\pi)$.[7] This is guaranteed to be the case if intermediate values of V are considered. In this case the demand function simplifies to:

$$q(p,s) = \frac{2}{s}\left(V - c\left(1-s\right) - p\right), \tag{1}$$

and the monopolist's problem is to choose s and p in order to maximize:

$$\Pi(p,s) = \frac{2}{s}\left[V - c(1-s) - p\right](p-m). \tag{2}$$

Note first that the demand function $q(p,s)$ is linear in p and that, the higher is s, i.e. the more targeted the design, the steeper is the slope of the (inverse) demand, corresponding to more diverse valuations by different consumers. A higher s also involves a higher intercept with the price axis, representing a higher valuation of the consumer who likes the good most. Thus, any two designs result in demands that cross only once, and so different design choices induce demand rotations as in Johnson and Myatt (2006).

Our assumptions on the differentiability of transport costs imply the differentiability of the profit function, and allow us to use first and second order conditions to characterize the optimal design if this is intermediate. Here in the text we present the results, while the algebra is deferred to the Appendix.

Proposition 1 *When the optimal design s^* is intermediate, it satisfies the following condition*

$$c'(1-s^*) = \frac{1}{2}q(p^*,s^*). \tag{3}$$

[7] The same qualitative results are obtained for the case in which it is optimal to serve the whole circle. Note that this is the case when B tends to 0.

This condition has a very intuitive economic interpretation. If the monopolist decides to serve a market of size q (note that choosing prices is equivalent to choosing quantities), the marginal consumer is located at horizontal distance $\frac{1}{2}q$ from the best-matched consumer. Now, design is chosen in order to minimize the transport cost for this marginal consumer. Thus, the marginal vertical quality loss from standardizing the product in the left hand side of equation (3) is equated to the marginal horizontal gain on the right hand side. Expressed in other words, the optimal design makes sure that the marginal rate of substitution of vertical and horizontal quality for the indifferent consumer are equalized. The next result provides further characterization of the optimal design.

Proposition 2 *A necessary condition for an intermediate design solution is that a consumer's vertical transport cost is locally convex. Meanwhile, if vertical transport costs are concave—that is $c''(x) < 0$ for all x—then a monopolist optimally chooses an extremal design $s^* \in \{B, 1\}$.*

We provide some intuition for this result. Note that the previous Proposition 1 shows that the marginal cost of standardizing the product is key in determining the optimal design. Thus, it is no surprise that how this cost changes explains whether an intermediate or an extreme design arises. Consider the following experiment: For a given fixed price, let the monopolist change the design towards standardization (reducing s). If a marginal change attracts more consumers, would a further move still do so? When $c''(\cdot) < 0$ that is the case, because while the horizontal costs are reduced linearly, vertical costs only increase at a slower speed, which makes inframarginal consumers join in. A similar argument would lead to an optimal fully niche design if the initial marginal change induced a reduction on the customer base. As a result, and as Proposition 2 states, when the vertical transport costs are concave the optimal design must be extreme. One can reinterpret this idea in the context of whether the demand rotations induced by design changes are ordered or not, in the sense of Johnson and Myatt (2006).[8] Consider in Figure 2 the different demand curves that are traced

[8] Demand rotations are ordered if the intersection point between two (inverse) demand

out as the monopolist chooses different designs. A concave travel cost $c(\cdot)$ ensures that as, the monopolist moves from niche designs that induce steep demand functions to flatter broad designs the drop-off in the price intercept is not too severe. This implies that the family of rotations are ordered. In particular, the upper envelope of sales/price combinations that can be achieved by the family of demand rotations is traced out be the most niche and the most broad designs. Thus, the monopolist chooses one of these two designs.

