Competition on Rugged Landscapes: The Dynamics of Product Positioning

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Working Paper

August 2013

Acknowledgements

I am indebted to Massimio Warglien for his hospitality and for exciting discussions. I am also grateful for many helpful comments from Thorsten Grohsjean, Johannes Koenen, Walter Zucchini, Jörg Claussen, Tobias Kretschmer, Nils Stieglitz, Oliver Baumann, Christoph Dehne, Pascal Kober, Janne Korhonen, E.S. Andersen, and participants at the DRUID Academy 2013. Financial support from the German Academic Exchange Service is gratefully acknowledged.

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Abstract

Many firms constantly compete through product positioning, but the resulting competitive interactions are not well understood, mainly because of the difficulties associated with modeling a fundamentally dynamic phenomenon. We present an agent-based model of firms' behavior when they compete through product positioning, i.e. horizontal differentiation. Our results suggest that the dynamics of competition through product positioning depend on the number of consumer niches in the market. In 'rugged' markets with many niches, product designs stabilize as firms disperse to serve individual niches. There, competition has little effect on performance. By contrast, in 'smooth' markets with few niches, product positioning remains volatile with firms jostling for favorable positions. In these markets competition is highly detrimental to performance and market leaders are frequently dethroned. By modeling the dynamics of product positioning we contribute to research on horizontal differentiation in industrial organization, as well as to work in evolutionary economics and population ecology.

Keywords: Competition, product positioning, Hotelling, Simulation

JEL: L22, M10, C15, D52

1. Introduction

Firms constantly face the question how best to position their products in competitive markets (Porter, 1980). For example, in 2003 China Central Television changed the positioning of its station CCTV1 by increasing the proportion of dramas and reducing news and talk-shows (Wang & Shaver, 2013). As a consequence, there was a flurry of activity as smaller channels adapted their positioning to the new competitive situation. This example illustrates two important aspects of competitive positioning: it is dynamic, and is conducted through horizontal differentiation.

Positioning is dynamic because firms' optimal strategy is constantly affected by their competitors' actions and changes in the environment. For example, in the late 1980s Hewlett Packard continuously experimented with new laser printers, using different combinations of resolution and speed (de Figueiredo & Silverman, 2007). By doing so, it displaced competitors, causing turbulent change in various market segments.

Horizontal differentiation is one of two basic positioning strategies for firms, the other being vertical differentiation (Koski & Kretschmer, 2007). Vertical differentiation is achieved by creating a product that is more attractive for all consumers, for example by increasing quality. By contrast, horizontally differentiated products appeal more to some consumers but less to others. Horizontal differentiation is especially important in mature markets where vertical differentiation is difficult to achieve (Adner & Zemsky, 2006; Koski & Kretschmer, 2007). In the example above, China Central Television was horizontally differentiating its station CCTV1, since changing from news and talk-shows to more drama is hardly a quality improvement. Another example is radio broadcasting, where stations compete for listeners using program format, timing, and announcer style (Greve, 1995). Clearly, there is no universal quality ranking of which program format or announcer style is better; it is a matter of personal taste.

Although dynamic competition through horizontal positioning is important for both managers and researchers (Lamberg, Tikkanen, Nokelainen, & Suur-Inkeroinen, 2009; Wang & Shaver, 2013), our understanding of it is currently very limited. An extensive body of work on 'spatial competition' in industrial organization has used formal models to describe competition through horizontal positioning (Eiselt, Laporte, & Thisse, 1993; Hotelling, 1929), but these studies are unable to describe dynamic situations because the game-theoretical models they use are based on static equilibria (Epstein, 2006; Nelson & Winter, 1982). Research on 'evolutionary economics' has studied vertical differentiation and its dynamics extensively, but so far has neglected horizontal differentiation (Nelson & Winter, 2002). Finally, studies in 'organization ecology' investigate dynamic positioning, but they focus on sociological mechanisms and the economic argument there is rudimentary (Baum & Shiplov, 2006; Nelson & Winter, 1982).

Consequently, this study investigates dynamic horizontal positioning, in particular how firms' positioning behavior depends on the number of competitors and the distribution of consumer preferences in the market. Using an agent-based model that combines the popular NK and discrete-choice models (Levinthal, 1997; McFadden, 1974) we show that the dynamics of horizontal positioning depend on the niche-structure of markets. In 'rugged' markets with many niches, firms disperse to serve individual consumer niches. In these markets, product designs and market leadership are stable, and additional competition has little effect on profitability. By contrast, in 'smooth' markets with only a few niches, firms constantly jostle around the most attractive positions, repeatedly chasing away competitors and being chased by them in return. As a consequence, additional competition strongly decreases profits and market leaders are frequently dethroned.

We contribute to research on competition by presenting the first model of dynamic competition through horizontal positioning. Specifically, our findings contrast with the static equilibria used in studies in industrial organization, suggesting they might benefit from considering the dynamics of competition (Eiselt, 2011; Leombruni & Richiardi, 2005). Second, we add to research on evolutionary economics by describing competition through horizontal differentiation and explaining how it differs from vertical differentiation (Nelson & Winter, 2002), thus opening up new avenues for research into the interdependencies between the two strategies. Third, our study complements studies of positioning in organizational ecology that use a sociological perspective by providing a formal economic description of dynamic positioning (Baum & Shipilov, 2006; Lieberman & Asaba, 2006). Finally, the structure of our model is quite general and represents first step towards a general formal theory of dynamic competitive interactions. We describe several ways it could be further extended towards this goal.

2. Theoretical Background and Contribution

We have observed that competitive positioning is dynamic and often involves horizontal differentiation. To date, positioning has been addressed in three different streams of literature: industrial organization, evolutionary economics, and organizational ecology. The following paragraphs briefly summarize how each of these streams has approached the phenomenon and explain how our study contributes to them.

Industrial Organization

Research on horizontal differentiation in industrial organization goes back to the seminal paper by Hotelling (1929). He demonstrated that under certain simplifying assumptions, pairs of competing firms end up offering exactly the same product design, a result known as the 'principle of minimum differentiation'. Since then, a large body of theoretical studies on 'spatial competition' has criticized Hotelling's results, as well as extending them by investigating what happens when one changes his assumptions (d'Aspremont, Gabszewicz, & Thisse, 1979; Eiselt & Laporte, 1989; Kress & Pesch, 2012; Younies & Eiselt, 2011). However, all of these models have a common drawback: they are unable to describe positioning as a dynamic phenomenon (Shapiro, 1989). The reason is that they all use game-theoretical models where 'results' are based on finding equilibria (Dasgupta & Maskin, 1986; Leombruni & Richiardi, 2005). On the one hand, concluding that equilibrium strategies will be played because they exist is theoretically questionable, because it implies that firms will find them in finite time, which need not be the case in general (Epstein & Hammond, 2002). More importantly however, equilibrium models of horizontal differentiation assume complete information and rationality, and only describe situations in which firms play optimal strategies, i.e. they are by their very nature static (Epstein, 2006; Nelson & Winter, 1982). However, numerous empirical examples suggest that positioning is a dynamic phenomenon: firms interactively adapt their positioning in reaction to competitors in industries as diverse as wine manufacturing, automobile production, radio broadcasting, retail banking, brewery, and food retailing (Carroll, Dobrev, & Swaminathan, 2002; Delacroix & Anand, 1991; Dobrev, Tai-Young, & Carroll, 2003; Greve, 1998; Greve, 2000; Lamberg et al., 2009). If positioning is a dynamic process in so many settings, it would seem that static models of positioning are missing a fairly important part of the phenomenon.

We add to this literature by presenting the first formal model of the *dynamics* of competition through horizontal positioning. Our agent-based model 'grows' macro-level phenomena from behaviorally plausible micro-level assumptions (Epstein, 2006), and consequently provides similar rigor to closed-form models while at the same time allowing us to observe dynamic processes (Adner, Pólos, Ryall, & Sorenson, 2009; Chang & Harrington, 2006). In particular, it enables us to predict what type of dynamics we would expect to observe in competitive positioning in different markets; the answer turns out to depend on the number of consumer niches and competitors.

Evolutionary Economics

The second stream of research on competitive positioning is known as 'evolutionary economics' and follows Nelson and Winter (1982). Studies there analyze how firms achieve temporary competitive advantage through innovation or quality improvements; this is what is known as 'vertical' differentiation (e.g. Adner & Zemsky, 2006; Knott, 2003; Safarzyńska & van den Bergh, 2010). This work also provides the theoretical basis for empirical research on 'competitive dynamics' (Chen & Miller, 2012; Smith, Ferrier, & Ndofor, 2001).

