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Competition on Rugged Landscapes

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Abstract

State-of-the-Art and Research Gap

Firms' competitive behavior strongly influences their performance - that much is obvious. But how does it work exactly? And how is competitive behavior shaped by customer preferences? Might competitive processes in different markets provide an explanation for performance heterogeneity? Amazingly, despite their importance we lack systematic answers to these questions.

Industrial organization offers a wealth of formal theory on competition. However, scholars there have followed Hotelling (1929) and focused predominantly on static models yielding closed-form solutions. This has obscured the dynamics of competitive processes. Competitive dynamics research has empirically investigated competitive processes (Chen & Miller, 2012), but it has focused on "dyads" and intra-firm processes, and does not provide insights into the economic implications of competition across industries.

Despite much formal theoretical and empirical research we thus have no systematic knowledge of how competitive processes influence performance. Our study takes a first step towards closing this gap by analyzing how market structure (the distribution and strength of customers' preferences) affects firms' competitive behavior, and how that in turn influences performance heterogeneity.

Theoretical Arguments and Method

We present an agent-based simulation model of competition as a horizontal positioning game. Initially, customers are endowed with product preferences. Firms then attempt to maximize their revenues by adjusting their single product to match customers' preferences (prices are fixed). In each period, customers buy a single unit of the product that best matches their preference, so firms' revenues depend on their own and their rivals' positions in the product space.

To investigate how market structure affects competition the model allows us to manipulate two key market features: the distribution of customer preferences ("ruggedness") and their strength ("pickiness"). This is achieved by using an NK model (Levinthal, 1997) to determine the distribution of customer preferences, and a discrete-choice model (McFadden, 1974) to determine their strength.

We argue that agent-based simulation models are a promising tool with which to study competitive processes and

discuss several extensions including competition in prices, entry and exit, and more sophisticated search mechanisms.

Results

We find that in markets with "smooth" customer preferences (few niches), firms are highly interdependent and constantly jostle for the best positions, resulting in heterogeneous and volatile performance. In these markets additional competitors have a strong negative influence on performance. This is reminiscent of commoditized markets like food retailing in Germany. Conversely, when customer preferences are "rugged" (many niches), firms disperse to serve individual market segments, resulting in lower but more homogeneous and stable performance. In these markets additional competitors have less impact on performance. An example is the market for clothes brands.

These results are moderated by the strength of customers' preferences: for increasingly "picky" customers, firms' absolute performance decreases (more customers exit the market), but relative performance remains approximately constant as firms are less interdependent and move to comparatively stable positions close to the center of niches (either dispersed or central).

Our study makes two main contributions: First, industrial organization has explained performance heterogeneity as a result of industry characteristics. We add a dynamic perspective to this explanation, at the same time loosening many problematic assumptions and using behaviorally plausible micro-rules (Epstein, 2006). Second, we present the first "true" agent-based model of competition where firms' search spaces are deformed by their rivals' positions, thus adding to research on competition and organizational learning (Baumann & Siggelkow, 2010).

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Competition on Rugged Landscapes: The Dynamics of Horizontal Differentiation [1]

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Competition through horizontal and vertical differentiation is central to managers and researchers alike. It is also a fundamentally dynamic process. Research on vertical differentiation studying technological innovation has long incorporated dynamic models of competition, but the same is not true for horizontal differentiation. This paper presents an agent-based simulation model that combines NK and discrete choice models to describe the dynamics of competition through positioning in horizontally differentiated markets. We find that in 'rugged' markets with many consumer niches firms disperse to stable distributions where they serve individual consumer niches, there is little adaptation of products, and the effect of competition on performance is small. In contrast, in markets with homogeneous consumer preferences, competition causes persistently volatile situations where firms constantly jostle for favorable positions. Here, competition is highly detrimental to performance and market leaders are frequently dethroned. We conclude that the dynamics of competition matter and are influenced by the distribution of consumer preferences. Our results contrast with the equilibrium solutions commonly used to model horizontal differentiation in industrial organization. It also responds to a recent call in the NK literature for models of interaction between firms.

Keywords: Competition, Horizontal Differentiation, Dynamics, Simulation
JEL classification: L22, M10, C15, D52

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1. Introduction

Competition is without doubt one of the most central concepts in management and economics. At the most basic level it can be modeled as firms with homogeneous goods competing by adjusting quantities or prices (the Cournot and Bertrand models). More sophisticated models recognize the importance of consumer preferences that enable firms to escape pure price competition by differentiating their products either vertically or horizontally (Hotelling, 1929; Lancaster, 1966; Shaked & Sutton, 1982). A vertically differentiated product is preferable to all consumers, e.g. a winter coat made of particularly fine cashmere wool. Vertical differentiation is typically associated with quality or technological innovation (Doraszelski & Pakes, 2007; Nelson & Winter, 1982). In contrast, a horizontally differentiated product appeals more or less to different consumers depending on their preferences, e.g. a black or a purple coat. Horizontal differentiation is typically associated with product and brand positioning. It is important in day-to-day competition, especially in markets where consumers' marginal returns from technological innovation are relatively low (Adner & Zemsky, 2006; Koski & Kretschmer, 2007).

Organizational and management scholars have long recognized that competition is an inherently dynamic process (Schumpeter, 1950). Models of innovation, i.e. of *vertical* product differentiation, have incorporated dynamic elements at least since the book by Nelson and Winter (1982). However, the same is not true for the equally important phenomenon of competition through *horizontal* differentiation. Horizontal differentiation has been extensively studied using game-theoretical models based on Hotelling (1929), but these are unsuited to describing dynamic processes (Epstein, 2006).

