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by

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Diversification: A Road to Inefficiency in Product Innovations?

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Abstract

Motivated by recent empirical observations made in industries like the automobile industry, this paper employs an agent-based industry simulation model to examine the strategic relationship between product diversification strategies in an industry and some aspects of the product innovation strategy of a single producer. In particular, it is established that an increase in the average degree of product diversification in an industry increases the incentive for a producer to reduce the time to market for innovations at the expense of product quality. However, if all firms adapt their strategies according to these incentives, this results in a severe loss of average firm profits in the industry and also to a reduction in consumer surplus. It is then studied how the strength of this dilemma depends on several parameters describing the market structure and patent policy.

1 Introduction

An important part of a firm's (product) innovation strategy is the design of new products and in particular the determination of the quality level to be reached before market introduction. Recently this issue has attracted increased attention both by academics and practitioners triggered by a substantial number of costly failures of new product introductions by well established manufacturers attributed to obvious quality deficiencies. Such observations can be made in several industries, including computers, consumer electronics and the car manufacturing industry.

The number of 'official' recalls of cars in Germany[1] per year has rapidly increased from 58

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[1]This statistic only includes recalls where the federal motor-vehicle agency ('Kraftfahrzeug-Bundesamt') has been officially notified and involved.

recalls in 1997 to 144 recalls in 2003. Almost 50% of the recalled cars were less than 2 years old[2]. A recent study of the German car industry (Bullinger et al. (2003)) highlights and analyzes this drop in product quality[3]. Among other factors, they identify the shortening of the 'time-to-market' as one of the main reasons for the quality problems. The tradeoff between early market entry and the performance of a product has been previously highlighted (see e.g. Kalish and Lilien (1986) or Cohen et al. (1996)). While it has been argued that speeding to the market is essential for success in the dynamic, globalized and hence more competitive structure in most modern industries (e.g. Bower and Hout (1988), Stalk (1988)), critics claim that the induced reduction of quality leads to social losses (c.f. FAZ.net(2003)).

Moreover, the car manufacturing industry with significant entry barriers is generally seen as a typical example of a stable oligopoly. Hence added competitive pressure due to an increase in potential entrants should not be seen as a major factor. The rationale for speeding to the market strategies given above is therefore not obvious. This is particularly true in the light of results of Bayus (1997) who has shown in a one-product setting with a fixed number of (two) competitors that speeding to the market with a low quality product is never optimal. So the question arises, which factors can explain speeding to the market phenomena in industries with a stable number of firms.

A possible candidate might be the degree of diversification of the producers. A significant recent trend in the car manufacturing industry has been the increasing degree of diversification. An empirical analysis of the number of models offered on average by the different car producers on the German car market[4] shows an increase of 14% since 1997 and of even 22% since 1995[5]. Similar observations for the Italian car market have recently been made by Barbiroli and Focacci (2003a) and for various consumer durables in Barbiroli and Focacci (2003b). The simultaneous increase in the diversity of available car models and decrease in development times has explicitly been stressed in Sumantran (2004), who points out that "*..., automakers are seeking more and more that elusive combination of attributes that will create the next success story. ... The prospective buyer today faces an array of products whose diversity has seldom been matched in the century that automobiles have been in existence.*"[p362]. Concerning development times, Sumantran (2004) states that: "*At the start of the 1990s, many automakers required anywhere from 30 to 45 months to execute a full development cycle, depending on the complexity of the product. Today, it is not uncommon for the*

[2]These numbers are given in the annual report 2003/2004 of the German Kraftfahrzeug-Bundesamt: http://www.kba.de/Stabsstelle/Presseservice/Jahrespressebericht/Jahrespressebericht_2003_20041.pdf

[3]Quality should here be seen as relative to the currently available level of technology. Bullinger et al. do not argue that cars in the 1980s had superior performance and safety features compared to today, but rather that reliability and maturity of new models at the time of market introduction does not match customer expectations in a way it did before.

[4]This analysis was carried out by the authors based on a widely used listing of prices for used cars with a given year of production provided by Schwacke GmbH.

[5]This phenomenon is also highlighted in the study of Bullinger et al. (2003). Furthermore, these authors point out that leading industry executives expect a prolongation of this trend.

cycle to be completed in less than 18 to 24 months."[p362f].

The increase in the average number of models offered by car producers is to a large extent due to the repeated addition of new automobile-variants to the existing range. The German 'Kraftfahrt-Bundesamt' currently lists 10 different segments for automobiles, like 'Mini', 'Compact', 'Lower Middle Class', 'Middle Class', 'Roadster', where most of these segments consist of several quite distinct sub-markets (e.g. sedans, convertibles and station-wagons). Sub-markets are established as one producer goes on the market with a new model with distinctive features from the existing product range and competitors imitate these features once they realize that there is a strong market for such a product. A recent example is the establishment of the market niche of mini-convertibles. In 2001 Peugeot was the first company to offer a convertible variant of a car below the compact size. Due to the large success of the Peugeot 206cc, similar types of cars have since been introduced in 2002 by Ford, in 2003 by Smart and Daihatsu and in 2004 by Mini and Opel. A new sub-market has emerged. Obviously there is some relationship between the number of existing sub-markets and the average number of models a producer offers, however it should be pointed out that there is by no means a one-to-one relationship in a sense that every producer serves each sub-market. Whether a certain producer should enter a sub-market, like the market for convertible minis, is an important strategic decision to be made.

Motivated by these empirical observations we examine in this paper whether the trend for diversification can indeed provide a rational explanation for the decrease in quality levels also in the framework of an oligopoly with a stable number of firms. By doing so we abstract from technical and organizational reasons for declining quality caused by problems to manage an extension of the product range and to coordinate the more complex production process, but rather focus on the strategic effects determining the incentives for companies to select the *planned* quality level of a new product. We study the non-cooperative interaction between competing innovative firms, where the quality of an innovative product is part of the innovation strategy, to examine the following two main questions. First, should a firm react to an increase in the average size of the product range of producers by reducing the time-to-market and thereby the quality of its product innovations? Second, is this increase in diversification coupled with a decrease in quality desirable from a total industry profit or from a welfare point of view? Or, more generally, does non-cooperative competition between innovating firms lead to socially desirable quality levels?

Our research strategy is to employ a dynamic agent based computational model in order to address the questions posed above. Our market environment is that of an oligopoly where different variants of the same basic good are traded. New variants are introduced and old variants loose their market appeal from time to time. The model incorporates diversified producers, endogenous product life cycles driven by innovative activities and profit-based firm growth and decline.

A firms strategy in our framework involves besides innovation decisions also market exit and entry decisions, output decisions and fund allocation decisions. Given this complex strategy space and the dynamic market environment an analytical treatment of firm behavior is not feasible. Hence we resort to using computer simulations.

From a methodological point of view our approach follows the large stream of literature in the fields of evolutionary economics, organization theory and agent-based computational economics, which was motivated by the work of Cyert and March (1963), Nelson and Winter (1982) and Simon (1978, 1983) and studies adaptive, rule based behavior of economic entities like firms. Deviating from the paradigm of neoclassical economics that behavior is always determined by maximizing behavior, it is argued in this literature that in many complex decision problems a firm faces, the task of determining the optimal action is either too demanding or too costly for a firm. In reality the actions of firms are rather determined by heuristic rules which are comparably easy to follow and have proved successful in the past. Studies in this tradition employ computer simulations which allow them to deal in a more realistic way with the complexity of interactions present in real world markets. In our case we are able to integrate closely related production and innovation decisions in a dynamic heterogeneous market framework. A wide range of issues like market development, price dynamics, information spreading and firm organization has been analyzed in the past using models of this type (see e.g. Chang and Harrington (2000, 2003), Dawid et al. (2001), Natter at el. (2001) or the special issues edited by Tesfatsion(2001a,b,c)). Agent-based models have also been employed to study a considerable range of issues concerning innovation and technological change both from an industry and a firm perspective (see Dawid (2005) for an extensive literature review).