In competition through vertical differentiation, changing a product always confers a benefit in relative terms, i.e. greater quality is always better, regardless of what the firm's competitors are doing. The trade-off a firm faces is whether the benefit conferred by changing a product justifies the cost, given factors like the speed of competitors' reactions (Nelson & Winter, 2002). By contrast, in horizontal differentiation the relative benefit of a new position depends on what the firm's competitors are doing. If a competitor is already offering a certain product design, then a firm may be worse off changing to that design even if the change is costless. This distinction goes beyond mere modeling; it is a basic conceptual difference between competition through horizontal and vertical differentiation. A similar point is made in Adner, Csaszar, and Zemsky (2010) who study the effect of competition through vertical differentiation on industry structure. Moreover, the same argument applies to recent research in industrial organization that uses dynamic models (Doraszelski & Pakes, 2007) and to two recent papers by Lenox et al. (2006, 2007) who study performance heterogeneity and industry shakeouts in NK models with subsequent competition.[1]

There is no doubt that competition through vertical differentiation is important in many settings, especially because of its close conceptual link to innovation (Schumpeter, 1950). However in mature markets it may be difficult to achieve if the marginal consumer utility from additional quality is small. There, horizontal differentiation may play an important role (Adner & Zemsky, 2006; Koski & Kretschmer, 2007). Moreover, horizontal positioning is a widespread phenomenon that has been documented, for example, in the newspaper, wine, and automobile industries (Delacroix & Anand, 1991; Dobrev, 2007; George & Waldfogel, 2003). We contribute to research on evolutionary economics by presenting a model of competition through horizontal positioning that complements models of vertical differentiation, and by discussing how the two directions could be integrated.

Organizational Ecology

Finally, a third class of models in 'organizational ecology' relates to positioning. It is based on Hannan and Freeman (1977), who argue that firms may find it difficult to change, and who therefore focus on selection, i.e. firms' entry to and exit from the market. A large part of the subsequent literature has followed their lead in making 'inertia' a central assumption (Baum & Shiplov, 2006; Carroll et al., 2002). While the idea that firms cannot change (sufficiently quickly) may make sense in some contexts, e.g. when a hotel chooses its location (Baum & Haveman, 1997), in others it seems difficult to justify. In particular, when thinking about competition through horizontal positioning it seems obvious that in many circumstances firms are indeed able to change their product designs or brands, and frequently do. Recent studies of competitive positioning in organizational ecology have recognized this and attempt to integrate both selection and adaptation through learning (e.g. de Figueiredo & Silverman, 2007; Dobrev et al., 2003; Greve, 1998). However, they use only sociological arguments, and while they mention 'competition' and 'density dependence', the economic arguments are rudimentary. By presenting a formal model of the economic mechanisms underlying competitive positioning, we provide a complementary explanation for the empirical regularities observed in these studies (e.g. Greve, 2000; Wang & Shaver, 2013).

[1] Specifically, in those models firms either a) draw marginal costs from an NK landscape and then engage in Cournot competition with undifferentiated products, or b) draw quality from an NK model and subsequently compete in Bertrand competition with vertically differentiated products. The difference to our model is that there, it is always desirable for firms to lower their cost or raise their quality. Having competitors with similar cost or quality may decrease profits, but the *relative* attractiveness of moving to a new position (e.g. quality) remains unchanged: higher is always better. This is an argument of vertical differentiation.

3. Model

To describe competition through horizontal positioning we need to model how consumers and firms behave. To illustrate this, consider a group of firms that make coats and can design them using three attributes, say length, color, and cut. Assuming for simplicity that each attribute can have two realizations, this means there are eight potential product designs given by length (long / short), color (red / black), and cut (conservative / sporty). In our example (as in the model) each firm will make only one type of coat.

We model consumers' preferences by giving each one of them a potential product design that they consider ideal. The more similar a firm's product is to their ideal design, the more likely they are to purchase from that firm. For example, if a consumer considers a long-black-conservative coat ideal, he might purchase a long-black-sporty coat, but probably not a short-red-sporty one. Firms start with a randomly specified product design and then adapt it over time, trying to find the product design that maximizes the number of consumers who purchase from them. Which product design is best depends on how the consumer preferences are distributed and also on what their competitors are offering. The following section describes the model in detail, starting with the consumers, and moving on to the firms.

Consumer Preferences and Choices

Modeling consumer behavior as described above requires that we solve two problems: first, we need to determine how many consumers consider each potential product design ideal (consumer preferences). Second, we need to determine how consumers make their decisions based on which product designs are actually offered by firms (consumer choices). We approach these problems using the NK and the discrete choice models, respectively.

Consumer preferences. The first step is to generate a distribution of consumer preferences. We do this by assigning each consumer to a product design which they consider ideal. The resulting distributions of consumer preferences, or 'landscapes', are illustrated in Figure 1.In Panel (A) the bold horizontal line represents a set of product designs. The height of the triangle at any given point i indicates the number of consumers m_i who consider that product design ideal.

*** Insert Figure 1 around here ***

There may be situations where there is one very popular product and all other products' popularity depends on how similar they are to it. This is the case illustrated in Panel (A) of Figure 1. We refer to this type of landscape as 'smooth'.[2] Alternatively, there may be several popular product designs which

[2] Note this means that 'smooth' does *not* refer to uniformly distributed consumer preferences.

are not similar at all, for example long-black-conservative and short-red-sporty coats. Moreover, the products that are similar to a 'star product' may be quite unpopular, for example long-red-conservative coats may be unpopular although they differ from long-black-conservative coats only in color. We refer to this type of landscape as 'rugged', and to popular potential product designs that are surrounded by unpopular ones as 'niches', i.e. clusters of large numbers of consumers who have similar product preferences.[3] Panel (B) in Figure 1 provides an illustration of a rugged landscape.

We generate landscapes of consumer preferences using an NK model (Kauffman, 1993; Levinthal, 1997). NK models have been widely used in management research, primarily to study organizational learning and the benefits of various organizational forms (Baumann & Siggelkow, 2011; Ganco & Hoetker, 2009). In our setting, N denotes the number of product attributes a firm can change. Each of the attributes can be either zero or one and the number of all possible product designs is 2^N. In the example, a long-black-conservative coat might be [0,0,1], and $N = 3$ (length, color, and cut) so there $2^N = 8$ possible designs. Product designs are thus conceptualized as bundles of attributes, an idea first popularized by Lancaster (1966).

Using the NK model, we allocate a mass of consumers $m_i \in [0,1]$ to each of the $i = 1, \dots, 2^N$ possible product designs, as indicated in Panel (A) of Figure 1. A product design i is considered ideal by all the consumers 'located' at that point. The parameter K is a measure of ruggedness: the higher K, the more local maxima the landscape possesses (Levinthal, 1997; Rivkin, 2000). In our interpretation, higher K means more consumer niches. The parameter K is frequently interpreted as the number of 'interactions' between product attributes. In our case a similar interpretation is possible but not necessary: we use the NK model only to generate landscapes with varying degrees of ruggedness, i.e. a varying number of consumer niches.

The advantage of using an NK model is that their structure is well understood (Ganco & Hoetker, 2009; Rivkin, 2000). This is of enormous benefit when interpreting the model's results, and differentiates it from related models where the processes of firm search and landscape generation are endogenous (Marengo & Valente, 2010; Windrum & Birchenhall, 1998). The details of constructing NK models and their properties have been documented extensively in prior work, for example in Chang and Harrington (2006), Rivkin (2000), and Rivkin and Siggelkow (2003). Note that the NK landscapes used in the model do not look like the illustrative examples in Figure 1: instead of being continuous in one dimension (a line segment like in the figure) they are discrete (1/0) hypercubes in N-dimensions.[4]

Consumer choices. To recap, we now have a landscape consisting of 2^N potential product designs, each of which has N attributes with values zero or one, and each of which is considered ideal by m_i

[3] Note that this usage of the term 'niche' corresponds to its use in natural language and not in organizational ecology as, "the region of a resource space in which an entity can persist in the absence of competition" (Hannan, Carroll, & Pólos, 2003: 309).

[4] Interested readers can find an illustration of a four-dimensional landscape (hypercube) in Kauffman and Levin (1987: 20).

consumers. The next step is to define how consumers make purchase decisions depending on which product designs are actually offered. For this we use the discrete choice model that is widely used in economics and has recently also been used in NK modeling (Lenox et al., 2006, 2007; McFadden, 1974).

Consumers gain utility from buying products. Their utility level depends on how much the product differs from their ideal design. In particular, the utility u_{ij} a consumer who prefers product design i gains from buying a product with design j is:

$$u_{ij} = \alpha - \tau\delta_{ij} + \epsilon_i$$

α is a base utility. The term δ_{ij} denotes the distance between the consumer's ideal product design i and the actual product design j. This is the number of product attributes where there is a mismatch between the consumer's preferred design and the actual product, i.e. the Hamming distance between the two binary vectors. For example, if a consumer's ideal coat is long-black-conservative [0,0,1], the distance to a short-red-conservative coat [1,1,1] is two. The negative sign indicates that the further the product design is from a consumer's ideal, the lower is their utility from buying it. The parameter τ is a measure of the strength of consumers' preferences for their ideal product design; it corresponds to the 'transportation cost' in classical Hotelling models (Eiselt & Laporte, 1989). With constant α, a small τ means that consumers derive relatively high utility from products that are far away from their ideal design, and vice versa. Each consumer is assumed to buy one product each period, and consumers have switching costs of zero.