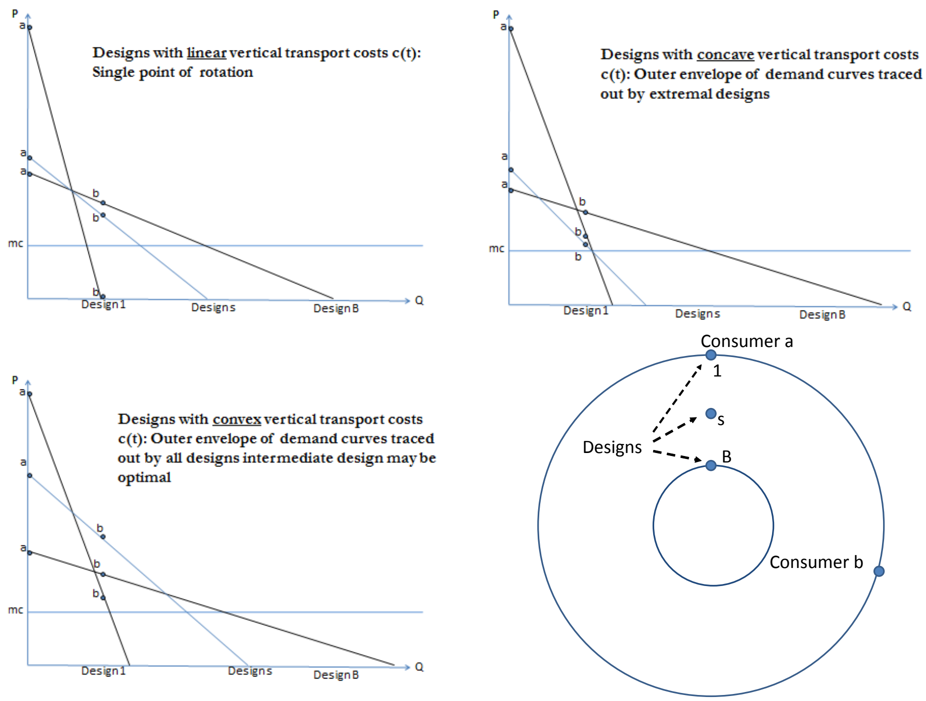

Figure 2: Summary of rotation orderings as a function of transport costs.

Meanwhile, when $c(\cdot)$ is convex one cannot immediately conclude that the optimal design is going to be an intermediate one. Note the knife-edge

functions moves upwards as the demand becomes flatter. See Johnson and Myatt (2006) for a formal definition.

case of linear transport costs still entails an extreme optimal design. As Figure 2 shows, in this case all demand curves cross through the same point of rotation. Thus, it is still the case that the upper envelope of the demand curves is composed by only the most niche and the most broad designs. An argument of continuity then proves that mild degrees of convexity would still result in extreme design choices. But once $c(\cdot)$ is convex, the family of rotation is no longer ordered, and all designs contribute to the upper envelope of the demand curves (see Figure 2). Thus, if the degree of convexity is sufficiently high the potential gains from choosing an intermediate design become strong enough to make such choice optimal.

Note that Propositions 1 and 2 are necessary conditions for an optimal intermediate design. We can, however, establish elementary conditions that are sufficient to guarantee it.

Proposition 3 *An intermediate optimal design arises if the vertical cost function $c(\cdot)$ satisfies the following two inequalities:*

$$2Bc'(1-B) + c(1-B) > V - m > 2c'(0)$$

Essentially, a sufficient condition for a solution to be interior is that the cost function $c(y)$ is sufficiently flat at $y = 0$ and steep enough at $y = 1 - B$. While these two conditions may not be always satisfied, they are interesting for two reasons. First, they are simple to check and interpret, and second, they do not impose any particular functional behavior in the interior of the domain, in particular whether the function needs to be globally concave or convex. In the context, of the restaurant example, these conditions correspond to checking the extent to which an aficionado suffers from moving from full authenticity, and gains from departing from the most bland cuisine.

Next we turn to the comparative statics of the optimal design, and show that a firm with higher marginal costs would choose a more targeted, niche design. As discussed in the introduction, this result has a simple intuition—a firm with a high marginal cost would need to charge a relatively high price, so for the firm to make sales it needs to find some consumers who fall in love with the product, leading to a targeted design. Instead firms with very low marginal costs would hope to sell to many consumers and would try to avoid choices that would put off any potential consumers, and would therefore choose more generic designs.