As a consequence we don't know how firms behave in competition through horizontal differentiation. Do they settle down to stable distributions where each offers an unchanging product and profits are equally distributed (as suggested by some models from industrial organization)? Are successful firms able to capture and defend the most favorable positions, forcing others to make do with second best? Does everybody have to jostle for profitable positions, constantly stealing each other's profits? What difference does it make how consumers' preferences are distributed, i.e. whether there are many or few consumer niches?

Our paper addresses these questions by studying competitive positioning in a horizontally differentiated market. We present an agent-based simulation model of competition based on the well-known NK and discrete choice models (Levinthal, 1997; McFadden, 1974). In the model, single-product firms compete for consumers by adjusting their product's attributes in markets with few or many consumer niches. This allows us to observe how the dynamics of competition and its influence on performance change depending on two key factors: the degree of competition in the market and the distribution of consumer preferences. We find that in 'rugged' markets with many consumer niches firms disperse and settle down to serve individual niches. In 'smooth' markets with few consumer niches competition causes persistently volatile situations. Instead of settling down firms constantly jostle for the most profitable positions, resulting in a large number of changes to their products. In these markets, competition hurts performance, and market leaders are frequently dethroned by competitors stealing their consumer base.

The study contributes to research on competition by presenting the first model of the dynamics of competition through horizontal differentiation. In particular, the finding that 'smooth' markets with few consumer niches are characterized by persistently volatile competition contrasts with the static solutions used in industrial organization (Eiselt, 2011). Furthermore, the results show that consumer heterogeneity plays a major role for the dynamics of competition, thus addressing a call in the management literature for a closer examination of the interaction between consumer heterogeneity and firm actions (Adner & Zemsky, 2006). Finally, the study answers a recent call in the NK literature for interactive models of industrial dynamics (Baumann & Siggelkow, 2011).

2. Model

2.1. Modeling Competition Through Horizontal Differentiation

Consider a group of rival firms that make coats and are faced with a choice of how to specify various attributes, say length, cut, and color. Assuming they are unwilling or unable to change prices, their revenue depends on which types of coat most consumers want. For example, long-black-conservative coats and short-sportive-purple coats may both be popular while nobody wants a long-conservative-purple coat. Note that the distribution of consumer preferences may be smooth, i.e. all consumers want more or less the same thing, or rugged like in the example where there are several popular specifications. In many cases it may not be feasible for the firm to map out consumer preferences for all possible product specifications and so it seems likely they will experiment by gradually changing the attributes of their product and seeing how consumers react.

In addition to consumers, the firms' best plan of action depends on what their competitors do. Even if long-conservative-black coats are very popular, if there are many firms making them it may be more attractive to try out other specifications. However, if everybody moves away to different coats then nobody will be serving the large long-black-conservative niche, and it will become attractive to move back. So what happens? Do firms spread out around the most popular coats? Can one firm 'capture' an attractive niche and drive others away? Do firms jump back and forwards between specifications? How does the distribution of consumer niches influence this dynamic?

The first model that springs to mind to describe this type of problem is Hotelling's (1929) model of spatial competition. He calculated that under certain simplifying assumptions pairs of competing firms would end up offering the same product specification. The reasoning is that if there is a continuum of product specifications (from zero to one) then by making its product more similar to its competitor's a firm can steal some consumers while retaining all the consumers 'behind' it. The same goes for the competitor, and so the firms end up making an average product. This result is known as the 'principle of minimum differentiation'. It was disproved by d'Aspremont, Gabszewicz, and Thisse (1979) who showed that not only is Hotelling's proof flawed, but with a slight change in assumptions exactly the opposite happens: firms make their products as different as possible. Scores of subsequent theoretical studies on 'spatial competition' have investigated what happens to these results when one changes the assumptions in the basic model (Kress & Pesch, 2012; Younies & Eiselt, 2011)but they suffer from results that are extremely vulnerable to very restrictive assumptions (Eiselt & Laporte, 1989). Moreover, they all have one thing in common that prevents them from providing answers to our questions: 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 an equilibrium strategy will be played because it exists is questionable from a theoretical point of view because it is unclear whether firms will reach it within feasible time frames (Epstein & Hammond, 2002). More importantly however, equilibria are by their very nature fixed points, and equilibrium models are therefore not well suited to describing the dynamics of competition, at least for horizontal differentiation (Shapiro, 1989). It is possible that in situations like the one described in the example firms will reach stable sets of 'equilibrium' positions in the competitive landscape, but unless we assume they have perfect information and are fully rational – assumptions criticized by Nelson and Winter (1982) and Epstein (2006) – it's equally possible they won't. Until we investigate the dynamics of competition in horizontal positioning we have no way of knowing.

Closed-form equilibrium models are not the only tool at our disposal. Recently, agent-based simulation models have gained popularity in management research (Baumann & Siggelkow, 2011; Chang & Harrington, 2006). They offer similar benefits in terms of rigor and the clear identification of causality as closed-form models, but at the same time allow us to observe dynamics (Adner, Pólos, Ryall, & Sorenson, 2009). There is also an epistemological case to be made for agent-based simulation models in the social sciences: Epstein (2006) argues that if an agent-based model using behaviorally plausible micro-level assumptions can generate a macro-level phenomenon (like competition), then it constitutes a sufficient (if not necessary) 'explanation' for it.

Another class of models that might address our problem is based on Hannan and Freeman (1977), who looked at how it is possible that several different types of organizations can survive in parallel. In doing so they chose to focus on the population-level effect of selection, i.e. the entry and exit of firms, and argued that this is feasible because in some cases firms might not be able to change. The subsequent literature on 'organizational ecology' has followed their lead and made firm 'inertia' a central assumption (Baum & Shiplov, 2006). The idea that firms cannot change (sufficiently quickly) may make sense in some contexts, e.g. when a hotel chooses its location it is difficult to change it later (Baum & Haveman, 1997), but in others it seems difficult to justify. In particular, when thinking about competition through horizontal differentiation it seems obvious that firms are able to adapt their products or brands to gain more consumers, and frequently do. Consequently, while population-level selection may be a suitable model for some questions, letting firms gradually adapt their products and learn about their environment seems a more intuitive way to model the situation described in the introductory example.