The term ϵ_i denotes a random component of consumer utility, for example caused through unobserved heterogeneity between consumers; its interpretation is discussed by McFadden (1974: 106ff.). If ϵ_i follows a double-negative exponential distribution and there are many consumers, the proportion of consumers with ideal design i who will buy a product j from a set of J alternatives is given by a multinomial logit:

$$\mathrm{P_{ijJ}} = \frac{e^{\alpha - \tau\delta_{ij}}}{\sum_{j=1,\ldots,J} e^{\alpha - \tau\delta_{ij}} + \underline{\mathrm{u}}}$$

where $\underline{u}$ denotes the value of the outside option. This term has an intuitive interpretation: if the product design j is close to the preference of consumers at i then δ_{ij} is small and they derive high utility from buying it. In this case the numerator of P_{ijJ} is large: a large proportion of the consumers at i will buy product j. Conversely, if the product design j is unlike i, then the numerator is small, and only a few of the consumers at i will buy j. Moreover, if many other products similar to i are currently being offered, then the sum in the denominator becomes large and the proportion of consumers buying j will be relatively small (small P_{ijJ}). Similarly, the larger the value of the outside option $\underline{u}$, the larger the denominator and thus the smaller the proportion of consumers buying product j. Note that $\underline{u} > 0$ means the market is not covered, i.e. some consumers do not buy any of the products offered.

Firms

The second step is to model firm behavior. In the model, F firms compete for consumers. Each firm f offers a single product whose design it can adapt over time. By offering a product with design f_j it can capture a proportion P_{if_jJ} of the m_i consumers who have preference i, given alternatives J (as described above). Its revenue in period t is therefore:

$$\pi_{\mathrm{ft}} = \sum_{i=1,\dots,2^N} \mathrm{P}_{\mathrm{if_jJt}} \times m_i$$

This is illustrated in Panel (C) of Figure 1. Firm A is located at position A_j and its revenue is indicated by the shaded area. At its position A_j a large proportion of consumers buy from it, i.e. P_{iA_jJt} is close to one. For consumers at i, Firm A's product design is some distance away from their ideal product design. Therefore, δ_{ij} is greater than zero and their utility from that product design is smaller, so only a small proportion of them buy from A: the proportion of the arrow inside the shaded area. In this model we do not allow firms to compete in prices and also abstract from costs, so firms' performance is equal to their revenues; this is discussed below.

Using Panel (D) in Figure 1 we can now illustrate more precisely the difference between vertical and horizontal differentiation. Consider a Firm B that needs to choose a product design. If it were alone in the market it would choose the most popular product design *a*. However, if a competitor A is already offering a product as marked in the figure, then the best product design for Firm B is *b*, because A has already captured part of the market. Thus, the relative attractiveness of product designs *a* and *b* for Firm B depend on what the competitor is offering, even if changing between alternatives is costless. This is different to vertical differentiation where one alternative is always strictly more attractive than the other, and the trade-off for firms depends on whether the benefit conferred by a new product design justifies its cost.

In the initial period of the simulation firms are assigned a random product design. In each subsequent period they attempt to increase their revenues through local search. To do so each firm randomly flips one of the *N* attributes of its product from zero to one or vice versa. It then calculates its expected revenue under the assumption that all other firms keep their previous product designs stable. If it expects to increase its revenues by changing its product design it decides to do so, otherwise it decides to stay with the old product design. All firms carry out this calculation independently and then simultaneously update their product designs. The new set of product designs is used to recalculate everyone's revenues, and the cycle begins again. The implications of this 'simultaneous' updating mechanism are discussed below.

Our interpretation of the NK landscape departs in two ways from previous NK models. First, in previous models firms' performance is typically equal to the height of the landscape at the position they occupy (often labeled 'fitness'). That is not the case here: the height of the NK landscape at a firm's location j is m_j, but its revenues are given by the sum of proportions of consumer mass at many different points. Second and more importantly, in previous models firms' performance is generally independent of the position of others in the landscape (notable exceptions are Lenox et al., 2006; Lenox et al., 2007). In our model, each firm's revenue depends both on their own position relative to the distribution of consumer preferences and on the position of all of their competitors. It is these two connected departures from the standard NK model that allow us to study competition in horizontal differentiation. Our model thus answers recent calls for a closer examination of the interaction between consumer heterogeneity and firm behavior (Adner & Zemsky, 2006) and for interaction in NK models (Baumann & Siggelkow, 2011).

The interaction in our model creates three countervailing forces. First, each firm wants to produce products that many consumers will purchase. That means there are certain product designs that are attractive for all firms, causing them to make their products more similar over time (centripetal force). Second, by making its product more similar to a competitor's, a firm can steal some of their consumers (centripetal force). However, making its product more similar to a competitor's also means the firm will lose more consumers to the competitor (centrifugal force). The relative strength of these three forces is what drives dynamic competitive behavior in our model.

4. Results

The aim of the model is to observe the dynamics of competition in horizontal differentiation and isolate how it is affected by different levels of competition and distributions of consumer preferences (ruggedness). Consequently, we generate consumer preference landscapes from the NK model for each level of ruggedness $K = 0, \dots, 9$. On each of these landscapes, groups of one, two, four, and eight firms attempt to increase their performance for 80 periods. The parameters in the consumer utility function are set to $\alpha = 1$, $\tau = 2$, and $\underline{u} = e$. An overview of parameter values is included in Table 1 and robustness tests are reported below. To ensure our results are not due to the specific form of an individual landscape, we repeat the process for 1000 randomly generated preference landscapes. Furthermore, to make results comparable across different levels of ruggedness we standardize all landscapes so they have the same total consumer mass. The latter is a slight departure from the standard procedure of standardizing landscape height and is discussed in the Appendix.

We present the results of the model in two steps. First, we discuss how firms compete over time on a smooth landscape with one large consumer niche ($K = 0$) and varying degrees of competition. In a second step we compare the effects of competition for varying degrees of ruggedness by analyzing firm performance, positions, and movement in the final period ($T = 80$).

*** Insert Table 1 around here ***

Competition on Smooth Landscapes

First, we consider performance in a smooth consumer landscape. As illustrated in Panel (A) of Figure 1, in this type of landscape all consumers have similar preferences so there is only one large niche with a single global peak. In Figure 2, Panel (A) shows how average firm performance develops in the smooth landscape over time for different levels of competition. The learning process is clearly visible: firms start from their randomly assigned positions and gradually increase their performance as they explore the landscape and locate the global peak. After approximately 40 periods average performance has stabilized. The influence of competition is also clear: for a rising number of firms (F) the average performance stabilizes at a lower level. Thus, competition is detrimental to performance, which is exactly what we would expect in a real world setting. The results in Panel (B) of Figure 2 provide a first insight into how performance levels are influenced by competition. There we see that firms' performance increases over time because they gradually approach the global peak: the distance initially drops sharply and then stabilizes after about 40 periods. This is what we would expect in an NK model with low ruggedness (Rivkin, 2001). However, in standard NK models without competition all firms would locate exactly at the global peak (Levinthal, 1997), whereas in Panel (B) an increasing number of competitors causes firms to locate at an increasing distance from the global peak. This is due to the difference between competition in horizontal and vertical differentiation that is illustrated in Panel (D) of Figure 1: if a firm has already located at the peak it becomes less attractive for all others. A corollary of this result is that with increasing competition the product designs offered in the market display greater heterogeneity: on average firms produce product designs that are similar but not identical to the modal consumer preference.

*** Insert Figure 2 around here ***

These results raise questions relating to firm behavior and movement. From Panel (A) we know that average firm profits stabilize over time and from Panel (B) that competition is important for positioning, but what are the competitive dynamics causing these results? Are they due to firms settling down to stable positions around the global peak and sharing profits equally? That would mean little variation in product designs and stable market shares. Alternatively, are they due to some firms quickly conquering the best product designs and forcing others to accept second-best positions, resulting in a stable ranking but skewed performance distribution? Or perhaps firms are constantly moving and the stable average performance reflects the average of a dynamic process? The lower panels in Figure 2 shed light on this issue. Panel (C) shows the average number of moves (changes of product design) per firm and period over time. When there is only one firm in the market (the solid line) it finds the global peak and settles down there: after approximately 40 periods there is hardly any movement. However, with competition the situation changes: after an initial decrease, the average number of moves per firm and period converges to a stable rate that increases with the number of competitors in the market. This means that in competitive markets with homogeneous consumer preferences firms never settle down but instead continue to adjust their product designs. Because firms only move when they can increase their (expected) performance and we know from Panel (A) that average performance has stabilized, that must mean that they are engaged in a constant process of stealing each other's customers.

This raises yet another question: which firms are moving? Does one dominant firm settle down on the peak while the others move around collecting the scraps, or does competition continue to threaten all firms? Panel (D) in Figure 2 shows that the latter is the case. It shows the proportion of market leaders, i.e. the firms with the highest market share, which are overtaken ('dethroned') in each period. With an increasing number of competitors it becomes increasingly likely that the most successful firm will be dethroned: defending a leading market share becomes increasingly difficult the more competitors there are in the market.

Taken together these results suggest that on smooth landscapes, increasing competition causes markets to become increasingly and persistently volatile. Firms do not settle down with stable product designs but rather dance around the peak (Teitz, 1968), continuously jostling for the best positions and being thwarted by their competitors. In terms of products the result is a continuous stream of new but similar product designs which become more and more diverse as competition increases. The cutthroat competition of stealing market shares in these markets is detrimental to firm performance, not only on average, but even for the most successful firms who are in constant in danger of losing their leading position.