Proposition 4 *A monopolist with higher marginal cost of production, m, chooses a more targeted design.*

So far we have characterized the design choices of a monopolist, in what follows we embed the design model in two competitive models. First, we analyze the duopoly case in which firms simultaneously compete in the design space. Next, we embed the monopoly setting within a sequential search model of monopolistic competition. We show that the monopoly results extend easily to these competitive environments, and further explore the market configurations that arise in such settings.

3 Bertrand Duopoly

We now analyze two firms $i = 1, 2$ with marginal costs of production $m_i \geq 0$ competing within the same price-design framework as above. We suppose that firms first choose their design simultaneously. These decisions then become public, and in a second stage, firms simultaneously choose prices. This timing is intended to capture that prices can adjust more easily than demand.[9] Finally, consumers observe the locations, prices and designs of both firms, and choose one of the two product (if any).

We assume that V is sufficiently high to guarantee full market coverage; that is, that all consumers buy from one or other of the two firms. Further, we assume that, with respect to the horizontal dimension, firms are located opposite each other (Firm 1 at angle 0, and Firm 2 at angle π).[10] We denote

[9] Building on an earlier version of this paper, González-Maestre and Granero (2014) consider the case where the design and pricing decision are simultaneous. They allow for $N \geq 2$ firms, but restrict attention to ex-ante identical firms (with the same marginal costs) and symmetric equilibria.

[10] For simplicity, we abstract from the firms' choices of angle of location. Such analysis has been shown to be involved or intractable even in the simpler Hotelling framework (Osborne and Pitchik, 1987; and Vogel (2008)).

x_{12} to be the consumer that is indifferent between buying from Firm 1 or Firm 2; this can be written explicitly as:

$$x_{12} = \frac{c(1-s_2) - c(1-s_1) + p_2 - p_1 + \pi s_2}{s_1 + s_2} \tag{4}$$

In the following analysis we concentrate on the case in which both firms are active in the market; that is, when $x_{12} \in (0, \pi)$. Firms' profits can be written simply as:

$$\begin{aligned} \Pi_1 &= 2x_{12}(p_1 - m_1), \text{ and} \\ \Pi_2 &= 2(\pi - x_{12})(p_2 - m_2). \end{aligned}$$

Given fixed designs, one can calculate optimal prices by solving for the Nash equilibrium of the last stage. In this way, firm 1's profits can be written as a function of s_1 and s_2 as follows:

$$\Pi_1(s) = \frac{2}{9}\frac{\left(c(1-s_2) - c(1-s_1) - m_1 + m_2 + \pi s_1 + 2\pi s_2\right)^2}{s_1 + s_2}.$$

Simple calculus and algebraic manipulation, implies that Firm 1's optimal design (when interior) satisfies

$$c'(1-s_1) = \frac{3}{2}x_{12} - \pi \tag{5}$$

This condition is the counterpart of Equation (3) in the monopoly model. The different expression stems from the fact that now the design choice has a strategic aspect (to influence the subsequent price competition) that was absent in the monopoly model.

We begin by establishing the same relationship between the shape of the vertical transport costs and the choice of product design that was present in the monopoly model:

Proposition 5 *A necessary condition for an intermediate design in the duopoly setting is that the vertical transport costs are locally convex. Moreover, if these costs are concave, then both firms choose an extremal design.*

The duopoly setting provides the following new result: At least one firm adopts an extreme most targeted design in equilibrium.

Proposition 6 *At least one firm (the one with higher cost) chooses an extreme most targeted design; that is if $m_1 \geq m_2$ then without loss of generality $s_1^* = 1$.*

The intuition for this result is a familiar one, when firms first choose locations then prices, then firms (and particularly a high cost firm) have an incentive to differentiate in order to soften price competition. But, depending on parameters, one might have the better firm choosing an intermediate or fully broad design. This firm does not want to fully soften competition, and prefers to exploit its comparative productive advantage. This result partially replicates that of the monopoly case, as it establishes that in competition it is the firm with lower marginal costs that would choose a broader design. This is further corroborated by the next result, that performs comparative statics on marginal costs.