To summarize, we use an agent-based simulation model to describe the dynamics of competition through adaptation in a horizontally differentiated market. The introductory example suggests that our model needs to capture two features to describe these situations: first, we need mechanisms to govern the distribution of consumer preferences and their resulting product choices, and second we need rules that tell firms what to do. The following paragraphs describe how we translate these two features into the model.

2.2. Consumer Preferences and Choice

The aim of the model is to observe how firms compete for consumers through horizontal differentiation. To achieve this we need to model consumers' behavior when they are offered several competing products. We therefore endow all consumers with an 'ideal' product preference. The more similar a product offered by a firm is to their ideal the more likely it is they will purchase it. This requires that we solve two modeling issues: first we need to determine how many consumers consider each potential product specification ideal (consumer preferences). Second, we need to determine how consumers make their decisions based on which product specifications are actually offered by firms (consumer choice). We solve these problems using the NK and the discrete choice models, respectively.

Consumer preferences. The first step is to generate a distribution of consumer preferences. This is achieved by assigning consumers to a large number of product specifications. Consumers assigned to a product specification consider it the 'ideal' product. In terms of our coat example that means mapping out all the possible combinations of length, cut and color and assigning to each of them a number of consumers. The potential distributions of consumer preferences, or 'landscapes', are illustrated in Figure 1. In panel (A) the bold horizontal line represents a set of product specifications. The height of the triangle at any given point i indicates the number of consumers m_i who consider that product specification ideal.

Insert Figure 1 about here

As indicated in the coat example 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 that is illustrated in panel (A) of Figure 1. We refer to this single-peaked landscape as 'smooth' (note this means 'smooth' does *not* refer to uniformly distributed consumer preferences). Alternatively, there may be situations in which there are several popular products which are not similar at all. The products that are similar to any given 'star product' may be quite unpopular, for example the unpopular long-conservative-purple coats that are almost like the popular long-conservative-black ones. We refer to this type of landscape as 'rugged', and to popular products that are surrounded by unpopular ones as 'niches', i.e. clusters of large numbers of consumers who have similar product preferences. Panel (B) in Figure 1 is an illustration of a rugged landscape.

We generate the consumer preference distributions using the popular NK model. It has been widely used in management research, primarily to model search processes to better understand 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, so the number of all possible product specifications is 2^N. In the introductory example with the coats $N = 3$ and there are eight possible product specifications determined by the attributes length (long / short), cut (conservative / sportive), and color (black / purple). Thus, product specifications can be thought of as bundles of attributes, an idea that goes back to 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 specifications, as indicated in Figure 1. The product specification i is considered ideal by all the consumers at that point. The parameter K is a measure of ruggedness: the higher K, the more local maxima the landscape possesses (Levinthal, 1997). In our interpretation higher K therefore means more 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 extensively documented in prior work, for example in Chang and Harrington (2006), Rivkin (2000), and Rivkin and Siggelkow (2003). Note 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) they are discrete (1/0) in N-dimensions.

Consumer choice. To recap, we now have a landscape consisting of 2^N potential product specifications, each with N attributes that can be 1 or 0. Each of these product specifications is considered ideal by m_i consumers. The next step is to define how consumers make purchase decisions depending on which product specifications are actually offered. For this we use a discrete choice model that is widely used economics and has recently also been used in NK modeling (Lenox, Rockart, & Lewin, 2006, 2007; McFadden, 1974).

Consumers gain utility from buying products. Their utility level depends on how much the product they buy differs from their ideal specification. In particular, the utility u_{ij} a consumer who prefers product specification i gains from buying a product with specification 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 specification i and the actual product specification j. This is the number of product attributes where there is a mismatch between the consumer's preferred specification and the actual product, i.e. the Hamming distance between the two binary vectors. For example, if a consumer's ideal coat specification is long-conservative-black (1;1;1), the distance to a short-conservative-purple coat (0;1;0) would be two. Thus, the further the product is from a consumer's preference, the lower is their utility from buying it. The parameter τ is a measure of the strength of consumers' preferences for their ideal product specification – 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 specification, and vice versa. Each consumer is assumed to buy one product each period and consumers have switching costs of zero. Note that consumer utility does not depend on price as we have excluded price competition for simplicity; this is discussed below.

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

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

where $\underline{u}$ denotes the value of the outside option. This term has an intuitive interpretation: if the product specification j is close to the preference of consumers at i 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 specification j is unlike i then the numerator will be small and only a few of the consumers there will buy j. Moreover, if there are many other attractive products in the market, 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 therefore the smaller the proportion of consumers buying each product j. If $\underline{u} > 0$ then the market is not covered, i.e. some consumers do not buy any of the products offered.

2.3. 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 specification it can adapt over time. By offering a product with specification 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

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

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_jJ} is close to one. For consumers at i firm A's product specification is some way away from their ideal product. Therefore, δ_{ij} is greater than zero and their utility from that product is lower. Therefore only a small proportion of them buy from A: the proportion of the arrow that is inside the shaded area. Note that we do not allow firms to compete in prices and also abstract from costs (this is discussed immediately below), so firms' performance is equal to their revenues.

In the initial period firms are assigned a random product specification. In each subsequent period they attempt to increase their revenues through local search. To do so each firm randomly changes 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 specifications stable. If a firm expects to increase its revenues by changing its product specification it decides to do so, otherwise it decides to stay with the old product. Finally, all firms' product specifications are updated simultaneously, the new set of products is used to recalculate everyone's revenues, and the cycle starts again.