Competition on Rugged Landscapes

We have established that in 'smooth' markets, competition leads to persistently volatile processes of adaptation. We now investigate how these dynamics are influenced by different distributions of consumer preferences. Figure 3 shows average results for different levels of ruggedness along the horizontal axis (from a single niche to many niches) and competition for the different lines (one, two, four and eight firms). The results are taken from the final period in the simulation ($T = 80$). Note that as illustrated by Figure 2 this is more than enough time for the results to settle into a pattern, whether static or volatile.

Panel (A) in Figure 3 shows how average performance changes with changing ruggedness and competition. For landscapes with few peaks (low K) increasing competition is detrimental to performance. This is the same result we saw in Figure 2. Here however, we see that as the landscape becomes increasingly rugged, the detrimental effect of competition on performance decreases: evidently, if there are several niches it matters less if there are lots of rivals.

*** Insert Figure 3 around here ***

Panel (B) in Figure 3 adds additional texture to this result. We already know that on smooth landscapes more competition causes firms to locate further away from the nearest peak. In Panel (B) we see that as the landscape becomes more rugged, firms locate closer to the nearest peak, regardless of the number of competitors in the market. This result suggests that firms may be dispersing to serve different niches. However, this result must be interpreted with caution because in more rugged landscapes there are also simply more peaks around. Note that firms that are alone in the landscape locate slightly further away from the nearest peak as K increases from zero. This is a model artifact that is discussed in the Appendix.

These results raise the same question as above: what is the dynamic driving competition? One possibility is that there is constant movement both on smooth and rugged landscapes alike, with firms jostling each other off the peaks. In that case the differences in results for high levels of ruggedness may be due to the fact that the alternatives are more attractive: displaced firms can find other attractive niches to serve. Another possibility is that there is simply less movement on rugged landscapes because firms disperse and 'settle down' to stable situations where each serves a local niche.

Panel (C) suggests that the latter explanation is more likely. For markets with few consumer niches competition has a large influence on volatility: the more firms in the market, the more movement we observe. As ruggedness increases, the average number of moves per firm and period decreases, regardless of the number of competitors. In very rugged landscapes ($K = 9$) it makes hardly any difference whether there are two or eight firms in the market: firms have reached an essentially stable distribution.

Panel (D) corroborates this finding. On smooth landscapes the probability that the market leader will be dethroned depends heavily on the number of competitors. Thus, if there is a single large consumer niche then it will be difficult for any one firm to defend a lead in the market. As the number of niches increases, the number of competitors matters less and less: in the extreme case ($K = 9$) the market leader has more than a 95% chance of defending its position even if there are eight competitors in the market. In these cases firms have dispersed to serve individual niches (local peaks in the consumer landscape) and are unlikely to move. That means firms which have located favorable niches with high performance (relative to their competitors) are unlikely to be overtaken.

To summarize, the distribution of consumer preferences matters for the dynamics of competitive positioning: On smooth landscapes we observe firms constantly jostling for competitive advantage around a few peaks. Competition is detrimental to performance and even successful firms are constantly in danger having their customers stolen by rivals. As the landscape becomes increasingly rugged, firms disperse more and more. Instead of clustering at some distance around a single peak they spread out to serve individual consumer niches. This has the additional effect that in very rugged markets movement drops to a minimum, and it is very unlikely that successful firms will be overtaken. Note that this result does not happen suddenly when the number of peaks becomes greater than the number of firms (at approximately $K = 3$), but occurs gradually as ruggedness increases.

Robustness Tests

To ensure our results are not due to the specific shape of a randomly generated landscape, we reported the aggregated results of 1000 simulation runs. We also conduct several robustness tests to ensure the results are not due specific choices of parameter values or model structure.

Alternative landscape structure. An important concern with the results of our main model is that they could be due to the structure of NK landscapes. Technically NK landscapes are hypercubes, implying a discrete and finite number of potential product designs. Importantly, there is no option for consumers and firms to be located 'between' the positions [0,0,0] and [0,0,1], for example. This also implies that the distance between different product designs is limited to positive integers in the range $[1, N]$. The structure of the NK model might influence our result that firms constantly jostle on smooth landscapes: it could be due to the fact that the most attractive product designs are not feasible for firms, causing them move around the theoretically optimal but practically unattainable product designs.

To ensure this is not the case we replicate our results for the smooth landscapes using an entirely different model structure to generate the consumer preference landscapes. In the alternative model the landscape comprises two continuous dimensions instead of N binary ones. In this continuous taste space we distribute 1000 consumers. The resulting landscapes are illustrated in two snapshots in Figure 4. Each panel in the figure shows a single period of one simulation run, with one firm (left panel) and two firms (right panel). The gray circles indicate the locations of consumers who do not purchase at all. The black squares and diamonds indicate consumers who purchase from each of the two firms. The firms' current locations are marked by the solid black square and diamonds, respectively.

*** Insert Figure 4 around here ***

Apart from the landscape structure, the model is as close as possible to the main model. Consumer choices follow a discrete choice model: the closer a firm's product to their preference, the more likely they are to purchase it. Firms are assigned random initial locations and compete by updating their product designs. The model setup and results are described in detail in the Appendix.

The results from the alternative model are structurally identical to our main results. In particular, we observe exactly the same jostling for competitive position in the continuous model that we obtain using the NK model. The fact that a radically different model of the competitive landscape yields the same dynamics as the main model is very reassuring. It strongly suggests that the results presented here are not model artifacts, but instead reflect general attributes of competition under behaviorally plausible decision rules.

Price competition. In our main model we assume that prices do not enter the utility function and that firms compete only by adapting their product, i.e. not by changing their prices. This allows us to clearly identify how positioning drives competitive dynamics without the effects being complicated by price competition. To check that including prices in the model does not change our results for movement, positioning, and dethronement, we conduct a robustness test using a simple price mechanism: in addition to offering a product with design f_j each firm f charges a price p_f for its product. The utility consumers with preference i obtain from buying from firm f is modeled as:

$$u_{if} = \alpha - \tau\delta_{ij_f} - p_{\mathrm{f}} + \epsilon_i$$

Note that here τ is closely related to price elasticity. The calculation of firms' market share P_{if_jJ} is adapted accordingly, and firm f's revenues are their market share multiplied their price p_f:

$$\pi_{fJt} = p_f \sum_{i=1,\dots,2^N} P_{ij_ft} \times m_i$$

In the initial period all prices are set to one. In each subsequent period, firms adapt not only their product design but also receive a potential price change drawn randomly from a uniform distribution $\Delta_p \sim U(-1,1)$. They then calculate whether their (expected) revenues increase with the new price-product combination and update both if it does. Including this price mechanism introduces some noise to the model but otherwise does not change the results reported above.

We also assume that costs are zero. For models including only adaptation this is unproblematic: the performance measure in the model can be interpreted as a profit margin and fixed costs do not influence firm actions when maximizing revenues.

Search costs. We do not impose search costs for the firms in the model. This might influence our results on stability because it makes movement attractive for firms. To test whether this was the case we run the model with the additional rule that firms only change their product design if they expect it to improve their performance by at least 2%. This can be interpreted as a size-dependent search cost, for example the cost of changing a brand that increases with the size of the brand. It is similar to the approach taken by Johnson and Hoopes (2003) in their model of managerial sense-making. With search costs, the absolute level of movement decreases strongly, but otherwise the results remain essentially unchanged.

Search heuristics. We only let firms engage in local search. To ensure that the jostling we observe on smooth landscapes is not due to the fact that firms are unable to 'jump over' each other we run the model allowing firms to change up to four out of the ten possible product attributes. This also does not substantially change our results.

Simultaneous updating. We assume that firms update their products simultaneously. This is equivalent to assuming they have information about their competitors' current product designs but not their future moves. This assumption seems to us a reasonable approximation of reality, where in most markets firms can observe rivals' products fairly easily but find it much more difficult to predict what they will do next. However, it has the drawback that firms sometimes make mistakes, i.e. they opt for an action that in retrospect reduces their performance. An alternative mechanism would be to have firms decide sequentially on moves, randomly assigning turns in each period. Tests with early versions of the model suggest that sequential moves reduce the absolute level movement but do not lead to fundamentally different dynamics.

Parameter values. In the analysis of the model we focus on the number of firms F and the ruggedness of the preference landscape K, and do not discuss the three other parameters τ, α, and $\underline{u}$. To ensure our results are not due to the specific values chosen for them we run the simulation for different values of the parameter that influences our results most strongly: the 'transportation cost' τ. Using values for τ between 1 and 5 has a large influence on the absolute level of performance because for large (small) τ more (less) consumers exit the market (results not reported). However, the performance levels do not change substantially in structure: within reasonable ranges for τ they are essentially shifted up or down. Furthermore, the results concerning distances, movement, and dethronement are unchanged. For extremely low τ values the results on smooth landscapes remain essentially the same, but the comparison between different levels of ruggedness changes. The reason is that for very low values of τ consumers have very weak preferences, meaning that small peaks and valleys in the preference landscape are de-facto flattened out. We would argue that extremely weak preferences are a special case and do not substantially affect the argument made here.