To our best knowledge the questions posed above have not been analyzed in an industry-simulation model so far. There is also little theoretical work[6] considering the optimal timing for the introduction of innovations with emphasis on the tradeoff between speed and quality. Dutta et al. (1995) study a simple duopoly model, where quality increases at a constant rate over time until the innovation is adopted. In a one shot game, where each firm has to make a decision when to adopt the innovation they find that there exists a race equilibrium as well as one with an early entrant with low product quality but temporary monopoly rents, plus a quality leader which enters later. Bayus et al. (1997), Bayus (1997) and Souza et al. (2004) examine 'optimal' strategies for new product introduction, incorporating timing and the quality as decision variables. In Bayus et al. (1997) a simple game theoretic model of a duopoly is analyzed, where market demand is assumed to be constant (i.e. there is no product life cycle). They restrict their attention to time-invariant strategies and show that even under the assumption of symmetric firms, asymmetric equilibria are possible both with respect to timing and quality. Under asymmetric R& D cost functions the efficient firm will be the leader, while it may provide a high or low quality product depending on the market sensitivity to quality. Bayus (1997) continues this stream of research and relates several

[6] R & D timing issues are considered in the extensive work on patent races (see e.g. Reinganum (1989)) but the focus there lies on the timing of R & D investments guided by the goal to be the first to obtain a certain given patent. Quality issues are not considered. Somehow related is also some of the literature on vertical differentiation. Without considering time-based competition it has been shown there that a first mover should supply a product of higher quality than late movers (e.g. Shaked and Sutton (1982, 1983), Donnenfeld and Weber (1995)).

firm and market characteristics to the 'optimal' new product strategy of a firm using a simple analytical framework. In particular he analyzes two scenarios. The first one is characterized by a new product introduction of a competitor which has to be matched, while the second one is a race situation, where a new product introduction by the competitor is anticipated. As mentioned above, the main result is that speeding to the market with a low quality product is never optimal in a race situation but only in the first scenario when market opportunities are only temporary, the competitor has a low quality product and R& D is expensive. In Souza et al. (2004) a further step is taken by including industry clockspeed, in terms of the speed at which industry prices decline, into the model of optimal introduction timing and product quality decisions. Using a Markov decision process approach, it is found that the optimal pace of new product introductions is mainly determined by industry clockspeed, while new product quality is primarily governed by internal factors, such as the firms cost structure.

Whereas these studies provide some interesting insights into the characteristics of an optimal innovation strategy incorporating quality and timing decisions, they do not consider efficiency issues and the impact of the market structure. Also, these models are static and highly stylized in order to allow analytical tractability.

Finally, in Krishna and Ulrich (2001) the literature on decision making in product development is reviewed. They comprehensively categorize the existing literature and find that while certain decisions are studied extensively within the different subject areas like marketing, operations management or organizations there exists ample need for research on more integrated models.

The remainder of this paper is organized as follows. We describe the model in detail in section 2. Section 3 discusses some issues concerning the simulation setup used. In section 4 we consider the evolution of the industry if diversification and innovation strategies of the firms follow a simple adaptation dynamic. This leads to a detailed analysis of individual incentives and strategic complementarities between the diversification and innovation strategy parameters in section 5. In section 6 the impact of a few key parameters determining the industry structure on individual incentives to speed to the market are examined and we close with a brief discussion of our main findings in section 7. In Appendix A we provide a table of notation as well as information about the ranges of the parameters in our agent based simulation model. Appendix B gives details about the statistical tests we performed to support our findings and conclusions.

2 The Model

In order to be able to deal with the questions discussed above we use a rather extensive industry-simulation model. The framework we use incorporates interlinked dynamic life-cycles of the sub-markets in the industry which is an important feature to understand the interplay of product innovation, imitation and industry growth. The production side of the industry is represented by an agent-based model allowing for heterogeneities of cost-structures and production strategies among the industry firms. On the other hand, the demand side is represented by a social indifference structure which is not explicitly derived from aggregation of individual demands of (heterogenous) consumers. This stylized representation on the demand side has been chosen to reduce the already large complexity of the employed simulation model. The focus of our analysis is on the innovation strategies of the producers in the industry rather than on the behavior of individual consumers. Although the model has been developed aiming at research questions like the one addressed here, it is a useful tool to study a larger range of topics concerning the interplay of product, process innovations and diversification in an industry (see Dawid and Reimann (2005)).

The basic structure of the model including the sequence of events within each period t is shown in Figure 1. The numbers in brackets indicate which subsection(s) describe(s) the details of the corresponding event. First, firms evaluate all existing sub-markets. Based on this evaluation firms decide which markets to serve in the current period. This selection involves three steps. First, a firm decides whether to launch and enter a new sub-market by introducing a product innovation, second the firm might exit unsatisfactory sub-markets it served in the previous period and, third, the firm considers whether to enter an existing sub-market which it did not serve in the previous period. For the selected sub-markets firms then make their output decisions. Given all the firms' output decisions markets are cleared and firm profits are realized. Finally, these profits are used by the firms to make their investments for product and process innovation.

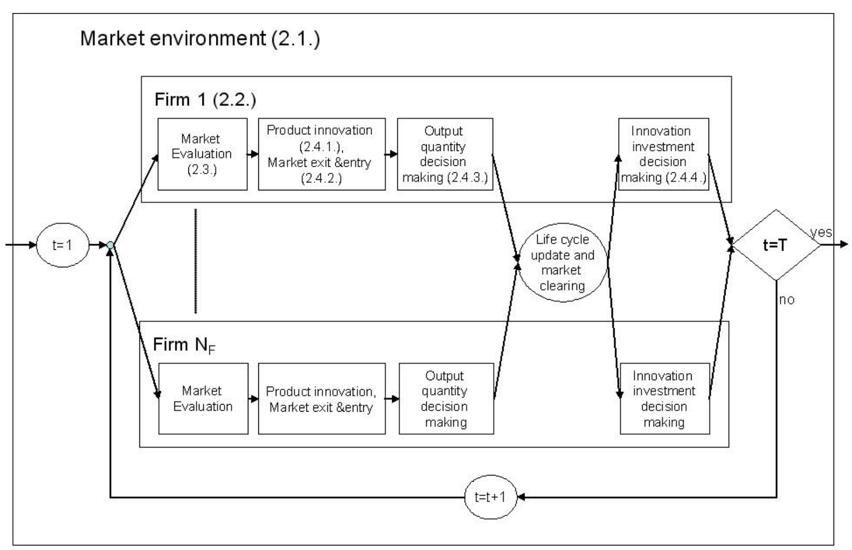

Figure 1: Sequence of events in the model

The main characteristics of the model are described in detail below. In section 2.1 the market environment is explained. The cost structure of the firms is presented in section 2.2. Market evaluation is described in section 2.3. Finally, the decision making of the firm concerning market selection, output and investment is explained in detail in section 2.4.

2.1 Market Environment

We consider an industry consisting of N_F producers. At any point in time $t = 1, \ldots, T$ there exist m_t sub-markets within this industry, where each sub-market represents a variant of the product considered. The model is initialized with m_0 sub-markets of identical given potential P_{ini}. Each firm is initially active in one randomly chosen market.

Each sub-market is characterized by a demand structure depending on the markets' attractiveness, a life-cycle over which its attractiveness changes and a market potential which determines its peak attractiveness. These three characteristics are described in more detail now.