This 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 (some exceptions are discussed below). In our model each firm's revenue depends both on the firms' position relative to the distribution of consumer preferences *and* the position of all of its competitors. It is these two connected departures from the standard NK model that allow us to study competition in horizontal differentiation.

2.4. Related Models: Horizontal vs. Vertical Differentiation

This model of competition through horizontal differentiation is related to two previous streams of research: evolutionary models of technological innovation, and recent NK models incorporating competition. We add to this research because it looks at competition through vertical differentiation whereas we focus on horizontal differentiation, a conceptual distinction that goes beyond mere modeling.

The first of the two research streams follows Nelson and Winter (1982). It studies how firms achieve temporary competitive advantage by investing in research and development. The basic premise is that innovative products are always more attractive to consumers and so innovation is always desirable given the extra revenues it generates cover its cost (Adner & Zemsky, 2006). That means it focuses firmly on vertical differentiation (e.g. Adner & Zemsky, 2006; Knott, 2003; Safarzyńska & van den Bergh, 2010). The same applies to recent research in industrial organization using dynamic models (Doraszelski & Pakes, 2007) and to the theoretical basis of empirical research on 'competitive dynamics' (Chen & Miller, 2012; Smith, Ferrier, & Ndofor, 2001).

The second literature stream comprises NK models that include competition. Lenox et al. (2006, 2007) look at the persistence of performance heterogeneity and industry shakeouts using two variations of a model combining search on an NK landscape with subsequent competition. In the first variation firms draw the marginal costs of production an NK landscape and subsequently engage in Cournot competition with undifferentiated products. In the second firms draw quality from an NK model and subsequently compete in a vertically differentiated Bertrand setup. The difference to the model presented here is that in Lenox et al. (2006, 2007) firms compete by lowering their cost or raising their quality, and changes in both are *always* desirable. Having competitors with similar cost or quality positions may harm a firm's profits, making it less attractive to move in absolute terms to move towards a peak, but the *relative* attractiveness of moving to a new position (in terms of cost or quality) remains unchanged: higher is always better. This is an argument of vertical differentiation.

By contrast, we are interested in horizontal differentiation where the not only the *absolute*, but also the *relative* attractiveness of an action to a firm depends on what its competitors are doing. This is illustrated in panel (D) of Figure 1: Assume a firm B wants to pick a product specification, taking into account the fact that a competitor A is offering a product as marked in the figure. Were A not in the market, B would pick specification a because it is favored by most consumers. However, A has already captured a portion of the consumers and the residual market available to B is no longer the full triangle but only the shaded area. That means a is no longer the most attractive point. B may prefer specification b or maybe even something to the right of it. The key is that the *relative* attractiveness of product specification a to b is changed by the competitor's action.

In a model of vertical differentiation it always makes sense for all firms to try and reach the highest point in the landscape, regardless of what its competitors are doing. In a model of horizontal differentiation that is not the case: the best position in the landscape depends on what competitors are doing. This is not merely a modeling artifact but a basic conceptual difference between competition through horizontal and vertical differentiation. In vertical differentiation the trade-off that firms face is whether the size of the advantage a move confers justifies its cost. In horizontal differentiation it is unclear that a move (in a certain direction) confers a benefit in the first place.

A similar point is made in Adner, Csaszar, and Zemsky (2010) who study the number of competitively viable positions in an industry depending on the degree of technological tradeoffs and consumer heterogeneity. They model competition as vertical differentiation in two product dimensions for which consumers have different preferences. However, they are interested in industry structure and therefore do not model competition explicitly. Instead, they opt for a value-based approach and abstract from competitive dynamics. Finally, Chang and Harrington (2003) describe a model of competition between multi-unit stores operating in several markets. However, since they are interested in decision structures of companies they have a very different focus than this paper.

Consequently, to the best of our knowledge our paper is the first to address the dynamics of competition through adaptation in horizontally differentiated markets.

2.5. Model Assumptions

All models contain simplifying assumption and ours is no exception. This section discusses the most important assumptions including the setup for prices and costs, entry and exit, and rationality and search behavior. Robustness tests for some of these and promising extensions to the model are discussed in Section 4.

We assume that prices do not enter the utility function and that firms compete exclusively by adapting their product, i.e. not by adapting their prices. Although simple forms of price competition would be easy to implement we are most interested in clearly identify how positioning drives competitive dynamics and therefore exclude prices. Robustness tests reported below suggest that including a simple price mechanism does not change our results. We also assume that costs are zero. For studying adaptation this is unproblematic: the performance measure in the model can be interpreted as a profit margin (revenue minus variable cost) and fixed costs do not influence firm actions when maximizing revenues. In models with entry and exit it may be interesting to consider costs as well as revenues.

We exogenously determine the number of competitors. An obvious alternative would be to allow entry and exit, and let the number of competitors emerge endogenously. Both approaches can be found in models of organizational learning and innovation (Baumann & Siggelkow, 2011; Chang & Harrington, 2006; Safarzyńska & van den Bergh, 2010): they represent different types of change in the population. Entry and exit causes population-level change through selection, i.e. more successful types of firms tend to survive and comprise an increasingly large proportion of the population. With adaptation, individual firms change over time, which also leads to a population-level change. Of the two complementary mechanisms (Levinthal, 1991) we choose to focus on adaptation to avoid confounding the effects of adaptation with selection.

Firms are myopically rational in that they only adapt changes that increase their performance, a standard assumption in NK modeling (Baumann & Siggelkow, 2011). This implies firms have insufficient information to derive the best-response strategies used in game-theoretical models. We find this plausible because solving the game with best-response strategies would require that firms completely map out the distribution of consumer preferences, an extremely difficult task especially in rugged landscapes (Rivkin, 2000). Moreover, even though firms can gradually learn, their feedback about consumer preferences is noisy because is distorted by the changes in their performance resulting from their competitors changing positions.