Proposition 7 *Holding constant the marginal cost of the rival, a higher marginal cost of production m leads to a (weakly) more targeted design.*

The results in this section allow us to characterize the equilibrium configurations that arise in the duopoly setting with perfectly informed consumers. When vertical transport costs are concave, the firm with the higher marginal cost chooses a fully targeted design. The firm with lower marginal cost chooses either a fully broad or niche design depending on its cost advantage. When vertical transport costs are convex, the same configurations can occur, but a third possibility may arise in which the low marginal cost firm chooses an intermediate design.

4 Monopolistic Competition

We maintain the form of consumer preferences, and firm design choices, but adapt the monopoly model of Section 2 to allow for competition by multiple firms in a relatively simple fashion by supposing that consumers must incur search costs to observe product offerings.

Formally, we adapt the model of Wolinsky (1986) or Anderson and Renault (1999) in which consumers incur a search cost a to learn both the price and utility they would obtain from a new firm. This modelling approach has been widely used to consider the impact of changes in search costs on market outcomes (examples include, Bakos (1997), Cachon, Terwiesch and Xu (2008) and Goldmanis, Hortaçsu, Onsel and Syverson (2010)). As in Bar-Isaac, Caruana and Cuñat (2012), we adapt the supply side to suppose that in addition to choosing prices, firms can choose designs. While that paper considers a reduced form design decision, in which only two optimal designs ever arise, here we consider the specific design choice outlined in Section 2, and demonstrate that the results in that section on design choice are robust to this form of competition.

Bar-Isaac, Caruana and Cuñat (2012) show the market restructuring following a fall in search costs (through the diffusion of the internet for example) can simultaneously account for both higher market shares of the most successful "superstar" firms, and the least successful "long tail" of firms with very low market shares. This is the result of an endogenous change in design choices. We highlight below, that those results are not driven by the functional form restrictions that entail firms choosing only extreme (fully targeted or fully generic) designs. In addition, we further establish the robustness of the qualitative results of Sections 2 and 3 above.

Consider a continuum of active firms indexed by $i \in I$ uniformly distributed around the circle in terms of their angle of rotation. We allow for heterogeneity in firms' marginal costs of production m_i, and assume that this attribute is independent from the horizontal location. All firms simultaneously decide their design s_i and price p_i.

Consumers now have to decide whether to search or not, and if so, when to stop searching and buy a product. Before visiting any store, they are ignorant of the actual price p_i, design s_i, and horizontal distance to the firm, x. In equilibrium, consumers hold the right expectations on the joint distribution of these three attributes on the market. Just as in McCall

(1970), if a consumer finds it worthwhile to search at all then she optimizes by choosing a threshold rule. This rule establishes that a consumer buys if and only if she obtains a net utility from purchase greater than or equal to some threshold level, U; otherwise, the consumer continues to search. Firm i's location from the consumer's perspective is uniformly distributed on $(0, \pi)$. Consequently, it can be shown that U is implicitly defined by:

$$\int_{i \in I} \int_0^{X_i} (V - c(s_i) - p_i - U - s_i x)\, dx di = a. \tag{6}$$

where

$$X_i = \max(0, \min(\frac{1}{s_i}(V - c(s_i) - p_i - U, \pi))$$

is the indifferent consumer for firm i. This formula has an intuitive interpretation. The left hand side is the average gain over purchasing a product that delivers net utility U if a new search is conducted. The right hand side is the cost of doing so. Thus, this formula determines U as the net utility from a product that leaves the agent indifferent between searching once again and buying it.