2.1.1 Sub-market demand

The demand structure is represented by a slight variation of love-for-variety preferences considered in Spence (1976) and Dixit and Stiglitz (1977) in the framework of monopolistic competition. There is a constant elasticity of substitution utility function

$$u_t(X_{1,t}, \ldots, X_{m_t,t}) = \left(\sum_{j=1}^{m_t} (a_{j,t} X_{j,t})^b \right)^{\frac{1}{b}}, \tag{1}$$

which as in Dixit and Stiglitz' model can be interpreted as a multiple of a representative consumer's utility or the representation of social indifference curves[7]. *Product diversity can then be interpreted either as different consumers using different varieties or as diversification on the part of each consumer.* [Dixit and Stiglitz (1977), p298]. The parameters $a_{j,t}$, which are absent in the standard love-for-variety preferences, denote the current attractiveness of product variant j and $X_{j,t}$ consumption of product variant j. The degree of complementarity between the different product variants is expressed by $b \in [0, 1]$, where values close to zero correspond to complementary goods whereas the variants are perfect substitutes for $b = 1$. The utility function is maximized subject to the budget constraint

$$\sum_{j=1}^{m_t} p_{j,t} X_{j,t} \leq B(t), \tag{2}$$

where $p_{j,t}$ is the price of variant j in period t and $B(t)$ denotes the overall amount of money allocated by consumers to purchases of goods produced in this industry. We will assume that it increases when the number and overall attractiveness of product variants increases, however at a decreasing rate:

[7] See Sattinger (1984), for a detailed analysis of aggregation conditions for heterogeneous consumers in this framework.

$$B(t) = msize \frac{\sum_{j=1}^{m_t} a_{j,t}}{A + \sum_{j=1}^{m_t} a_{j,t}}. \tag{3}$$

Here $msize$ gives the maximal amount of money that could be allocated to purchases in this industry and A governs how fast the allocated funds grow with increasing overall attractiveness of the sub-markets. By making this assumption we intend to capture that the goods produced in this industry do not only compete among themselves but also compete for consumer budget allocation with outside products. A concave relationship between attractiveness of markets and total consumer expenditures can for example be derived by incorporating utility of money with an exogenously given attractiveness in the consumer's utility function.

Maximization of (1) subject to (2) yields the following inverse demand curve for a market j:

$$p_{j,t} = B(t) \frac{a_{j,t}^b}{X_{j,t}^{1-b} \sum_{k=1}^{m_t} (a_{k,t} X_{k,t})^b}. \tag{4}$$

Consumer expenses in each sub-market in each period depend on the current relative attractiveness (compared to the other sub-markets) and the prices in this sub-market. They are bounded above by $B(t)$.

All producers in this industry set production quantities for all the sub-markets they are in, and prices are then determined such that markets clear. Accordingly, every period prices are given by (4), where $X_{j,t}$ denotes the aggregate production quantity of variant j of all producers at time t.

2.1.2 Sub-market potential

At any point in time one of the producers might introduce a new product variant and thereby open a new sub-market. At the time $t_{ini}(j)$, when sub-market j is founded, a market potential $P_j \in [0, 1]$ for this variant is determined. This market potential depends on the amount of effort invested in the product development (see **below**) and gives an indication of the maximal level of attractiveness this variant might attain. It is important for us to capture the trade-off between short development times and expected product attractiveness. Therefore, the expected potential of a new market is assumed to increase with the amount of product R & D previously invested and the time spent in the development of the new variant. To model this we use a product R & D stock variable $RD_{i,t}$ which is gradually increased over time by product R & D investments of the firm. Analogous to the market potential the range of $RD_{i,t}$ is restricted to $[0, 1]$.

Our formulation of the accumulation process of the R & D stock incorporates the stylized fact that the build-up of a knowledge stock for innovations requires a time consuming, cumulative learning process (see e.g. Malerba (1992)). Hence, large investments in one period are only an incomplete substitute for past R & D investments and experience. Also, it is assumed that returns to investments measured by increases in $RD_{i,t}$ decrease as the company approaches the frontier of

$RD_{i,t} = 1$. Formally, we set $RD_{i,t} = 0$ at $t = 0$ and whenever the firm starts a new project after a product innovation. After that we update the stock as follows:

$$RD_{i,t+1} = 1 - (1 - RD_{i,t}) \frac{1 + \beta_i^{RD} \alpha_i^{RD} I_{i,t}^{prod}}{1 + \alpha_i^{RD} I_{i,t}^{prod}}. \tag{5}$$

Here $I_{i,t}^{prod}$ denotes the investment in product R & D by firm i in period t, whereas $\alpha_i^{RD}, \beta_i^{RD}$ are firm-specific parameters. The parameters $(\alpha_i^{RD}, \beta_i^{RD})$ describe the ability of the firm to develop new products and the efficiency of the use of R & D funds. In particular, firm i can each period reduce the gap to the current frontier ($RD = 1$) at most by the factor β_i^{RD}. It could be argued that this parameter is closely related to the knowledge base built by the company in the past and hence should depend on aggregated previous product R & D investments, but for reasons of simplicity it is taken as exogenous here.

The potential P_j of a new sub-market j founded by firm i in period t is uniformly randomly selected from the interval $[(1-\chi)RD_{i,t}, \min(1, (1+\chi)RD_{i,t})]$, i.e. the expected value of P_j is $RD_{i,t}$. The parameter $\chi \in [0, 1]$ measures the uncertainty associated with the success of a new product innovation. Our formulation implies that additional R & D efforts during the development of the new product will *on average* increase the potential of the new product variant, but it might be that a firm who introduces a new variant with only little R & D investment becomes lucky and the new variant nevertheless has a high potential to attract consumers.

To guarantee a certain degree of appropriability of returns for the founder of a sub-market, we assume that no competing firm can enter this sub-market for $d_p \geq 0$ periods. The duration d_p will be referred to as patent length, however it should be noted that there are various factors other than patent protection which might guarantee delays in market-entry of imitators, like information protection measures, lead times or costs of duplication (see e.g. Dosi (1988)). Which of these factors is actually most important for appropriability differs between industries. For reasons of simplicity we will refer to patents as the means of guaranteeing appropriability. With $d_p = 0$ the innovator has a guaranteed monopoly position only in the founding period.

2.1.3 Sub-market life cycle

The actual attractiveness of any given product variant evolves according to the following stochastic dynamics:

$$\begin{aligned} a_{j,t_{ini}(j)} &= 0 \\ a_{j,t+1} &= a_{j,t} + (1 + \varepsilon_{j,t}) P_j h'(t + 1 - t_{ini}(j)) \qquad t > t_{ini}(j), \end{aligned} \tag{6}$$

where ε is a noise term and $h(t)$ is a function describing a typical normalized life-cycle. This formulation implies that the actual trajectory of $a_{j,t}$ follows a randomly perturbed path around

$h(t - t_{ini}(j))$. To capture main life-cycle properties (see Bass (1969)) h is a uni-modal convex-concave-convex function. It has a peak at $L/2$ where the value of h at the peak is 1, which implies that the expected attractiveness of the product variant at age $L/2$ is given by the potential P_j of the sub-market. Furthermore, $h(0) = h(L) = 0$. A sub-market dies if at a period t there is either no demand ($a_{j,t} \leq 0$) or no supply ($X_{j,t} = 0$). Dead markets cannot be revitalized. In slight abuse of notation we will refer to L as the expected length of the life cycle.

The stochastic formulation chosen on the one hand allows for a certain predictability of market growth in dependence of market age, but, on the other hand, also captures path dependencies in a sense that the actual size of a sub-market not only depends on the technical quality of the product but also on an aggregation of stochastic shocks during the market evolution. It follows from (4) that, given $B(t)$, the size of the demand for a product variant depends only on the relative attractiveness compared to that of the other variants currently offered. Absolute levels of attractiveness however have some impact because the overall market size $B(t)$ increases with the sum of all attractiveness parameters.