Firms are restricted to local search in that they may only change one randomly chosen product attribute at a time. Various search mechanisms have been explored in NK modeling, in particular local and global search and a dynamic mixture of the two (Levinthal, 1997), imitation (Rivkin, 2000), and recently more advanced mechanisms like analogies (Ethiraj & Levinthal, 2004; Gavetti, Levinthal, & Rivkin, 2005; Gavetti & Warglien, 2007). We chose the local search mechanism to preserve simplicity. Robustness tests with larger search horizons and possible extensions using more sophisticated search heuristics are discussed below.

Firms update their products simultaneously. This is equivalent to assuming they have information about their competitors' current product specifications but not their future moves. This 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. Using this assumption 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 a similar model suggest that sequential moves reduce the absolute level movement but do not lead to fundamentally different dynamics.

3. 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 in the Appendix 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 1000 times. 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.

The first set of results shows simulations on a smooth consumer preference landscape with one large consumer niche ($K = 0$) and varying degrees of competition over time. The second set of results compares the effects of competition for varying degrees of ruggedness by analyzing firm performance, positions, and movement in the final period ($t = 80$).

3.1. 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 from rivals stealing consumers hurts 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 in to *how* performance levels are influenced by competition. There we see that firm 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 dynamic that differentiates competition in horizontal differentiation from vertical differentiation and is illustrated in Figure 1: if a rival 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 variants offered in the market display greater heterogeneity: on average firms produce products that are similar to but not identical with the modal consumer preference.

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 is the competitive dynamic causing these results? Is it because firms are settling down to stable positions around the global peak and sharing profits equally? That would mean little change of the existing product specifications and stable market shares. Alternatively, the results might be due be a stable distribution where some firms are quickly conquering the best positions and forcing others to accept second-best positions, resulting in a stable ranking but skewed performance distribution. Alternatively, perhaps firms are constantly moving and the stable average performance reflects the average of a dynamic process.

Insert Figure 2 about here

The lower panels in Figure 2 shed light on this issue. Panel (C) shows the average number of moves (changes of product specification) 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 no more 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*. Instead, they continue to move around by adjusting their products. 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 consumers.

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 unlikely that the most successful firm today is the same one it was yesterday: defending a leading market share becomes increasingly difficult the more competitors there are in the market.

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

3.2. Competition on rugged landscapes

We have established that in 'smooth' markets competition leads to persistently volatile processes of adaptation. We now ask 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 in 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 hurts performance. This is the same result we saw in Figure 2. However, here we see that as the landscape becomes increasingly rugged, the detrimental effect of competition on performance decreases. If there are several niches it matters less if there are lots of rivals.

Panel (B) in Figure 3 provides additional texture to this result. We already know that in smooth landscapes more competition causes firms to locate further away from the nearest peak. In panel (B) we see that as the landscape becomes rugged, firms locate closer to a 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; in very rugged landscapes firms couldn't get very far from a peak if they tried. Note that firms which are alone in the landscape locate slightly further away from the nearest peak as K rises. This is due to the structure of the model and 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 in smooth and rugged landscapes alike, with firms jostling each other off the peaks. In that case the differences in results for high 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 in rugged landscapes because firms disperse and 'settle down' to stable situations where each serves a local niche.

Panel (C) suggests that the latter situation 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. In 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: In smooth landscapes we observe firms constantly jostling for competitive advantage around a few peaks. Competition hurts performance and even successful firms are constantly in danger having their consumers 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. It is interesting to note that this result does not happens suddenly when the number of peaks becomes greater than the number of firms (at approximately $K = 3$), but occurs gradually as ruggedness increases.

4. Discussion

Competition between firms has been studied across 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 degrees of competition and numbers of consumer niches.

Several conclusions can be drawn from our results. First, the dynamics of competition matter. We find that in markets with few large consumer niches competition causes volatile situations where firms jostle for profit by constantly adapting their products. In these 'smooth' markets firms constantly steal each other's market shares and even successful firms are unable to retain a lead for long. This strongly contrasts with equilibrium situations commonly used in previous (game-theoretical) models of competition with horizontal differentiation (Eiselt, 2011).

Second, market leaders are regularly dethroned in competitive markets with homogeneous preferences but are comparatively safe in markets with many niches. This finding complements previous work on dethronement that focuses on vertical differentiation (Ferrier, Smith, & Grimm, 1999). Empirically identifying the effects of horizontal and vertical differentiation remains a challenge for future research.

Third, the distribution of consumer preferences influences the dynamics of competition and its influence on firm performance. We find that as the number of consumer niches increases, firms disperse to serve individual peaks and settle down quickly to stable solutions. There, differentiation softens competition and successful firms are likely to remain market leader for some time. This speaks directly to the call by Adner and Zemsky (2006) for models of the influence of consumer heterogeneity on firm actions.

Finally, competition with different degrees of consumer heterogeneity may cause interesting effects in positioning. The results from the model suggest that in markets with homogeneous preferences we should observe a large number product specifications that are similar but not identical to what most consumers want. Furthermore, we should observe constant changes to products. In markets with heterogeneous preferences we should observe product specifications catering to the tastes of individual niches. There, we would expect comparatively static offerings with few adaptations in product specifications. These dynamics are an interesting new take on the 'minimum differentiation' principle that has caused much debate in industrial economics (d'Aspremont et al., 1979; Irmen & Thisse, 1998).

To summarize, considering dynamics in competition through horizontal positioning enables us to contribute new perspectives to several existing streams of research. We are hopeful that future agent-based models of competition will extend these findings and at the same time provide a link between the various literatures on competition in economics and management research.