5. Discussion

Interpretation and Contribution

Competitive positioning has been studied in a number of literatures and using different perspectives and models. The model of horizontal differentiation presented here sheds light on the dynamics of competition and its influence on performance in markets with varying numbers of competitors and consumer niches. In particular, it allows us to make predictions about the nature of competitive dynamics in different markets, depending on how consumers' preferences are distributed. Two main conclusions can be drawn from our results.

First, our results suggest that in markets where consumers have relatively homogeneous preferences, we should observe firms offering fairly similar product designs that are changed often. Interestingly, the product designs will be similar but not identical to what most consumers want. Moreover, the more competitors in the market, the worse will be the fit between the product designs they offer and the 'average' (more precisely: modal) consumer's preference. In markets with heterogeneous preferences exactly the opposite applies: there we would expect to observe product designs catering quite accurately to the tastes of individual consumer niches, and comparatively static offerings with few changes in product design.

Second, our model predicts that the effect of competition on firm performance will differ between markets. In markets with homogeneous preferences, additional competitors are highly detrimental to performance. However, as the number of consumer niches increases, differentiation softens competition. Similarly, we expect that market leaders will be regularly dethroned in competitive markets with homogeneous preferences, but will be comparatively safe in markets with many niches. This complements previous empirical work on dethronement by considering the influence of consumer preferences and horizontal positioning (Ferrier, Smith, & Grimm, 1999).

Our study makes three contributions to research on competitive positioning. First, it adds to research on industrial organization by calling into question the standard assumption of 'stability in competition' (Eiselt & Marianov, 2011; Hotelling, 1929). Using behaviorally plausible assumptions we demonstrate that in certain markets dynamic interactions are not a passing occurrence on the way to an equilibrium, but instead represent a systematic and persistent part of competition through horizontal positioning. Moreover, the result that the degree of product differentiation depends on the distribution of consumer preferences provides a new perspective on the 'principle of minimum differentiation' that has caused much debate in industrial economics (d'Aspremont et al., 1979; Irmen & Thisse, 1998). These results suggest that these models need to take dynamics into account or else risk misrepresenting competition through horizontal differentiation and possibly even drawing incorrect conclusions due to oversimplification.

Second, we offer a new perspective for dynamic models of vertical differentiation by showing how firms are faced with very different trade-offs and competitive situations in horizontally differentiated markets (Nelson & Winter, 2002). Our study also provides an economic description of competition that may be useful for future studies of positioning in organization ecology (Dobrev & Kim, 2006; Greve, 1998).

Finally, our model is quite general and may provide a platform for future research on dynamic competitive interactions. Specifically, in a recent paper Chen and Miller (2012) lament the lack of a coherent theoretical foundation in empirical work on competitive dynamics. Our model is able to describe fairly complex interactions between agents, yet is structurally comparatively simple. We are therefore hopeful that it might complement models of vertical differentiation to provide just such a theoretical basis for research on the dynamics of competition. In the next section we explore some of the most promising extensions for the model.

Directions for Future Research

A first interesting extension would be to let firms compete in prices. A simple mechanism for this was described above; more sophisticated models would require an exact argument about how the consumers' utility function includes prices, i.e. how the price elasticity of taste is modeled (similar to our parameter τ). Moreover, researchers could give firms more sophisticated rules for finding new prices in addition to new product designs. Allowing price competition would make the model correspond more closely to actual competitive situations and might also allow us to study phenomena like the simultaneous occurrence of high-end niche and low-price broad strategies. A related extension would be to include competition through vertical and horizontal differentiation in one model. This could be implemented by including some product features that are 'valued' by all consumers, similar to the approach taken by Marengo and Valente (2010). This too, would require us to specify a degree of 'taste elasticity', but could give us insight into even more nuanced strategies, and at the same time bridge the gap to the extensive literature on evolutionary economics (Nelson & Winter, 2002).

In this model we focus on adaptation, i.e. firms change their products over time but do not enter or exit the market. An alternative way to model population-level change is selection, which is popular in research on organizational ecology (Baum & Shipilov, 2006; Hannan & Freeman, 1977). The two mechanisms are complementary (Levinthal, 1991) and both can be found in models of organizational learning and innovation (Baumann & Siggelkow, 2011; Chang & Harrington, 2006; Safarzyńska & van den Bergh, 2010). We chose adaptation because it seems to us the natural way to think about product positioning, and exclude selection to avoid confounding its effect with the effects of adaptation. However, including selection would have the advantage that the number of firms would emerge endogenously from the model, and integrating both mechanisms might provide interesting insights into the carrying-capacity of markets. It would also provide a link to studies on positioning in organizational ecology, whose argument is based primarily on selection (Deephouse, 1999; Dobrev, 2007; Dobrev, Kim, & Carroll, 2002; Wang & Shaver, 2013).

A third interesting line of enquiry would be to study what happens when firms have access to more sophisticated search heuristics. Various search mechanisms have been explored in NK modeling, in particular a dynamic mix of local and global search (Levinthal, 1997), and recently advanced mechanisms like analogies (Ethiraj & Levinthal, 2004; Gavetti, Levinthal, & Rivkin, 2005; Gavetti & Warglien, 2007). Moreover, models of learning and competition, imitation of successful competitors is often cited as an important mechanism (Lieberman & Asaba, 2006; Rivkin, 2000). We use a local search mechanism to preserve simplicity, but investigating imitation and other mechanisms in a competitive setting would nicely complement the emerging literature on advanced search heuristics in agent-based models (Gavetti & Levinthal, 2000; Gavetti et al., 2005).

Finally, there are several other promising directions for studying dynamic competition based on the model presented here. They include allowing firms to have multiple products, similar to the approach by Chang and Harrington (2003), providing a rigorous theoretical description of the alternative benefits of commitment and flexibility by introducing heterogeneous switching costs for firms (Lamberg et al., 2009), and revisiting first-mover advantages in a horizontally differentiated model by creating a Stackelberg-like situation where firms move sequentially and some systematically move earlier.

Conclusion

Competitive positioning through horizontal positioning is both empirically pervasive and theoretically important in management research. This study presents an agent-based simulation model of competition through horizontal differentiation based on the well-known NK and discrete-choice models (Levinthal, 1997; McFadden, 1974). It provides insight into the dynamics of competition, highlighting the difference in competitive volatility for different distributions of consumer preferences. To the best of our knowledge it is the first theoretical description of dynamic competition through horizontal differentiation, and it contributes new perspectives to several existing streams of research. Most importantly however, we are optimistic that agent-based simulation models are a powerful tool for building a formal theory of competitive dynamics and look forward to future research in this area.

References

Adner, R. & Zemsky, P. 2006. A demand-based perspective on sustainable competitive advantage. ***Strategic Management Journal***, 27(3): 215-239.

Adner, R., Pólos, L., Ryall, M. D., & Sorenson, O. 2009. The case for formal theory. ***Academy of Management Review***, 34(2): 201–208.

Adner, R., Csaszar, F. A., & Zemsky, P. B. 2010. Positioning on a multi-attribute landscape, ***Atlanta Competitive Advantage Conference 2010 Paper***.

Baum, J. A. C. & Haveman, H. A. 1997. Love thy neighbor? Differentiation and agglomeration in the Manhattan hotel industry, 1898-1990. ***Administrative Science Quarterly***, 42(2): 304-338.

Baum, J. A. C. & Shipilov, C. 2006. Ecological Approaches to Organizations, ***Handbook of organization studies***: 55-110.

Baum, J. A. C. & Shiplov, A. V. 2006. Ecological approaches to organizations. ***The SAGE Handbook of Organization Studies***: 55-110.

Baumann, O. & Siggelkow, N. 2011. Complexity and competitive advantage. In P. Allen & S. Maguire & B. McKelvey (Eds.), ***Handbook of Complexity and Management***: 494-505. London: Sage.

Carroll, G. R., Dobrev, S. D., & Swaminathan, A. 2002. Organizational processes of resource partitioning. ***Research in Organizational Behavior***, 24(0): 1-40.

Chang, M.-H. & Harrington, J. E. 2006. Agent-based models of organizations. In L. Tesfatsion & K. L. Judd (Eds.), ***Handbook of Computational Economics***, Vol. 2: 1273-1337: Elsevier.

Chang, M. H. & Harrington, J. E. 2003. Multimarket competition, consumer search, and the organizational structure of multiunit firms. ***Management Science***, 49(4): 541-552.

Chen, M.-J. & Miller, D. 2012. Competitive dynamics: themes, trends, and a prospective research platform. ***Academy of Management Annals***, 6(1): 135-210.

d'Aspremont, C., Gabszewicz, J. J., & Thisse, J. F. 1979. On Hotelling's "Stability in competition". ***Econometrica***, 47(5): 1145-1150.

Dasgupta, P. & Maskin, E. 1986. The existence of equilibrium in discontinuous economic games, I: Theory. ***The Review of Economic Studies***, 53(1): 1-26.

de Figueiredo, J. M. & Silverman, B. S. 2007. Churn, baby, churn: Strategic dynamics among dominant and fringe firms in a segmented industry. ***Management Science***, 53(4): 632-650.