2.2 The Cost Structure of Producers

A firm's total production costs consist of both fixed costs $F_{i,t}$ and quadratic variable costs $c_{i,j,t}x_{i,j,t}^2$ for each sub-market served, where $x_{i,j,t}$ is the output quantity of firm i on sub-market j. The fixed costs

$$F_{i,t} = |M_{i,t}|^{\mu_i} \Phi_i \qquad \mu_i \in [0,1] \tag{7}$$

depend on the number of sub-markets, where the parameter μ_i indicates how fast fixed costs go up with the number of variants produced. This can be seen as a measure of centralization of the firm where centralized firms have high values of Φ_i but small μ_i whereas for companies, where the different sub-markets are managed in a decentralized way, this relationship is reversed.

Variable production costs can be decreased over time through process improvements. The variable cost parameter $c_{i,j,t}$ is a result of such process improvements. At the time where firm i starts producing variant j we have $c_{i,j,t} = c_{i,j}^{ini}$ but afterwards i can invest in every period t where $j \in M_{i,t}$ in cost-reducing process improvements in the production of j. We assume that $c_{i,j,t}$ cannot be reduced below $c_{i,j}^{min} = c_{min} c_{i,j}^{ini}, c_{min} \in (0,1)$ where $(1 - c_{min})$ is the maximal fraction by which this cost parameter can be reduced through process improvements. Similar to the build-up of the product R & D stock the cost reduction is realized in small steps over time, where the maximal reduction per period is given by $(c_{i,j,t} - c_{i,j}^{min})(1 - \beta_i^c)$. Cost parameter reductions generated by process improvements decrease over time as the cost parameter approaches the minimal level $c_{i,j}^{min}$. This formulation stresses the fact that early entrants in a market initially tend to have advantages in know-how and production costs which cannot be easily equalized by late-comers even with large monetary investments. These first-mover cost advantages disappear as the sub-market matures.

Formally, we have

$$c_{i,j,t} = c_{i,j}^{ini}\tilde{c}_{i,j,t} + c_{i,j}^{min}(1 - \tilde{c}_{i,j,t}), \tag{8}$$

where

$$\begin{aligned} \tilde{c}_{i,j,t_{ini}(j)} &= 1 \\ \tilde{c}_{i,j,t+1} &= \tilde{c}_{i,j,t}\frac{1+\beta_i^c\alpha_i^c I_{i,j,t}^{proc}}{1+\alpha_i^c I_{i,j,t}^{proc}} \qquad t > t_{ini}(j). \end{aligned} \tag{9}$$

Here $I_{i,j,t}^{proc}$ is the investment of firm i in process improvement for variant j at time t and α_i the efficiency of such an investment. The parameters (α_i^c, β_i^c) characterize the technological expertise and the quality of process innovation management of firm i.

Given this cost structure, profits of firm i in period t are given by

$$\pi_{i,t} = \sum_{j \in M_{i,t}} (x_{i,j,t}p_{j,t} - x_{i,j,t}^2 c_{i,j,t}) - F_{i,t}. \tag{10}$$

To keep the model as simple as possible we ignore all investments other than that for product and process innovation and also any distribution of dividends. Profits remaining after investment are added to the savings of the firm

$$S_{i,t+1} = S_{i,t} + \pi_{i,t} - \sum_{j \in M_{i,t}} I_{i,j,t}^{proc} - I_{i,t}^{prod}. \tag{11}$$

Each firm is endowed with initial money stock S_0. Firms need these savings to be able to pay for production in the following period (there is no external financing in this model).

2.3 Market Evaluation

The evaluation of the different available sub-markets is the basis for the innovation, the diversification and the investment allocation decisions of the firm. Our approach concerning market evaluation is motivated by actual managerial approaches. Within the framework of the well known 'Industry Attractiveness-Business Strength Matrix' approach (see e.g. Wind and Mahajan (1981) or Kotler (1997)) key factors for market evaluation have been identified. Hax and Majluf (1983) name as the main factors to asses industry attractiveness '*total market, market growth rate, and industry profitability*' [p.59]. Based on this, we assume that firms evaluate markets based on market potential, market growth rate and current profitability. It is assumed that at the end of a period all firms can observe the attractiveness $a_{j,t}$ of all variants j in the current period t, the number of producers and the average quantities and profits in each sub-market. Furthermore, firms know the founding period of each sub-market and the shape of the expected life-cycle curve $h(\cdot)$. Using this information firms calculate an unbiased estimate of the market potential of each market, $\hat{P}_j^t$, and anticipated future values of the attractiveness parameters $\hat{a}_{t+l,j}^t$, where the superscript t indicates that the estimate is made in period t[8]. Since all firms have identical information about the attractiveness of the markets, these estimates are homogeneous. Based on the estimated evolution of the attractiveness each firm calculates an estimated average market growth rate

$$\xi_{i,j,t} = \frac{1}{\tau_i} \sum_{l=1}^{\tau_i} \frac{\hat{a}^t_{j,t+l}}{a_{j,t}}, \tag{12}$$

where τ_i is the planning horizon of firm i. The evaluation function of a sub-market j then reads

$$v_{i,j,t} = \hat{\pi}^{3\delta_{i,\pi}}_{i,j,t-1} \xi^{3\delta_{i,\xi}}_{i,j,t} \left(\frac{\hat{P}^t_j}{\hat{P}^t_{av}} \right)^{3\delta_{i,P}}. \tag{13}$$

The exponents satisfy $\delta_{i,\pi} + \delta_{i,\xi} + \delta_{i,P} = 1$. They are important parameters of the firm's diversification strategy since they represent the weights assigned to profits, growth rates and potential of a market, respectively. The profit term $\hat{\pi}_{i,j,t-1}$ is given by a firm's previous period profit if it was active in this market and by the observed average profit made on sub-market j if the firm did not produce the variant in the previous period. The expression $\hat{P}^t_{av}$ denotes the average of the estimated potential of all existing markets, which means that the third term gives a ratio of actual to average market potential and is unit free. If the firm puts equal weight on all three factors ($\delta_{i,\pi} = \delta_{i,\xi} = \delta_{i,P} = 1/3$), and it is assumed that profits grow at the same rate as the product attractiveness, then $v_{i,j,t}$ gives the expected average payoff (excluding fixed costs) over the time-horizon τ_i for firm i on an average-potential sub-market j. The role of the three weighting parameters and the relationship of this formulation to the Industry Attractiveness-Business Strength matrix is discussed in more detail in Dawid and Reimann (2005).

2.4 Decision making of the firms

2.4.1 Product Innovation

Every period firms decide whether they consider their ongoing product innovation efforts sufficiently advanced in order to take the new product to the market. They base this decision on a comparison of the expected attractiveness of the new product (which is determined by the R&D stock accumulated at that point) with the anticipated development of the attractiveness of the existing products. To this end, firms calculate the anticipated average attractiveness of existing sub-markets at the end of their planning horizon $t + \tau_i$. This expression is given by

$$\hat{a}_{i,av} = \frac{1}{m_t} \sum_{j \in m_t} \hat{a}^t_{j,t+\tau_i} \tag{14}$$

[8] The estimate $\hat{P}^t_j$ is the mean of the expressions $\frac{a_{j,s} - a_{j,s-1}}{h'(s - t_{ini}(j))}$ for $s = 1, \ldots, t$. It follows directly from (6) that this estimator is unbiased. The estimators $\hat{a}^t_{t+1,j}$ follow directly from (6) by inserting $\hat{P}_j$ for P_j and setting $\epsilon_{j,t} = 0$.

The expected market potential of a product the firm could introduce in period t is given by $RD_{i,t}$ and the firm chooses to introduce a new product whenever

$$RD_{i,t} > \kappa_{i,innov} \hat{a}_{i,av} \tag{15}$$

The strategy parameter $\kappa_{i,innov}$ is therefore the crucial factor determining the quality level of a firm's product innovations. It is one of the two strategy parameters our analysis will focus on. A high value of $\kappa_{i,innov}$ corresponds to higher aspirations with respect to product quality but a smaller number of product innovations whereas a low $\kappa_{i,innov}$ implies a speeding to the market strategy.