Firms' decisions are determined ex-ante and not observed by consumers until they visit the firm. Therefore a firm deviating from its equilibrium strategy will have no effect on consumers' reservation utilities. Thus, if a firm's demand per consumer visit is interior ($X_i \in (0, \pi)$) it is determined by:

$$q(p_i, s_i, U) = 2X_i = \frac{2}{s_i}\left(V - U - c\left(1 - s_i\right) - p_i\right). \tag{7}$$

Note that this expression is similar to (1) but features the term $V - U$ in place of V. The stopping rule U is determined by consumer preferences and the overall market configuration. Therefore, from the firm's perspective this is a constant which it cannot effect. As a result of all this, one can directly apply all results from Section 2, and Propositions 1, 2, 3, and 4 hold by simply replacing V for $V - U$. Thus, it is again the concavity-convexity of the adjustment costs of vertical quality that determine whether design is intermediate or not, and firms with lower costs have broader designs.

Moreover, analogous to Proposition 4, it is immediate that the higher is U, the more targeted a firm's design. That is, if consumers are more picky—in the sense that they require a higher net utility in order to purchase—firms choose more targeted designs. Intuitively, this is the case when search costs fall.[11]

Moreover, in allowing for competition by many firms through their choices of product designs as well as through prices, the model in this section can generate rich and varied market structures. Suppose that firms vary in the marginal costs of production, m_i and for concreteness suppose that this is uniformly distributed on the unit interval $[0, 1]$. If the vertical transport costs $c(\cdot)$ are concave, then since Proposition 2 holds, a polarized distribution of product designs arises, with firms choosing either the most targeted kind of design $s = 0$ or the broadest one $s = B$. By Proposition 4, firms with low marginal costs prefer the broadest kind of design. Simultaneously, the least efficient firms opt for the most targeted kind of design. Thus, a threshold determines which firms choose each of the two designs.

Similarly, when Proposition 3 holds, firms choose intermediate designs according to each firm's marginal cost; again with more efficient firms preferring broader designs. These market configurations also have straightforward implications for prices and quantities sold. It is straightforward to show that, keeping design fixed, higher marginal costs are associated with higher prices and lower sales. Moreover, the endogenous design choices reinforce these effects, as higher marginal costs induce firms to choose more specific designs that, in turn induce higher prices and lower sales. Therefore, regardless of the market configuration, prices are monotonically increasing and sales are monotonically decreasing as design moves from being more generic to more targeted.

The model provides a tractable framework to consider how a change in search costs, for example, affects a market's product offerings and the effect on individual firm's sales, profits and the market structure. This can give

[11] As discussed in Bar-Isaac, Caruana and Cuñat (2012), the intuitive property that lower search costs lead to more picky consumers may require focus on a subset of stable equilibria.

insight on how the Internet and other developments that improve consumer information can affect market structure, through changes in product offerings as well as more directly through price competition and better matches of consumers to products that they like. As an example, Figure 3 plots designs (Panel 1) and sales (Panel 2) against a firm's marginal costs when the vertical transport cost is convex leading some firms to choose intermediate designs. In this example B is set at 0, so that a fully broad product is valued identically by all consumers—in particular, this implies that any firm that chooses a fully broad design and makes sales would sell to all consumers who visit the firm. The blue dashed line corresponds to a lower search cost and the green solid line to a higher search cost. The first panel shows that with a lower search cost fewer firms choose a fully broad design, and that all firms choose more targeted designs. Intuitively, with the more intense competition implied by lower search costs, firms compete in part by offering consumers products that are better targeted. The second panel shows an interesting implication: sales of both the most and least efficient firms increase when consumer search costs falls. In other words, there is simultaneously a superstar and "long-tail" effect.[12] That such superstar and long-tail effects can simultaneously arise is consistent with the findings in Bar-Isaac, Caruana and Cuñat (2012). But this example highlights that this can arise with convex as well as concave vertical transport costs (and consequently, when firms choose intermediate designs).

[12]The term "long tail" was introduced in an article in Wired (Anderson, 2004). See also Brynjolfsson, Hu and Smith (2006).