Deephouse, D. 1999. To be different, or to be the same? It's a question (and theory) of strategic balance. ***Strategic Management Journal***, 20: 147-166.

Delacroix, J. & Anand, S. 1991. Cosmetic, speculative, and adaptive organizational change in the wine industry: A longitudinal study. ***Administrative Science Quarterly***, 36(4): 631-661.

Dobrev, S. D., Kim, T.-Y., & Carroll, G. R. 2002. The evolution of organizational niches: U.S. automobile manufacturers, 1885-1981. ***Administrative Science Quarterly***, 47(2): 233-264.

Dobrev, S. D., Tai-Young, K., & Carroll, G. R. 2003. Shifting gears, shifting niches: Organizational inertia and change in the evolution of the U.S. automobile industry, 1885-1981. ***Organization Science***, 14(3): 264-282.

Dobrev, S. D. & Kim, T.-Y. 2006. Positioning among organizations in a population: Moves between market segments and the evolution of industry structure. ***Administrative Science Quarterly***, 51(2): 230-261.

Dobrev, S. D. 2007. Competing in the looking-glass market: imitation, resources, and crowding. ***Strategic Management Journal***, 28(13): 1267-1289.

Doraszelski, U. & Pakes, A. 2007. A framework for applied dynamic analysis in IO. ***Handbook of Industrial Organization***, 3: 1887-1966.

Eiselt, H. A. & Laporte, G. 1989. Competitive spatial models. ***European Journal of Operational Research***, 39(3): 231-242.

Eiselt, H. A., Laporte, G., & Thisse, J.-F. 1993. Competitive location models: A framework and bibliography. ***Transportation Science***, 27(1): 44.

Eiselt, H. A. 2011. Equilibria in competitive location models. In H. A. Eiselt & V. Marianov (Eds.), ***Foundations of Location Analysis***: 139-162. New York: Springer.

Eiselt, H. A. & Marianov, V. 2011. Pioneering developments in location analysis. In H. A. Eiselt & V. Marianov (Eds.), ***Foundations of Location Analysis***: 3-22. New York: Springer US.

Epstein, J. M. & Hammond, R. A. 2002. Non-explanatory equilibria: An extremely simple game with (mostly) unattainable fixed points. ***Complexity***, 7(4): 18-22.

Epstein, J. M. 2006. ***Generative Social Science: Studies in Agent-Based Computational Modeling***. Princeton: Princeton University Press.

Ethiraj, S. K. & Levinthal, D. 2004. Bounded rationality and the search for organizational architecture: An evolutionary perspective on the design of organizations and their evolvability. ***Administrative Science Quarterly***, 49(3): 404-437.

Ferrier, W. J., Smith, K. G., & Grimm, C. M. 1999. The role of competitive action in market share erosion and industry dynamics: A study of industry leaders and challengers. ***Academy of Management Journal***, 42(4): 372–388.

Ganco, M. & Hoetker, G. 2009. NK modeling methodology in the strategy literature: Bounded search on a rugged landscape. In D. D. Bergh & D. J. Ketchen (Eds.), ***Research Methodology in Strategy and Management***, Vol. 5: 237-268. Bingley, UK: Emerald.

Gavetti, G. & Levinthal, D. 2000. Looking forward and looking backward: Cognitive and experiential search. ***Administrative Science Quarterly***, 45(1): 113-137.

Gavetti, G., Levinthal, D. A., & Rivkin, J. W. 2005. Strategy making in novel and complex worlds: The power of analogy. ***Strategic Management Journal***, 26(8): 691-712.

Gavetti, G. & Warglien, M. 2007. Recognizing the new: A multi-agent model of analogy in strategic decision-making. ***SSRN eLibrary***.

George, L. & Waldfogel, J. 2003. Who affects whom in daily newspaper markets? ***Journal of Political Economy***, 111(4): 765-784.

Greve, H. R. 1995. Jumping ship: The diffusion of strategy abandonment. ***Administrative Science Quarterly***, 40(3): 444-473.

Greve, H. R. 1998. Managerial cognition and the mimetic adoption of market positions: What you see is what you do. ***Strategic Management Journal***, 19(10): 967-988.

Greve, H. R. 2000. Market niche entry decisions: Competition, learning, and strategy in Tokyo banking, 1894-1936. ***Academy of Management Journal***, 43(5): 816-836.

Hannan, M. T. & Freeman, J. 1977. The population ecology of organizations. ***American Journal of Sociology***, 82(5): 929-964.

Hannan, M. T., Carroll, G. R., & Pólos, L. 2003. The organizational niche. ***Sociological Theory***, 21(4): 309-340.

Hotelling, H. 1929. Stability in competition. ***The Economic Journal***, 39(153): 41-57.

Irmen, A. & Thisse, J.-F. 1998. Competition in multi-characteristics spaces: Hotelling was almost right. ***Journal of Economic Theory***, 78(1): 76-102.

Johnson, D. R. & Hoopes, D. G. 2003. Managerial cognition, sunk costs, and the evolution of industry structure. ***Strategic Management Journal***, 24(10): 1057-1068.

Kauffman, S. & Levin, S. 1987. Towards a general theory of adaptive walks on rugged landscapes. ***Journal of Theoretical Biology***, 128(1): 11-45.

Kauffman, S. 1993. ***The origins of order: Self organization and selection in evolution***. Oxford: Oxford University Press.

Knott, A. M. 2003. Persistent heterogeneity and sustainable innovation. ***Strategic Management Journal***, 24(8): 687-705.

Koski, H. & Kretschmer, T. 2007. Innovation and dominant design in mobile telephony. ***Industry and Innovation***, 14(3): 305-324.

Kress, D. & Pesch, E. 2012. Sequential competitive location on networks. ***European Journal of Operational Research***, 217(3): 483-499.

Lamberg, J.-A., Tikkanen, H., Nokelainen, T., & Suur-Inkeroinen, H. 2009. Competitive dynamics, strategic consistency, and organizational survival. ***Strategic Management Journal***, 30(1): 45-60.

Lancaster, K. J. 1966. A new approach to consumer theory. ***Journal of Political Economy***, 74(2): 132-157.

Lenox, M. J., Rockart, S. F., & Lewin, A. Y. 2006. Interdependency, competition, and the distribution of firm and industry profits. ***Management Science***, 52(5): 757–772.

Lenox, M. J., Rockart, S. F., & Lewin, A. Y. 2007. Interdependency, competition, and industry dynamics. ***Management Science***, 53(4): 599-615.

Leombruni, R. & Richiardi, M. 2005. Why are economists sceptical about agent-based simulations? ***Physica A: Statistical Mechanics and its Applications***, 355(1): 103-109.

Levinthal, D. A. 1991. Organizational adaptation and environmental selection-interrelated processes of change. ***Organization Science***, 2(1): 140-145.

Levinthal, D. A. 1997. Adaptation on rugged landscapes. ***Management Science***, 43(7): 934-950.

Lieberman, M. B. & Asaba, S. 2006. Why do firms imitate each other? ***Academy of Management Review***, 31(2): 366-385.

Marengo, L. & Valente, M. 2010. Industry dynamics in complex product spaces: An evolutionary model. ***Structural Change and Economic Dynamics***, 21(1): 5-16.

McFadden, D. 1974. Conditional logit analysis of qualitative choice behavior. In P. Zarembka (Ed.), ***Frontiers in Econometrics***: 105-142. New York: Academic Press.

Nelson, R. R. & Winter, S. G. 1982. ***An evolutionary theory of economic change***: Belknap press.

Nelson, R. R. & Winter, S. G. 2002. Evolutionary theorizing in economics. ***Journal of Economic Perspectives***, 16(2): 23-46.

Porter, M. E. 1980. ***Competitive Strategy: Techniques for Analyzing Industry and Competitors***. New York: The Free Press.

Rivkin, J. W. 2000. Imitation of complex strategies. ***Management Science***, 46(6): 824–844.

Rivkin, J. W. 2001. Reproducing knowledge: Replication without imitation at moderate complexity. ***Organization Science***, 12(3): 274-293.

Rivkin, J. W. & Siggelkow, N. 2003. Balancing search and stability: Interdependencies among elements of organizational design. ***Management Science***, 49(3): 290-311.

Safarzyńska, K. & van den Bergh, J. C. J. M. 2010. Evolutionary models in economics: A survey of methods and building blocks. ***Journal of Evolutionary Economics***, 20(3): 329-373.

Schumpeter, J. A. 1950. ***Capitalism, Socialism and Democracy***. New York: Harper and Row.

Shapiro, C. 1989. Theories of oligopoly behavior. ***Handbook of industrial organization***, 1: 329-414.

Smith, K. G., Ferrier, W. J., & Ndofor, H. 2001. Competitive dynamics research: Critique and future directions. In M. A. Hitt & R. E. Freeman & J. S. Harrison (Eds.), ***The Blackwell handbook of strategic management***: 314–361. Oxford: Blackwell Publishing.

Teitz, M. B. 1968. Locational strategies for competitive systems. ***Journal of Regional Science***, 8(2): 135-148.