We have also tried to introduce a rule where, besides this relative quality measure, an absolute quality threshold level is used, but it turned out that positive absolute quality requirements always had detrimental effects on firm profits. Hence we do not consider this option here any further.

2.4.2 Market Exit and Entry

The decision of the firm, whether to exit a currently served market or to enter an *existing* market[9] currently not in the firms product range, rely on the comparison of the evaluations of markets among each other and on the comparison with the marginal change of fixed costs induced by a change of the number of variants produced. We denote by $M_{i,t}$ the set of product variants offered by firm i in period t. In the exit step the firm considers all sub-markets in $M_{i,t-1}$ whose current profits do not cover the corresponding fraction of fixed costs and stops producing a variant if

$$v_{i,j,t} < \kappa_{i,ex} \Delta^{ex}_{i,t}, \tag{16}$$

where $\Delta^{ex}_{i,t}$ denotes the savings in fixed costs if the number of variants in the product range is reduced by one. This means that markets are only dropped if there is little hope that the market will be able to cover fixed costs in the future. The parameter $\kappa_{i,ex} \geq 0$ determines the inertia of the firm's market exit strategy, where the degree of inertia decreases with increasing $\kappa_{i,ex}$. In the extreme case of $\kappa_{i,ex} = 0$ a market is only dropped if anticipated prices cannot even cover variable costs. Large values of $\kappa_{i,ex}$ on the other hand correspond to a selective strategy where markets are only kept if large future profits are expected. It is further assumed that firms grant each market an 'examination-period' and do not leave markets they have just entered in the previous period.

After the firm has eliminated all dissatisfactory variants from its product portfolio, it considers entering a new market. Because of the organizational and managerial challenges of market entry, at most one new market can be added to the portfolio per period. This includes own product innovations, which means that market entry decisions are only considered in periods where the firm has not opened a new sub-market.

[9]Entry in this sense has to be distinguished from product innovation discussed in the previous subsection, where a new sub-market is founded and automatically entered.

To make the entry decision the firm ranks all available markets it does not currently serve according to their evaluations and determines the best existing non-served market as the entry candidate. The set of available markets consists of all existing product variants which are currently not protected by a patent. The entry candidate is added to the portfolio if

$$v_{i,j,t} > \kappa_{i,en}\Delta^{en}_{i,t}, \tag{17}$$

where $\Delta^{en}_{i,t}$ denotes the additional fixed costs if the number of variants in the product range is increased by one. The parameter $\kappa_{i,en} > 0$ is again an inertia parameter and represents the aggressiveness of the firm's entry policy. The optimal value of this parameter is a-priori not clear. Entering a market which currently does not cover the additional fixed costs might be profitable because cost reductions achieved by process improvements now might be very valuable in the future if demand grows sufficiently fast.

In principle, the diversification strategy of a producer is determined by the parameters $(\kappa_{i,ex}, \kappa_{i,en})$. However, in the following analysis we represent the diversification strategy only by $\kappa_{i,ex}$, as initial simulation runs have shown that the influence of $\kappa_{i,en}$ is negligible compared to that of $\kappa_{i,ex}$. This is intuitively plausible. Since market entry costs in this model are implicitly given by large initial production costs, firms have only minor costs of 'testing' a market with small quantities for a short period. Hence, the selection of markets should rather be based on the decision to exit non-promising markets after the testing period, than on a restrictive entry policy.

2.4.3 Output Quantity Decisions

Firms determine the output quantities for their product portfolio using estimated demand elasticities. Each firm bases its decision on the simplifying assumption that all its competitors change their output quantities by the same factor as the firm itself. We discuss and justify this assumption below.

In order to describe the rules which govern the quantity decision making of the firms we should first be more explicit about the amount of information firms can use. We assume that the aggregate output quantities and the number of firms in all sub-markets at $t-1$ can be observed by all producers including those that were not active in this market. Furthermore, the price elasticities of demand for these quantities are also common knowledge $(\eta_{j,t-1})$. Each firm has in all periods perfect information about the own fixed and marginal costs of production of all product variants. Firms however do not have perfect information about the exact shape of the entire demand function and also do not know other firm's cost structures.

Given the set of sub-markets $M_{i,t}$ firm i tries to maximize

$$\max_{x_{i,j,t}:j\in M_{i,t}} p_{j,t}x_{i,j,t} - c_{i,j,t}x^2_{i,j,t} \tag{18}$$

subject to the constraint that current production has to be paid for by the current stock of savings (to keep things simple we do not allow firms to borrow):

$$|M_{i,t}|^{\mu_i}\Phi_i + \sum_{j\in M_{i,t}} c_{i,j,t}x_{i,j,t}^2 \leq S_{i,t}. \tag{19}$$

The corresponding first order conditions read

$$MR_{i,j,t} - 2(1+\nu_{i,t})c_{i,j,t}x_{i,j,t} \quad = \quad 0 \quad \forall j \in M_{i,t}, \tag{20}$$

where $\nu_{i,t} \geq 0$ is the Lagrange multiplier of the firm's budget constraint and $MR_{i,j,t}$ the marginal revenue. Due to the limited information about the shape of the demand function and the competitor's production costs firms cannot simply determine the Nash equilibrium of this quantity setting game. Rather they use some heuristic approximations to determine their output quantity. They assume that price elasticities of demand are constant and hence approximate marginal revenue by the following expression typically used in standard markup pricing formulas

$$\hat{MR}_{i,j,t} = \hat{p}_{j,t}\left(1 + \frac{x_{i,j,t}}{\hat{X}_{j,t}}\,\frac{1}{\eta_{j,t-1}}\right). \tag{21}$$

Note that $p_{j,t}$ and $X_{j,t}$ are unknown at the time of the decision making and hence estimates have to be used. Firm i believes that all producers in the industry change their output quantity by the same factor $\lambda_{i,j,t}$ which means that $\hat{X}_{j,t} = \lambda_{i,j,t}X_{j,t-1}$ and $\hat{p}_{j,t} = p_{j,t-1}\left(1 + \frac{\lambda_{i,j,t}-1}{\eta_{j,t-1}}\right)$. For firms that have been in sub-market j in period $t-1$ inserting these expressions into (20) gives the output quantity $x_{i,j,t} = \lambda_{i,j,t}x_{i,j,t-1}$, where

$$\lambda_{i,j,t} = \frac{p_{j,t-1}(\eta_{j,t-1}-1)(X_{j,t-1}\eta_{j,t-1} + x_{i,j,t-1})}{2c_{i,j,t}(1+\nu_{i,t})x_{i,j,t-1}X_{j,t-1}\eta_{j,t-1}^2 - p_{j,t-1}(X_{j,t-1}\eta_{j,t-1} + x_{i,j,t-1})}. \tag{22}$$

It becomes obvious from this expression that the actual rates of change of output are heterogeneous and the homogeneity assumption of the firms is in general violated. Nevertheless this formulation captures the effect that output quantities of all firms in markets with increasing or decreasing attractiveness tend to move in parallel and avoids extreme overshooting which for example would be induced by naive expectations. The approach might look like a conjectural variation model with variation parameter plus one but here firms do **not** believe that changes in their own quantity directly influence the output decision of the other firms. Rather they believe that all competitors will independently arrive at the same quantity adjustment factor as they do. Given that firms do not know their competitors cost structure no more specific calculations about the competitors adjustment factors are possible.

A firm which did not produce variant j in period $t-1$ but added this sub-market in t first tries to estimate the change of output quantity of the incumbents and determines its optimal quantity based on this. The expected rate of change of output of the incumbents in the market is determined analogously to (22) where $x_{i,j,t-1}$ is replaced by the average output of a producer of variant j in period $t-1$. The expectation of firm i about total output in t in such a case is $\hat{X}_{j,t} = \lambda_{i,j,t} X_{j,t-1} + x_{i,j,t}$.