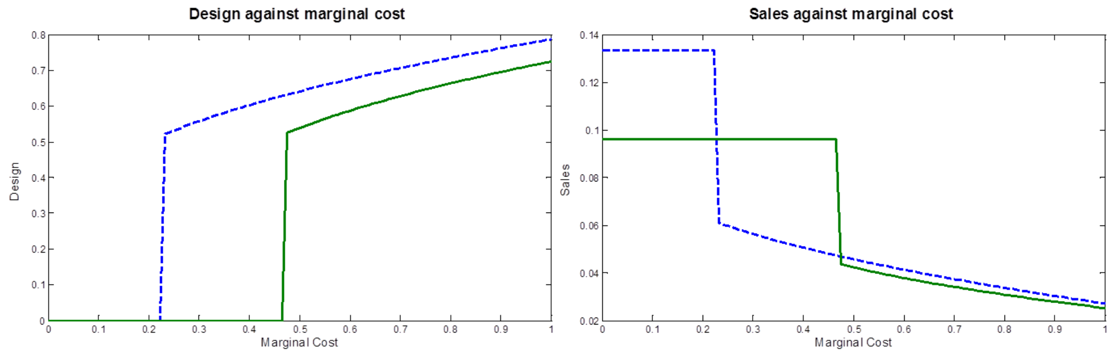

Figure 3: Designs and sales against marginal cost with $c(y) = 3/2y^2$, $B = 0$ and $V = 3$, at $a_1 = 0.4$ and $a_2 = 0.5$.

5 Conclusions

Choosing what kind of product to produce is a key strategic and marketing decision. There has been a great deal of literature on horizontal and vertical differentiation that addresses different aspects of the design question. This paper combines both kinds of differentiation and represents design as a choice that trades off vertical quality and consumers' horizontal dispersion of valuations. This results in design choices that are represented as demand rotations, and captures the tension between focused, targeted designs that are intended to strongly appeal to a narrow consumer segment, and broad designs that aim to have some (though more limited) appeal to a broader audience.

Our result that firms with lower marginal costs choose broader designs has an immediate parallel when one considers heterogeneity in ex-ante quality (that is, in the V values). Specifically, better (higher quality) firms position themselves more broadly than worse firms who target narrower niches. There is a clear intuition for this: Better firms presume that most customers are likely to buy, and, thus, they want to minimize the ex-post dispersion of consumer valuations. In this way, they avoid consumers drawing low preference shocks and choosing not to buy. This broad strategy implies high sales and low markups. Similarly, worse firms anticipate that most consumers would not buy and prefer to generate more ex-post dispersion to provide some consumers with sufficiently high preference shocks that they choose to buy.

Throughout the paper, we assume that design decisions entail no production cost. Introducing costs of design could be done in a relatively straightforward fashion by considering that the vertical cost function $c(.)$ studied in the model also incorporates the costs of design.[13] In this interpretation, the firm incurs costs in bringing products close to consumers and, in this way, the model is related to the work on convenience by Bronnenberg (2014).

The model provides a simple representation of product design that can be embedded in different competitive environments, thus providing a useful starting point for further applications, such as the analysis of more efficient production or lower search costs on design choices and market structure.

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A Appendix

Proof of Proposition 1 and 2 If the solution is interior, the first order conditions of the maximization of (2) determine the optimal price and design:

$$\begin{aligned} \frac{2}{s}\left(V - c(1-s^*) - 2p^* + m\right) &= 0, && (8) \\ \frac{2(p^*-m)}{s^*}\left(c'(1-s^*) - \frac{1}{s}\left(V - c\left(1-s^*\right) - p^*\right)\right) &= 0. && (9) \end{aligned}$$

The first equation delivers the optimal price

$$p^* = \frac{V - c(1-s^*) + m}{2},$$

which, one can then substitute on the second equation to get

$$c'(1-s^*) = \frac{V - c\left(1-s^*\right) - m}{2s^*},$$

which implicitly defines the optimal design s^*. Finally, one can also combine (9) with (1) and obtain

$$c'(1-s^*) = \frac{1}{2}q(p^*, s^*) \tag{10}$$

which proves Proposition 1.

At an optimal interior design the second order conditions must also be satisfied. In particular, the one with respect to design delivers:

$$\frac{2(p^*-m)}{s}\left(\frac{2}{s^{*2}}\left(V-c\left(1-s^*\right)-p^*\right)-\frac{2}{s^*}c'(1-s^*)-c''(1-s^*)\right)<0$$

Now one can use equations (1) and (10) and simplify it to:

$$\left(\frac{q(p^*,s^*)}{s^*}-\frac{2}{s^*}c'(1-s^*)-c''(1-s^*)\right)<0\Leftrightarrow c''(1-s^*)>0$$

which proves Proposition 2.