4.1. Robustness

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

First, we tested whether including prices in the model changed our results for movement, positioning, and dethronement. To do so we implemented a simple price mechanism: in addition to offering a product with specification f_j each firm f charges a price p_f for its product. The utility customers with preference i obtain from buying from firm f is modeled as $u_{if} = \alpha - \tau\delta_{ij_f} - \mathrm{p_f} + \epsilon_i$, and P_{if_jJ} is adapted accordingly. Firm f's revenues become $\pi_{fJt} = p_f \times \sum_{i=1,\dots,2^N}(P_{ij_ft}\, m_i)$. In the initial period all prices are set to one. In each subsequent period, firms adapt not only their product specification but also pick a price change $\Delta_p \in [0,1]$ at random. They then check 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 does not substantially change the results reported here.

Second, we do not impose search costs for the firms in the model. That may influence our results because it means firms can change their product specification without cost, making movement more attractive. To check whether this was the case we ran the model with the additional rule that firms only change their product specification if they expected it would 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 qualitatively our results remain essentially unchanged.

Third, we only let firms engage in local search. To ensure that the jostling effect we observe in the case of smooth landscapes is not due to the fact that firms are unable to 'jump over' each other we ran the model allowing firms to change up to four out of the ten possible product attributes. This did not substantially change our results.

Finally, the analysis of the model we focused on the number of firms F and the ruggedness of the preference landscape K. The three other parameters τ, α, and $\underline{u}$ were not discussed in detail. To ensure our results are not due to the specific values chosen for them we ran the simulation for different values for the parameter which influence our results most strongly: the transport cost τ. Using values for τ between 1 and 5 had a large influence on the absolute level of performance because for large (small) τ

more (less) consumers exit the market. However, the performance levels did not change substantially in structure: within reasonable ranges for τ they were essentially shifted up or down. Furthermore, the results concerning distances, movement, and dethronement are unchanged. For extremely low τ values (e.g. $\tau = 0.1$) 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 τ values consumers have very weak preferences, meaning that small peaks and valleys in the preference landscape are de-facto flattened out. We consider this case of extremely weak preferences a special case that does not substantially affect the argument made here.

4.2. Directions for future research

The model was kept structurally as simple as possible. This allowed us to clearly identify the causal mechanisms by which product adaptation influences movement and profitability. It also makes interesting several extensions feasible.

In the current version of the model firms do not compete in prices. To loosen this strong assumption in a model similar to ours would require two things: First, the consumers' utility function would need to include prices. That implies determining a degree of price elasticity of taste (similar to our parameter τ). Second, firms would need a rule for finding new prices in addition to new product specifications. A simple mechanism to do this was described above. This would make the model correspond more closely to actual competitive situations and might also allow us to study interesting phenomena like the simultaneous occurrence of high-end niche and low-price broad strategies. Therefore, it warrants closer analysis.

Two other obvious extensions would be to allow firms to enter and exit the market, and to include both vertical and horizontal differentiation. The first would mean that selection would join adaptation as a cause of population-level change. It would be interesting to see how selection influences the dynamics of horizontal differentiation, by increasing or decreasing stability, and the final distribution of firms in the market. Including vertical and horizontal differentiation could be implemented by including some product features that are 'valued' by all consumers, similar to the approach taken in Marengo and Valente (2010). This would give us insight into even more nuanced strategies and at the same time bridge the gap to the extensive literature on innovation and evolutionary economics (Nelson & Winter, 2002).

Another interesting line of enquiry would be to study what happens when firms have access to more sophisticated search heuristics. In particular, imitation of successful competitors is often cited as an important mechanism in research on learning and competition (Lieberman & Asaba, 2006; Rivkin, 2000). Investigating imitation and other mechanisms in a competitive setting would complement the emerging literature on advanced search heuristics in agent-based models (Gavetti & Levinthal, 2000; Gavetti et al., 2005).

Further promising directions for studying dynamic competition based on the model presented here include allowing firms to have multiple products (related to Chang and Harrington (2003)), analyzing the alternative benefits of commitment vs. flexibility by introducing heterogeneous switching costs for firms, and revisiting first-mover advantages in a horizontally differentiated setup by creating a Stackelberg-like situation where firms move sequentially and some systematically move earlier.

5. Conclusion

Competition through vertical and horizontal differentiation is both empirically pervasive and of central theoretical importance for economics and management. Competition is also an inherently dynamic phenomenon and models of it need to incorporate dynamics. While a large body of work on technological innovation has studied dynamic processes in vertical differentiation (Nelson & Winter, 1982), prior literature is silent on the equally important phenomenon of dynamic competition through horizontal differentiation.

This paper 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.

We contribute to studies of competition through horizontal differentiation by providing a dynamic perspective of competition. In particular, our results call into question the standard assumption of 'stability in competition' in industrial organization (Eiselt & Marianov, 2011; Hotelling, 1929). Our study also adds a new perspective to dynamic models of vertical differentiation – usually framed as technological innovation – by showing how firms are faced with a very different trade-off and competitive situation in horizontally differentiated markets (Nelson & Winter, 2002). Finally, we answer calls for interactive models of industry dynamics in the NK literature (Baumann & Siggelkow, 2011), and for models the influence of consumer heterogeneity on firm actions in the management literature (Adner & Zemsky, 2006). The model is lends itself to extensions, some of which were discussed. We are convinced that agent-based simulation models are a powerful tool for studying competition and look forward to future research in this area.