Finally, there is a minimal production quantity $x_{min} > 0$ which has to be produced by any firm which decided to keep this sub-market in its portfolio. If the result of the quantity calculations above is below this level the firm still produces x_{min}. Also in the initial period when a new sub-market is founded the quantity x_{min} is produced by the founder.

2.4.4 Investment Decisions

At the end of a period each firm decides on its investments in product and process innovation. The R & D investment quota for product innovation is denoted by q_i^{prod} and accordingly product R & D investments are $I_{i,t}^{prod} = q_i^{prod} \pi_{i,t}$. This investment increases the R & D stock $RD_{i,t}$ as described in (5). The overall investments for process innovation are $q_i^{proc} \pi_{i,t}$ and have to be distributed to the different current production lines. Since process investment leads to a reduction of per unit costs of production the firm allocates these funds to the different sub-markets proportional to an adjusted expression of its current output in each market, where the adjustment takes into account future growth potential. In particular the following expression (compare the market evaluations (13)) is used:

$$\tilde{v}_{i,j,t} = x(i,j,t) \xi_{i,j,t}^{\delta_{i,\xi}/(\delta_{i,\xi}+\delta_{i,P})} \left(\frac{\hat{P}_{j,t}}{\hat{P}_t^{av}} \right)^{\delta_{i,P}/(\delta_{i,\xi}+\delta_{i,P})} . \tag{23}$$

Hence, we have $I_{i,j,t}^{proc} = q_i^{proc} \pi_{i,t} \frac{\tilde{v}_{i,j,t}}{\sum_{k \in M_{i,t}} \tilde{v}_{i,k,t}}$ for all $j \in M_{i,t}$. As discussed above, these investments in process improvements lead to reductions of the unit costs for the corresponding product variant in $t+1$ (compare (9)).

3 Simulation setup

In order to obtain valid results from the model presented above a careful choice of the numerical simulation setup is necessary. This includes both model calibration and parameter sensitivity testing.

Model calibration deals with the choice of parameter value ranges that allow the model to find reasonable and, more importantly, robust results. In particular, long run viability of the industry is by no means certain in this model and hence viability requirements already put certain bounds on the ranges of parameters to be considered. We performed a large number of runs with different parameter settings to obtain these ranges.

However, varying parameters within these ranges may still have considerable impact on the dynamics of the model. Also, one has to be aware that the model has a significant stochastic component and hence results are not deterministic either. We are interested in the structural qualitative impact of the variation of certain key control parameters. To measure the impact of different values for our control parameters, and to avoid picking up effects caused by particular settings for the other parameters or by noise, we generated 100 different profiles of all model parameters excluding only the ones determining the very basic structure like the number of periods considered (T), the degree of complementarity (b), the number of firms (N_F), patent length (d_p), overall market size ($msize$) or the expected length of a life-cycle (L). Values of L and d_p chosen are vaguely consistent with empirical observations if one period in our model is interpreted as a quarter of a year. The profiles were generated randomly, where each parameter was drawn from the uniform distribution bounded by its range as we determined it before. The structure parameters mentioned above were fixed in our random profiles because changing them would have had severe impact on the ranges for the other parameters which guarantee viability[10]. However, we will also comment on the robustness of our results with respect to changes in these parameters below.

Each particular setting for our control parameters was run over all 100 profiles and the results obtained were averaged over these runs. As an additional robustness check we repeated the procedure with another 100 random profiles in the same manner and tested several of our qualitative insights obtained with the initial set of profiles. In all these cases our findings were confirmed by such a check.

Summarizing, all the results below were found to be very robust under the settings we discussed above, namely 100 distinctly different runs, with profiles based on parameter ranges that were determined by plausibility checks beforehand.

4 Dynamic Adaptation of Strategies

In the basic setup of the model we have assumed that the strategic parameters of the producers are fixed over time. Whereas this assumption is overly simplistic for some of the key parameters, it allows us to study individual firm incentives in a given environment. This will be done in the following sections. In this section we partly relax this assumption by studying an imitation type learning rule concerning the key parameters κ_{ex} – governing the degree of diversification – and κ_{innov} – governing the desired quality of a new product. The aim is to identify the effects of adaptive firm behavior on long run industry profits, average product quality and consumer surplus. Each firm is characterized by its strategy $\kappa_{i,ex}, \kappa_{i,innov}$ and the learning dynamics governs the evolution of the distribution of firms over the set of all strategies.

As our analysis focuses on oligopolistic industries with a rather small number of firms we keep the number of potential strategies as small as possible. In particular, we assume that each

[10]The actual ranges for all parameters used for the generation of the stochastic profiles are given in Appendix A.

strategy parameter can take only two values which we refer to as $\kappa_j^H,\ j \in \{ex, innov\}$ ('high') and $\kappa_j^L,\ j \in \{ex, innov\}$ ('low')[11]. This is also justified by the fact that we are interested in qualitative comparative statements rather than in the determination of 'optimal' values for κ_{ex} and κ_{innov}. To account for the fact that κ_{ex} and κ_{innov} govern rather basic long term decisions we consider imitation dynamics with a large degree of inertia.

We consider dynamics of an aspiration-level type where only dissatisfied companies contemplate changing their strategy. With a given frequency 'updating periods' arise during the simulation. In such an updating period all firms calculate their average profit since the last updating period and compare it with the profits earned by the other companies in the market. The N_F^{sel} companies with the lowest payoffs are dissatisfied and look for strategy improvements. Due to organizational costs and inertia firms are only willing to change at most one strategy parameter at the same time. In order to determine which parameter to change[12] the firm tries to estimate the expected gain of a change of each of the parameters. Let $\bar{\pi}_i$ denote the average profit of firm i since the last updating period and $\bar{\pi}_{-\kappa_{ex},i}$ the average profit of firms in the industry that have chosen the same value of κ_{innov} as firm i but differed with respect to κ_{ex}[13]. Analogous for $\bar{\pi}_{-\kappa_{innov},i}$. The probability that firm i changes the parameter value of κ_{ex} is

$$\mathbb{P}(\kappa_{i,ex} \text{ is changed}) = \frac{\max(0, \bar{\pi}_{-\kappa_{ex},i} - \bar{\pi}_i)}{\max(0, \bar{\pi}_{-\kappa_{ex},i} - \bar{\pi}_i) + \max(0, \bar{\pi}_{-\kappa_{innov},i} - \bar{\pi}_i)}, \tag{24}$$

otherwise $\kappa_{i,innov}$ is inverted. If both terms in the denominator are zero this probability is set to 0.5. The dynamic adaptation model used here is of extremely simple structure. It is not supposed to be a realistic picture of firms' strategy adaptation processes but merely a tool to illustrate size and direction of the basic incentive effects at work in our framework.

As pointed out in the introduction, recent industry trends in car manufacturing are to diversify and to introduce new products with lower quality. Since our aim is to explain such a dynamic development, we initialize our adaptation dynamics with a scenario, where the majority of producers has a strategy with high values for both strategic parameters, i.e. the industry is non-diversified with a high quality level prevailing. Particularly, we choose an initial point where each strategy different from $(\kappa_{ex}^H, \kappa_{innov}^H)$ is present only once in the market whereas all remaining companies use $(\kappa_{ex}^H, \kappa_{innov}^H)$. This initialization is also interesting from another point of view. Initial simulation runs suggest that this setting is from a social point of view the most efficient one among those possible in our setup.

Figure 2 (a) shows the evolution over time of the average potential of all active markets and the average number of markets served by a company for a typical run with $N_F = 8, d_p = 9, N_F^{sel} =$

[11] In our numerical simulations high and low values of a parameter are always given by upper and lower bound of the relevant range described in the previous section. In particular, $\kappa_{ex}^H = 1.5$, $\kappa_{ex}^L = 0.5$, $\kappa_{innov}^H = 3$, $\kappa_{innov}^L = 1.5$.