Proof of Proposition 3 The firm necessarily prefers an interior solution if the objective function (2) satisfies $\Pi'(1,p^*(1))<0$ and $\Pi'(B,p^*(B))>0$. Substituting $p^*=\frac{V-c(1-s)+m}{2}$ into (2) allows us to write profits as a function of design alone:

$$\Pi(s):=\frac{2}{s}\left(\frac{V-c(1-s)-m}{2}\right)^2. \tag{11}$$

Given that

$$\Pi'(s)=-\frac{\left(V-c(1-s)-m\right)^2}{2s^2}+\frac{c'(1-s)}{s}\left(V-c(1-s)-m\right),$$

we can write

$$\begin{aligned}\Pi'(1)<0&\Leftrightarrow V-m>2c'(0)\\ \Pi'(B)>0&\Leftrightarrow 2Bc'(1-B)+c(1-B)>V-m,\end{aligned}$$

which concludes the proof.

Proof of Proposition 4 To prove this, it is sufficient to show that

$$\forall m_1>m_2,\forall s_1>s_2\ \Pi(s_1,m_2)>\Pi(s_2,m_2)\Rightarrow\Pi(s_1,m_1)>\Pi(s_2,m_1). \tag{12}$$

Note that $\frac{2}{s_1}(\frac{V-c(1-s_1)-m_2}{2})^2=\Pi(s_1,m_2)>\Pi(s_2,m_2)=\frac{2}{s_2}(\frac{V-c(1-s_2)-m_2}{2})^2$ implies that $\left(\sqrt{s_1}-\sqrt{s_2}\right)m_2>\sqrt{s_1}(V-c(1-s_2))-\sqrt{s_2}(V-c(1-s_1))$. Given that $\left(\sqrt{s_1}-\sqrt{s_2}\right)m_1>\left(\sqrt{s_1}-\sqrt{s_2}\right)m_2$ we can write $\left(\sqrt{s_1}-\sqrt{s_2}\right)m_1>\sqrt{s_1}(V-c(1-s_2))-\sqrt{s_2}(V-c(1-s_1))$, which implies that $\Pi(s_1,m_1)>\Pi(s_2,m_1)$.

Given that Π is continuous in (s,m), that the condition (12) above implies that Π satisfies the single crossing property in (s,m) as defined in Milgrom and Shannon (1994). Thus, this proposition is just a particular case of Theorem 4 in Milgrom and Shannon (1994), which establishes monotone comparative statics.

Proof of Proposition 5 In order to have an interior design decision one needs $\frac{d^2\Pi_1(s)}{ds_1^2} \leq 0$.

$$\begin{aligned}
\frac{d^2\Pi_1(s)}{ds_1^2} &= 2\frac{\partial x_{12}}{\partial s_1}\left(\frac{2}{3}\left(c'(1-s_1)+\pi\right)-x_{12}\right)+2x_{12}\left(-\frac{2}{3}c''(1-s_1)-\frac{\partial x_{12}}{\partial s_1}\right) \\
&= \frac{4}{3}(\frac{\partial x_{12}}{\partial s_1}\left(c'(1-s_1)+\pi\right)-x_{12}c''(1-s_1))-4x_{12}\frac{\partial x_{12}}{\partial s_1} \\
\stackrel{FOC}{=} 2x_{12}\frac{\partial x_{12}}{\partial s_1}&+2x_{12}\left(-\frac{2}{3}c''(1-s_1)\right)-4x_{12}\frac{\partial x_{12}}{\partial s_1} = 2x_{12}(-\frac{\partial x_{12}}{\partial s_1}-\frac{2}{3}c''(1-s_1)) \leq 0.
\end{aligned}$$