Wang, R. D. & Shaver, J. M. 2013. Competition-driven repositioning. ***Strategic Management Journal***, forthcoming.

Windrum, P. & Birchenhall, C. 1998. Is product life cycle theory a special case? Dominant designs and the emergence of market niches through coevolutionary-learning. ***Structural Change and Economic Dynamics***, 9(1): 109-134.

Younies, H. & Eiselt, H. A. 2011. Sequential location models. In H. A. Eiselt & V. Marianov (Eds.), ***Foundations of Location Analysis***: 163-178. New York: Springer US.

Appendix

Appendix A: Figures and Tables

Figure 1: Illustration of landscapes

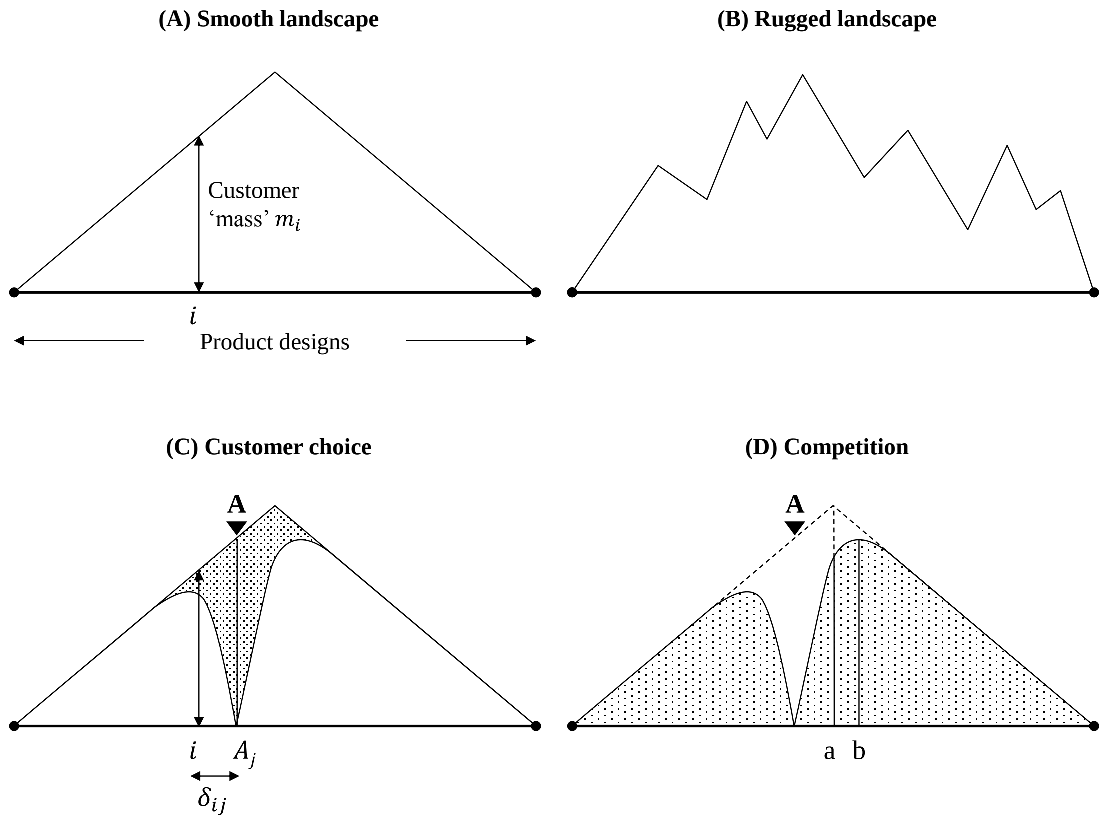


Table 1: Parameter values for simulation

Parameter	Values	Interpretation
N	10	# product attributes (the landscape size is $2^N = 1024$)
K	$[0, 1, \dots, 9]$	# interactions for each attribute (***ruggedness***)
F	$[1; 2; 4; 8]$	# firms (***competition***)
T	80	# periods for each simulation run
S	1000	# simulation runs per parameter combination
α	2	Base utility
τ	2	Transportation cost
$\underline{u}$	$e \approx 2.178$	Utility of outside good

Figure 2: Competition on smooth landscapes (K=0)

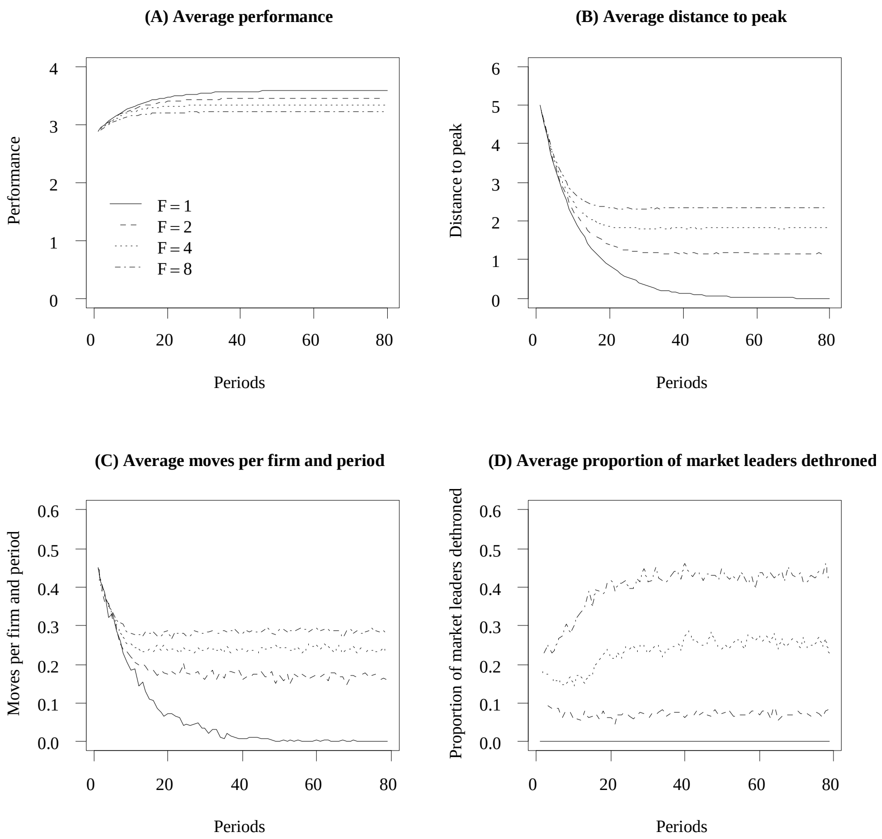


Figure 3: Competition on rugged landscapes (T=80)

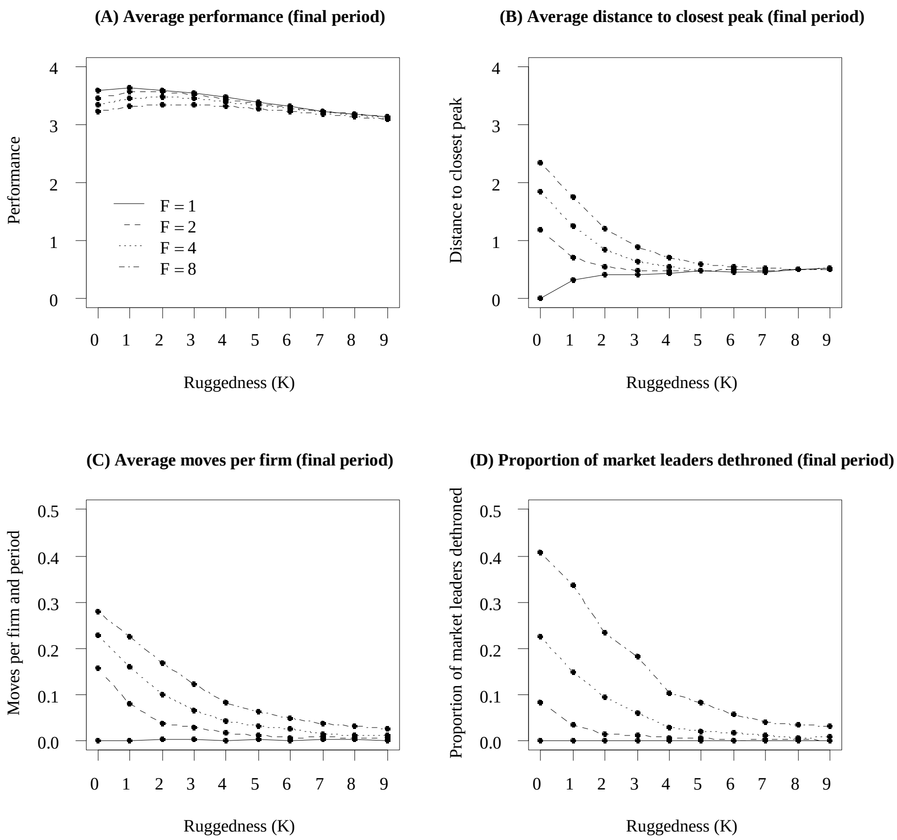
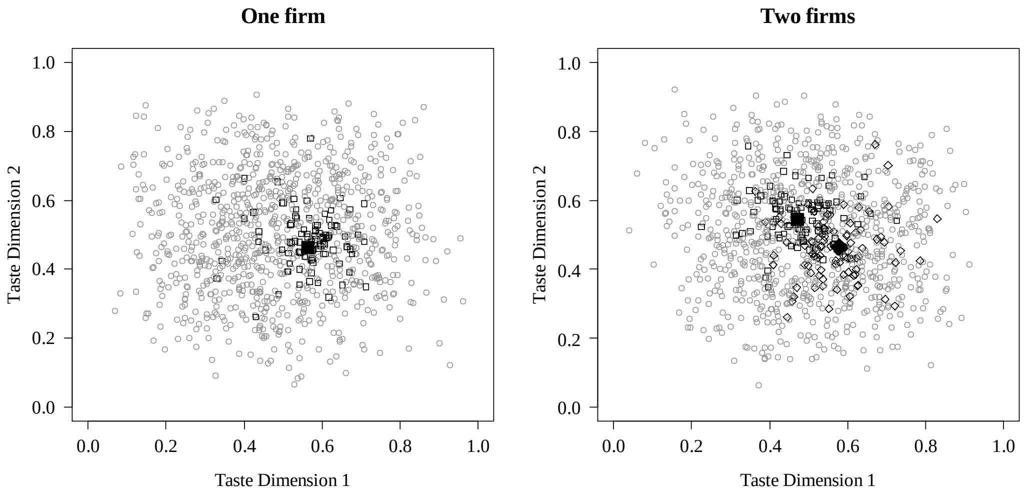