[12] Since each parameter can only take two different values there is only one option for the value of the parameter after the change and hence no decision in this respect is needed.

[13] If there was no such firm we set $\bar{\pi}_{-\kappa_{ex},i} = 0$.

$2, b = 0.5$ and $msize = 60$. Fifteen updating steps are considered each occurring after a full run of $T = 150$ periods. To add stability to the results, the payoff values used in the updating periods are averages over the profits for our 100 parameter profiles where only the values of κ_{ex} and κ_{innov} are exogenously fixed[14].

The effects observed in Figure 2 (a) are quite striking. After an initial period of increasing and then constant quality levels but increasing diversification there is a rather significant drop in the average quality of the goods traded in the market. Finally, both variables stabilize with quality way below and diversification way above the initial level. If we look at the corresponding average profits in the industry (see Figure 2 (b)) we realize that profits go up in the initial phase where the level of diversification goes up and the quality is kept at a high level, but decreases rapidly afterwards as the quality level goes down. Hence the industry faces a kind of dilemma where individual incentives lead to a downwards spiral of quality which is in the long run detrimental for the profits of all producers. This decrease in quality however does not only hurt the producers but also induces a downwards trend for the utility of the representative consumer in our market as can be seen by considering updating periods 5-8 in Figure 2 (c).

However, same as for firms for consumers the initial diversification phase has significant positive effects. For consumers this is due to their love for variety preferences and the increased competition on the individual markets. Stronger competition is a direct effect of increased diversification which implies more producers on each market. The evolution of the distribution of strategies in the population which generates these phenomena can be seen in Figure 2 (d).

Initially all unsatisfied firms consider diversification as the appropriate step to increase profits, but, once all firms are highly diversified, firms start to switch to strategies with low quality requirements on product innovations introduced to the market. After all firms have adopted this low quality approach, unsatisfied companies keep trying high quality strategies from time to time but no trend back to a high quality industry can be established. In the following section we will analyze in some detail the strategic effects which are responsible for this dilemma.

It might be argued that the observations made here should depend rather sensitively on the degree of the 'love for variety' of consumer preferences. To check that we have carried out similar runs of adaptation dynamics for different values of the parameter b in the range $[0.25, 0.9]$. Although the relevant ranges of the κ_{ex} and κ_{innov} parameters differ quite substantially depending on b, the qualitative picture with an initial decrease of the average κ_{ex} value followed by a decrease in the average κ_{innov} value could be observed in all the considered scenarios. Hence we will in the following sections restrict our attention to the case where $b = 0.5$.

[14]If one likes to interpret this averaging over different profiles literally, one could think of consulting companies that sell their recommended strategies at the same time on numerous markets thereby receiving multiple feedbacks.

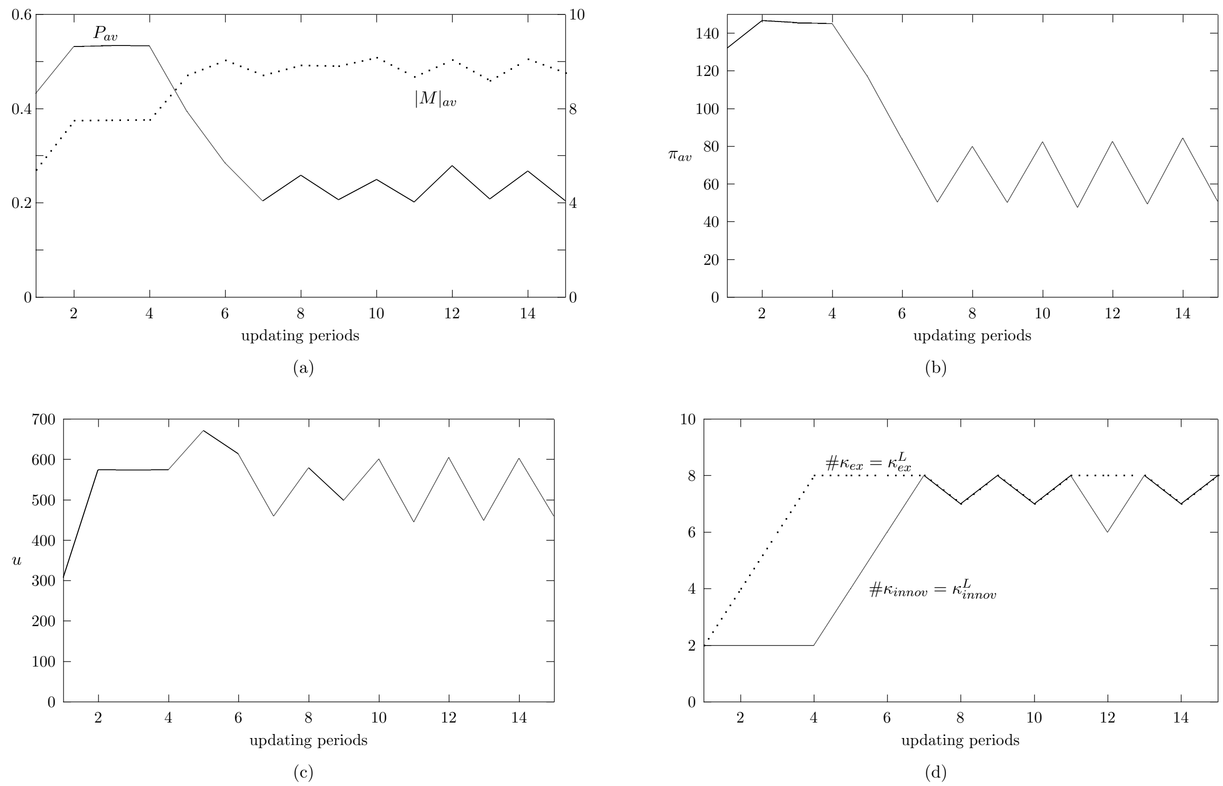

Figure 2: Dynamics resulting from a run with strategy adaptation: (a) The average market potential (solid line) and the average number of sub-markets served by a firm (dotted line). Labels on the left y-axis relate to the solid line, labels on the right y-axis to the dotted line. (b) The average profit made in the industry. (c) The utility of the representative consumer. (d) The number of firms using $\kappa_{innov} = \kappa_{innov}^L$ (solid line) and $\kappa_{ex} = \kappa_{ex}^L$ (dotted line) strategies.

5 Analysis of Individual Firm Incentives

The results above indicate that the decrease in the quality of innovations is triggered by increased diversification. This suggests that there should be strategic interdependence between these strategy parameters. The aim of this section is to clarify the underlying principle of this observation. In particular, we are interested in the effect of industry wide diversification and innovation strategies on individual incentives to speed to the market. To this end, we return to a setting were firm strategies are fixed over time. Considering a fixed environment allows us to determine more easily the individual incentives of firms to change their strategy.

In what follows we will often consider two different scenarios of industry diversification, namely one in which $\kappa_{i,ex} = \kappa_{ex}^H$ for all firms i (referred to as *diversified industry*) and the other one where $\kappa_{i,ex} = \kappa_{ex}^L$ for all firms i (referred to as *non-diversified industry*). In order to measure individual incentives to decrease quality we introduce a 'profit ratio' variable ι. This variable is well defined for all scenarios where all parameters other than κ_{innov} are uniform among all firms but the values of κ_{innov} are heterogeneous in the industry with at least one firm with $\kappa_{innov} = \kappa_{innov}^L$ and at least one with $\kappa_{innov} = \kappa_{innov}^H$. The value of ι is then given by the average profit of all firms with $\kappa_{innov} = \kappa_{innov}^L$ divided by the average profit of all firms with $\kappa_{innov} = \kappa_{innov}^H$. If $\iota > 1$ the firms with 'speeding to the market' strategies earned on average larger profits than those with high quality strategies. Since apart from the innovation strategy firms are equal, this implies that there are incentives[15] to decrease κ_{innov} which corresponds to a reduction of quality standards required for innovations. The larger ι is, the stronger are these incentives.