Proof. This is equivalent to

$$\begin{aligned}
&\frac{\partial x_{12}}{\partial s_1}+\frac{2}{3}c''(1-s_1) \geq 0 \Leftrightarrow \frac{1}{3}\frac{c'(1-s_1)+\pi}{s_1+s_2}-\frac{x_{12}}{s_1+s_2}+\frac{2}{3}c''(1-s_1) \geq 0 \stackrel{FOC}{\Leftrightarrow} \\
&\stackrel{FOC}{\Leftrightarrow} \frac{\frac{1}{2}x_{12}}{s_1+s_2}-\frac{x_{12}}{s_1+s_2}+\frac{2}{3}c''(1-s_1) \geq 0 \Leftrightarrow c''(1-s_1) \geq \frac{3}{4}\frac{x_{12}}{(s_1+s_2)}
\end{aligned}$$

which shows that $c''(1-s_1) > 0$ is a necessary but not sufficient condition for an interior decision. ■

Proof of Proposition 6 We proceed in two stages. First we argue that at least one firm chooses a most targeted design and then we show that this must be the one with higher marginal cost.

Suppose, for contradiction that both firms choose interior or broad designs, then (5) states that $c'(1-s_1^*)+\pi \leq \frac{3}{2}x_{12}$. Similarly, the first order condition for Firm 2 requires that $c'(1-s_2^*)+\pi \leq \frac{3}{2}(\pi - x_{12})$. Summing these we obtain $c'(1-s_1^*)+c'(1-s_2^*)+2\pi \leq \frac{3}{2}\pi$ or $c'(1-s_1^*)+c'(1-s_2^*) \leq -\frac{\pi}{2}$. Since $c' > 0$, this provides a contradiction.

Next suppose that $s_1^* \in [0,1)$ then $c'(1-s_1^*)+\pi \leq \frac{3}{2}x_{12}$, since $c'(1-s_1^*) > 0$, it follows that $\frac{3}{2}x_{12} > \pi$. Substituting for optimal prices in (4) and rearranging this last inequality we obtain: $m_2 - m_1 > \pi s_1^* + c(1-s_1^*) - c(1-s_2^*)$. Now from the first half of the proof if $s_1^* \in [0,1)$ then necessarily $s_2^* = 1$ and since c is an increasing function $c(1-s_1^*) > c(1-s_2^*) = c(0)$, this in turn implies that $m_2 - m_1 > \pi s_1 > 0$ which completes the proof.

Proof of Proposition 7 Following Proposition 6, the firm with a higher marginal cost necessarily chooses the extreme most targeted design. Thus without loss of generality suppose $m_1 > m_2$ and that $s_1^* = 1$ and consider $\frac{ds_2^*}{dm_2}$ for an interior design. Substituting for optimal prices and setting $s_1^* = 1$ allows us to write Firm 2's profit function as:

$$\Pi_2 = \frac{2}{9}\frac{\left(c(0)-c(1-s_2)-m_2+m_1+\pi s_2+2\pi\right)^2}{1+s_2}.$$

The second order condition can be shown to be equivalent to

$$(\pi + c'(1 - s_2^*))^2 < c''(1 - s_2^*). \tag{13}$$

The first order condition is equivalent to $c(0) - c(1 - s_2^*) - m_2 + m_1 - \pi s_2^* = 2(1 + s_2^*)c'(1 - s_2^*)$. Taking the total derivative of this expression with respect to m_2 we obtain that $\frac{ds_2}{dm_2}(2(1 + s_2^*)c''(1 - s_2^*) - c'(1 - s_2^*) - \pi) = 1$. It follows that $\frac{ds_2}{dm_2} > 0$ as long as

$$2(1 + s_2)c''(1 - s_2^*) > c'(1 - s_2^*) + \pi.$$

Following (13), $2(1 + s_2)c''(1 - s_2^*) > 2(1 + s_2)(\pi + c'(1 - s_2^*))^2$, so that the above expression is implied by $2(1+s_2)(\pi+c'(1-s_2^*))^2 > c'(1-s_2^*)+\pi$ which is necessarily true since $c_2' > 0$ and $s_2 \geq 0$.