Figure 4: Alternative landscape structure - illustrative landscapes



Appendix B: Supplementary Material

Alternative Model – Continuous Landscape

To ensure our results are not an artifact of the discrete structure of NK landscapes we replicate our results for smooth landscapes using a distribution of consumer preferences in a two-dimensional, continuous taste-space. The following section briefly describes the model setup and results.

Consumer preferences. Consumers are distributed at random locations in two continuous dimensions on the interval $[0; 1]x[0; 1]$. The simulations reported below use 1000 consumers whose tastes are fixed for each individual simulation run.[5] To generate landscapes we allocate consumers' tastes using random draws from a bivariate beta distribution with parameters $\alpha = 4,\ \beta = 4$. The peak of the landscape is located (approximately) at the mode of the distribution [0.5, 0.5], as illustrated in Figure 4.

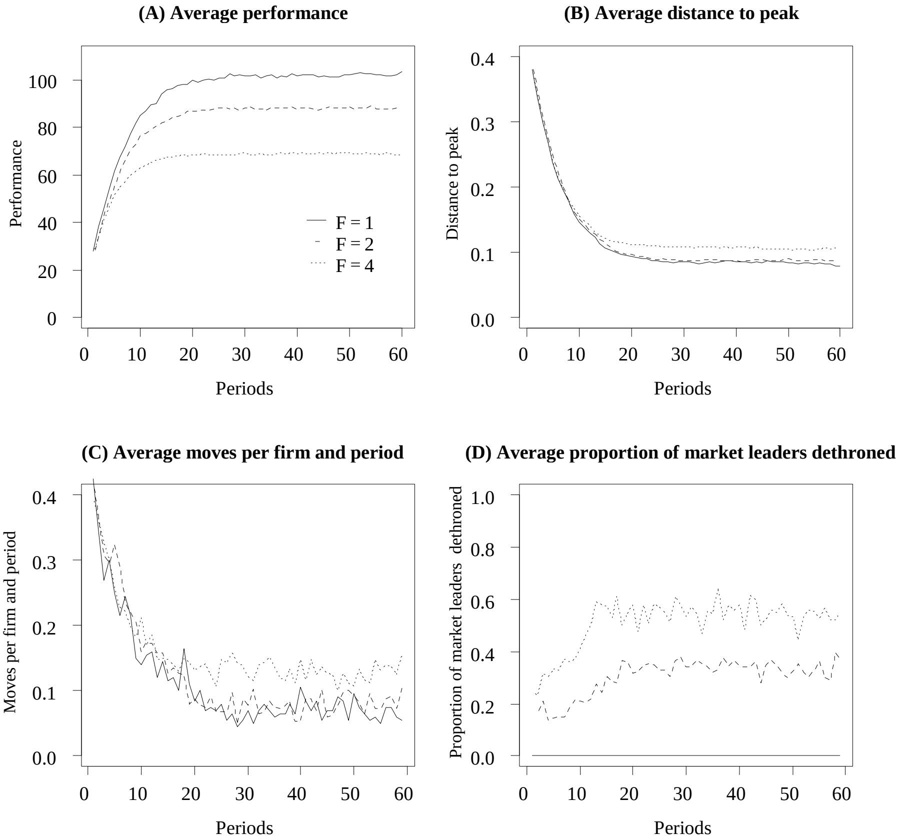
Consumer choice. The mechanism for calculating consumer utility and the probability of their choice is identical to the main model, except that the distance δ_{ij} is now no longer a Hamming distance between two binary vectors, but instead the Euclidean distance between the firm location and the consumer's ideal design. In this model δ_{ij} is scaled in $[0; 1]$, instead of being a non-negative integer in the range $[0, \ldots, 10]$, and we therefore use $\tau = 20$ because otherwise transport costs are insignificant.[6] Using the discrete choice model as described above we calculate for each consumer the probability that they will purchase from each firm (or choose the outside option). Since consumers are discrete, we then use their probabilities to flip a coin and determine from which firm each of them purchases in that period.

Firms. Firms are initially assigned random positions in the landscape. Their payoffs are calculated as the number of (discrete) consumers purchasing from them in that period. In each period they select a candidate for a new position at a distance of 0.2, then simultaneously calculate whether it would be an improvement and update their positions as in the main model. Note this means that in this model firms can reach *any* position in the landscape given a sufficient number of moves – this is exactly what we are aiming for in the robustness test. Note also that due to computational limitations we model only 60 periods (instead of 80 as in the main model) and only competition between one, two and four firms (not eight as in the main model).

[5] Note this means that although the taste space is continuous, the consumers are discrete, unlike in the main model where the taste space is continuous but the consumer 'mass' is continuous at each point. This means the consumer landscape is only *approximately* continuous, the limiting factor being computation time. The alternative in the continuous model would have been to lay down a lattice over the taste space and assign each node a consumer mass, but that would have created a discrete space again, which is precisely what we are trying to avoid. Note that in contrast to the NK landscape firms can reach any location in this landscape, which is what we are trying to achieve.

[6] Insignificant transport costs would mean consumers are indifferent to how far away the firm's product is from their preference, which rather defeats the purpose of distributing consumer preferences in the first place.

Figure B.1 Alternative model – continuous and smooth landscapes



Results. Average results for 200 simulation runs are illustrated in Figure B.1. They are structurally identical to the main results in Figure 2, albeit with different scaling due to the differences in model structure. In Panel (A) we see that performance initially increases and then flattens out, and is negatively influenced by an increasing number of competitors F. Panel (B) shows that firms approach a peak but that more competitors (higher F) mean that on average their position stabilizes further away from the peak. Panel (C) shows that firms continue to move over time and that the rate of movement increases for more competitors. Finally, in Panel (D) we see that the market leader is much more likely to be dethroned if there are more competitors in the market.[7]

This result is reassuring, in particular the extremely similar results in Panels (C) in Figure 2 and Figure B.1. By replicating the jostling between firms in a model using a continuous landscape we can be confident that the continued movement is not due to the discreteness of the NK landscape.

Standardization of Landscapes

An artifact of NK landscapes is that while mean performance is constant, the absolute height of global maxima ('fitness', or in our model 'consumer mass') increases with increasing ruggedness. A standard maneuver to make results comparable across different K values is therefore to standardize landscape

[7] Readers may note that on average even a single firm does not reach the peak exactly (Panel B), or stop moving entirely (Panel C). This is due to the discrete number of 1000 consumers as illustrated in Figure 4, which causes very slight 'bumpiness' in the landscape.

height by measuring performance relative to the global maximum (Ganco & Hoetker, 2009). In our model that approach is not feasible because dividing the consumer mass at each point by the mass at the global maximum means that more rugged landscapes have systematically less mass. In previous models this has not been a problem because firms' profits are equal to the height of the landscape at their current position (or a transformation of it), not a sum of (part of) the mass at several different points like in our model. To make results comparable over different values of K we therefore standardize the total consumer *mass* in the different landscapes, i.e. the market size. This is fairly unproblematic, because apart from the absolute height of performance between K values it makes no difference to our results whether we standardize by height or mass: our results regarding movement, positioning and dethronement remain unchanged.

Distance to Nearest Peak on Rugged Landscapes

In Panel (B) of Figure 3 the average distance of a single firm to the global maximum (the solid line) does not stay at zero for increasing levels of ruggedness. Instead, it rises to a level of approximately 0.7, a similar level as under competition. The reason for this initially surprising result is that the firms' performance is the sum of consumer mass over several points and not the height at a single point like in standard NK models. With a sufficient number of peaks this makes it attractive for firms to locate between peaks to gather the consumers at both of them.