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Appendix A: Figures

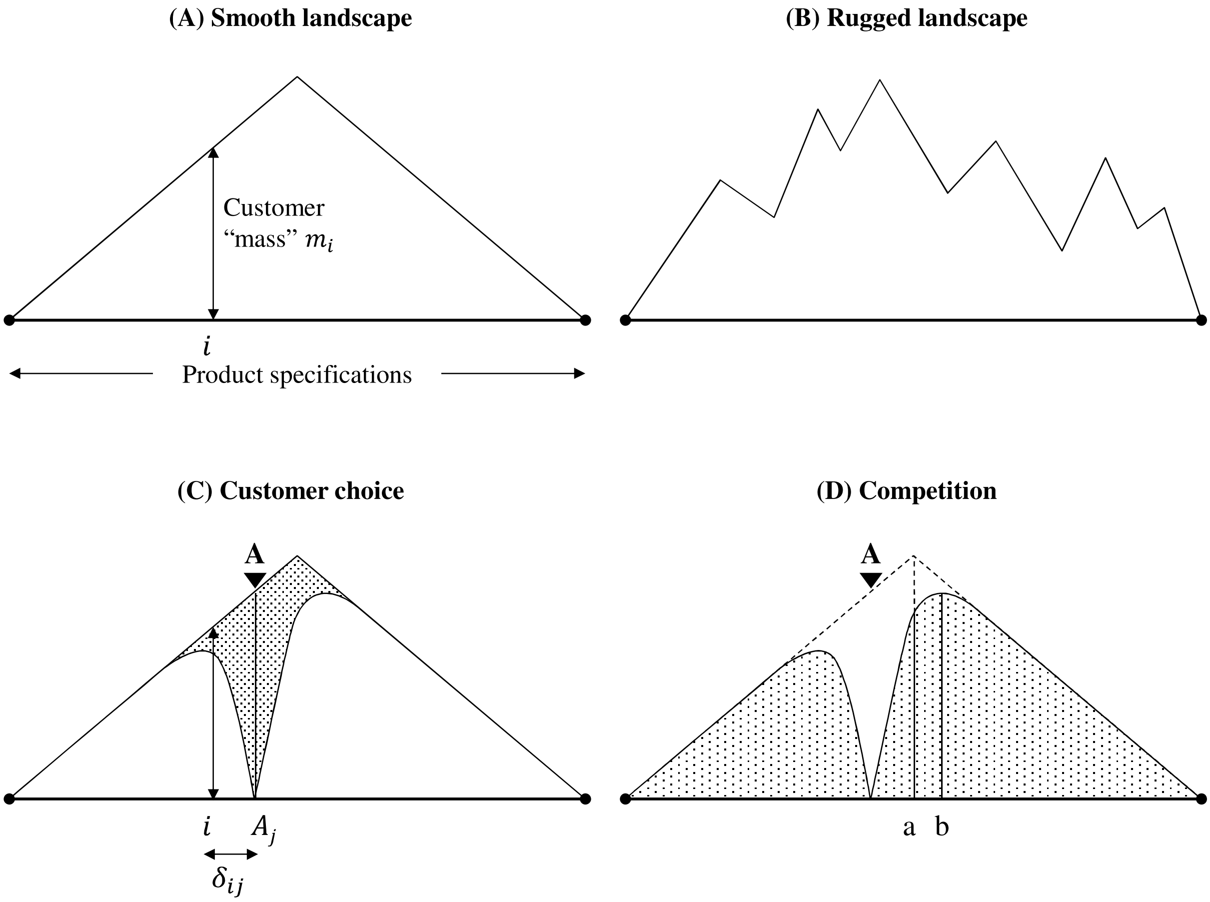

Figure 1: Illustration of landscapes

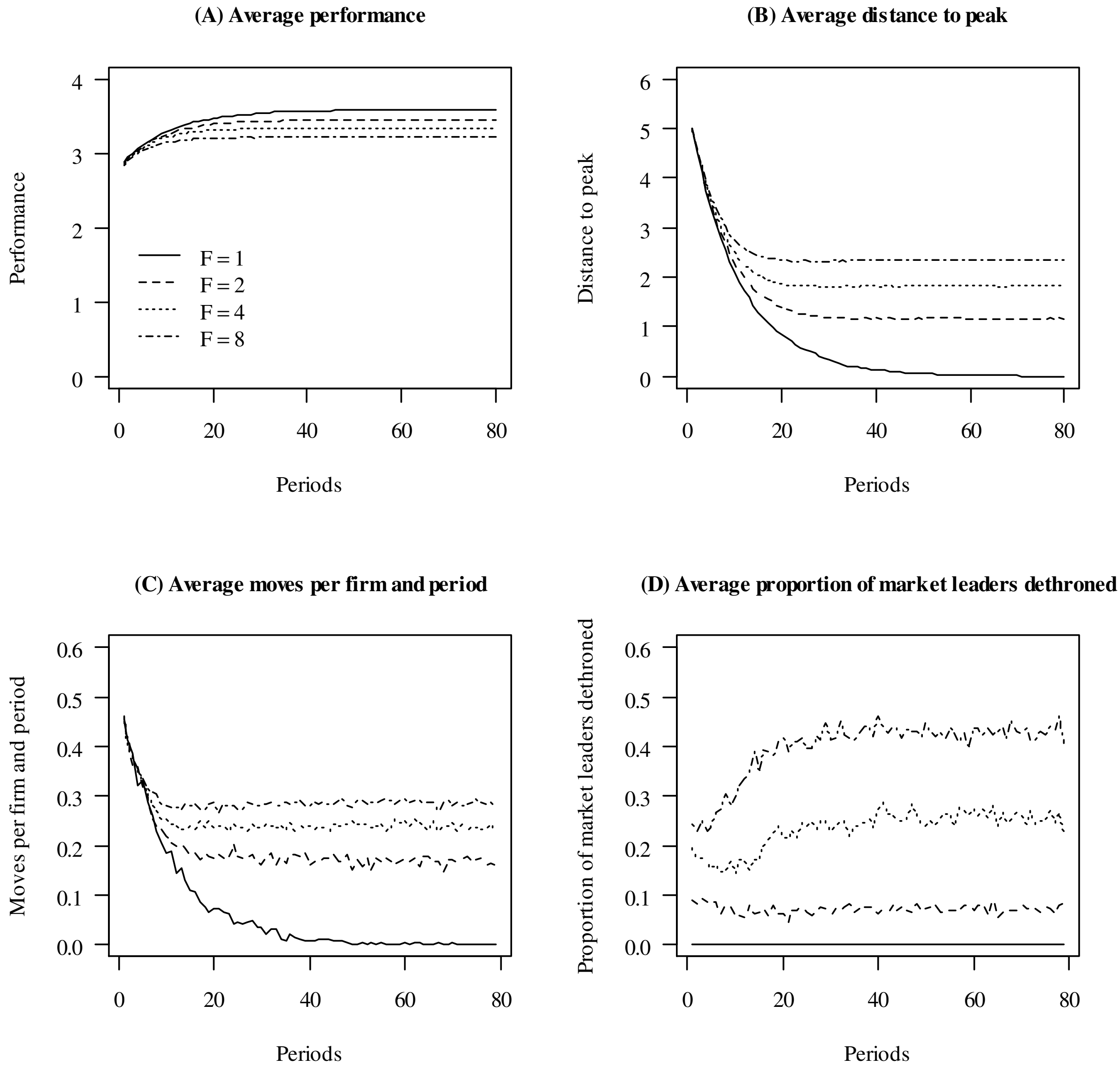

Figure 2: Competition on smooth landscapes ($K = 0$)

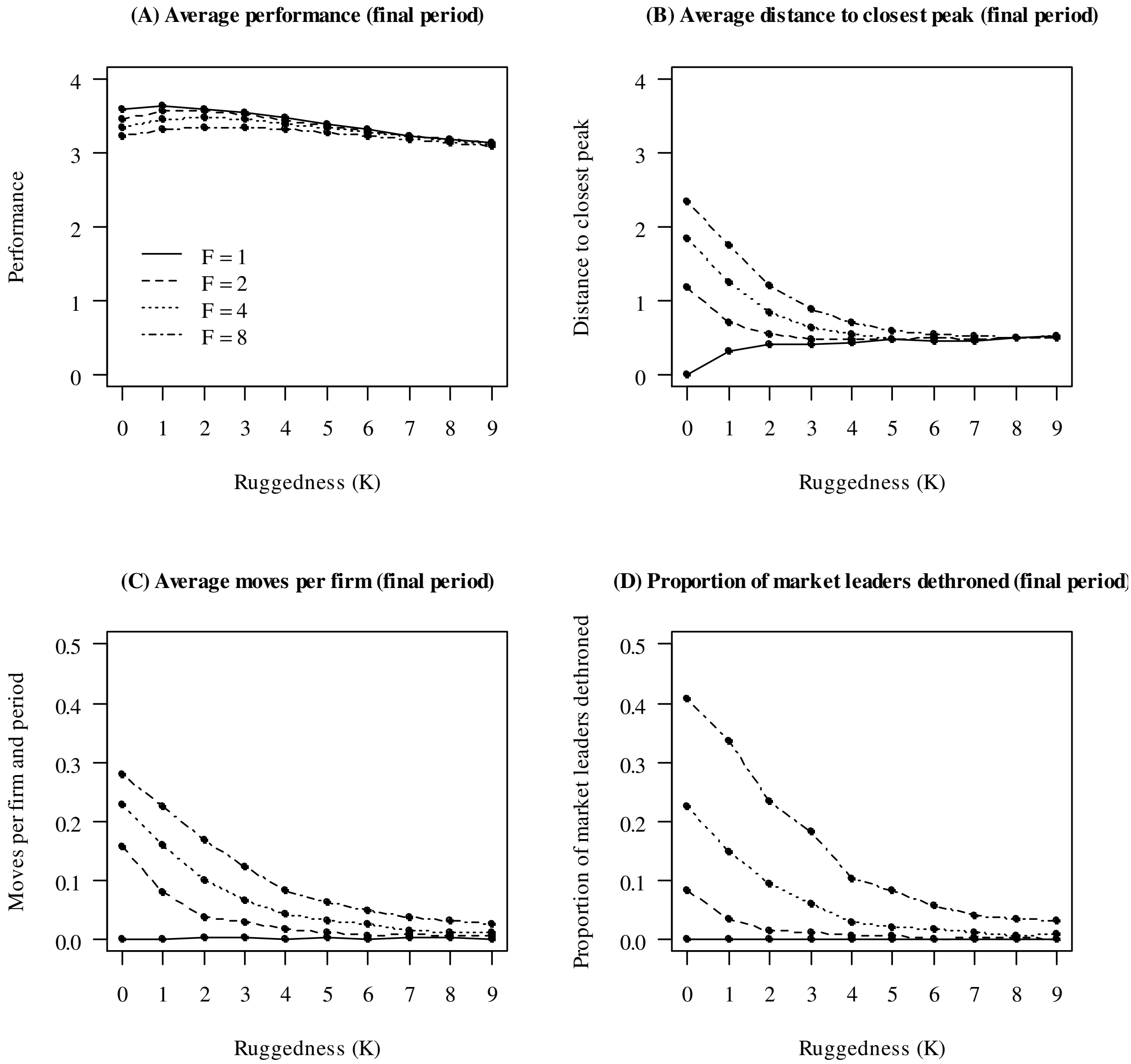

Figure 3: Competition on rugged landscapes ($t = 80$)

Appendix B: Additional Information

Table 1: Parameter values for simulation

Parameter	Values	Interpretation
N	10	# product attributes (size of landscape 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	Utility of outside good

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 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 landscapes by making the total consumer mass, i.e. the market size, comparable. We consider this 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 stay unchanged.

Distance to Nearest Peak in Rugged Landscapes

In Figure 3, panel (B) 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.