5.1 Industry wide levels of diversification and individual incentives

Let us first consider the impact of an industry-wide increase of κ_{ex} on the values of ι. In order to do so, we compare 6 different scenarios with respect to diversification where in each scenario the values of κ_{ex} of all firms were exogenously set to the same value in all 100 runs carried out. In particular, the 6 scenarios correspond to values $\kappa_{ex} = 0.5, 0.7, 0.9, 1.1, 1.3, 1.5$. Concerning the parameter κ_{innov} two different scenarios were considered: a 'high quality' scenario where 7 firms use $\kappa_{innov} = \kappa_{innov}^H$ and one $\kappa_{innov} = \kappa_{innov}^L$ and a 'low quality' scenario where 7 firms use $\kappa_{innov} = \kappa_{innov}^L$ and one $\kappa_{innov} = \kappa_{innov}^H$. Hence, in total there are 12 scenarios where for each scenario 100 runs were carried out with all parameters other than κ_{ex} and κ_{innov} determined by the 100 different stochastic parameter profiles. For each of the two quality scenarios we examine how the profit ratio ι changes as κ_{ex} in the industry is increased.

The corresponding results averaged over the 100 runs for each scenario are depicted in Figure 3. Note that we have put $1/\iota$ instead of ι on the y-axis. Doing so, allows us to interpret the graphs as

[15] Our use of the term 'incentives' is a slight abuse since firms when comparing the own payoff to that of competitors do not take into account the effect a change of the own strategy will have on quantities and prices on the different markets. As discussed above, the firms in this setting are no strategic players in a game-theoretic sense.

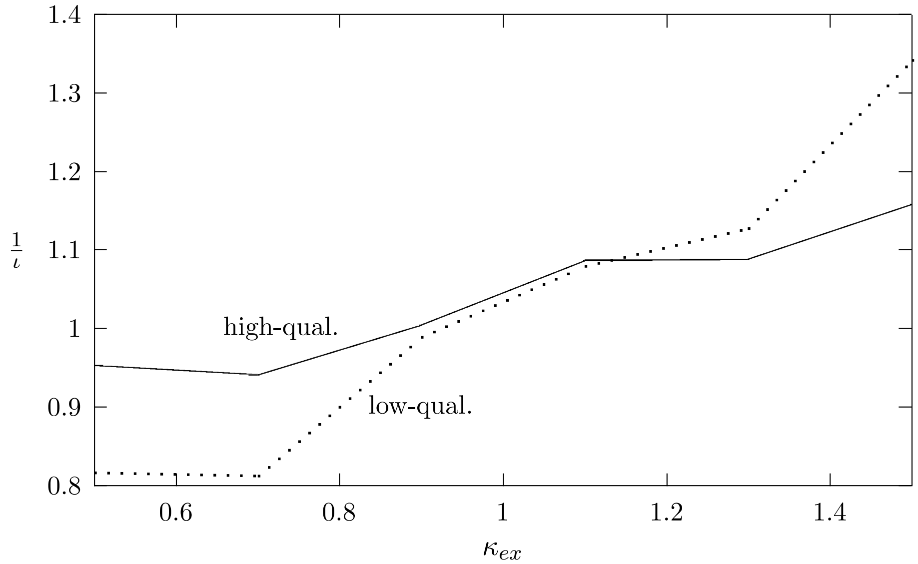

Figure 3: Incentives to choose $\kappa_{innov} = \kappa_{innov}^H$ depending on the diversification strategy used in the industry. In the low-quality case all but one firm use $\kappa_{innov} = \kappa_{innov}^L$, in the high-quality case all but one use $\kappa_{innov} = \kappa_{innov}^H$.

a proxy for the individual optimal reaction function for κ_{innov} with respect to the competitor's κ_{ex}. A high value of $1/\iota$ means that there are large incentives to choose a high κ_{innov}. As in the case of actual game-theoretic reaction functions, we have that an increasing graph implies that the considered variables are strategic complements whereas decreasing graphs indicate strategic substitutes. Considering Figure 3 we realize that κ_{innov} and κ_{ex} are indeed strategic complements. The incentives for high quality innovations go up as κ_{ex} is increased and therefore the level of diversification is decreased. This effect on individual incentives is much stronger if the competitors run a low-quality innovation strategy rather than having high quality-requirements for innovations. Interestingly, the ranking of the strength of incentives between high and low quality scenarios inverts as the level of diversification is changed. Whereas for highly diversified industries a low quality surrounding implies stronger incentives to **decrease** quality requirements than a high quality market, for a non-diversified industry low quality strategies of competitors seem to give stronger incentives to **increase** quality requirements.

The intuition for these findings is that in an industry where firms are highly diversified and aggressive in their market entry strategy the returns for founding a market with high attractiveness evaporate very fast once the patent protection of the market ends. This effect is even stronger if the average market in the industry is of low quality. The appropriate reaction for a firm therefore is to generate numerous low cost, low quality markets with little attractiveness in order to accumulate a large number of small profit streams. On the other hand, in an industry where competitors have inert entry strategies, the competition even in attractive sub-markets increases sufficiently slowly such that the incumbent can, due to his initial cost advantages, generate substantial profits for an extensive period of time. These profits are even larger in an environment where the average market is of low quality and hence the relative attractiveness of a high-quality product variant is particularly high.

As mentioned above, Figure 3 depicts results averaged over 100 runs with different parameter profiles. Accordingly, there is a significant variance of the single ι values for the different runs. To make sure that the findings we discuss here are significant in a statistical sense, we formulate in Appendix B several statistical hypotheses corresponding to the main observations made and provide statistical tests. Summarizing these results here, we found (i) that the level of diversification indeed has a significant influence on the quality of product innovations, (ii) that in a diversified, low quality industry individual incentives to decrease quality are higher than in a high-quality industry and (iii) that in a non-diversified industry the industry quality level does not play a significant role for individual incentives.

Further simulations showed that the strategic complementarity between κ_{ex} and κ_{innov} also works in the opposite direction. The incentives to reduce κ_{ex} go up as the industry level of κ_{innov} is decreased. Since the focus here is on incentives to speed to the market we do not present the corresponding results in detail.

5.2 Industry wide levels of innovation quality and individual incentives

We now turn to the relationship between the industry level of κ_{innov} and the individual incentive to increase $\kappa_{i,innov}$. To examine this relationship we have again considered different scenarios where firms are heterogenous with respect to κ_{innov}. In order to be able to determine the ι values in each scenario, we have one firm with $\kappa_{i,innov} = \kappa_{innov}^{L}$ and one firm with $\kappa_{i,innov} = \kappa_{i,innov}^{H}$. The remaining firms always have identical κ_{innov} values denoted by $\kappa_{-i,innov}$. We considered scenarios for values $\kappa_{-i,innov} = 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3$. For each of these scenarios again 100 runs with our stochastic profiles were carried out. Figure 4 gives the inverse of the average ι values for the cases of a diversified and a non-diversified industry. Both curves are of flat U-shape which means that as long as average quality requirements are low the incentives to increase quality go down as the average quality level increases but in industries with high average quality requirements there is strategic complementarity between the individual incentives to require high quality and the average quality level. Consistent with our findings above, the incentives for high κ_{innov} are substantially larger in a non-diversified than in a diversified industry.

To check whether the homogeneity of the κ_{innov} values of $N_F - 2$ firms in the industry is crucial for this finding, we have also considered scenarios where all firms used either κ_{innov}^{L} or κ_{innov}^{H}, but the average κ_{innov} value in the industry equals those in the different scenarios for Figure 4. The resulting average ι values were almost identical to those presented in Figure 4.

Based on the incentive analysis carried out here we can claim that the 'road to inefficiency' observed in our simulations with strategy adaptation is indeed due to the existence of strategic

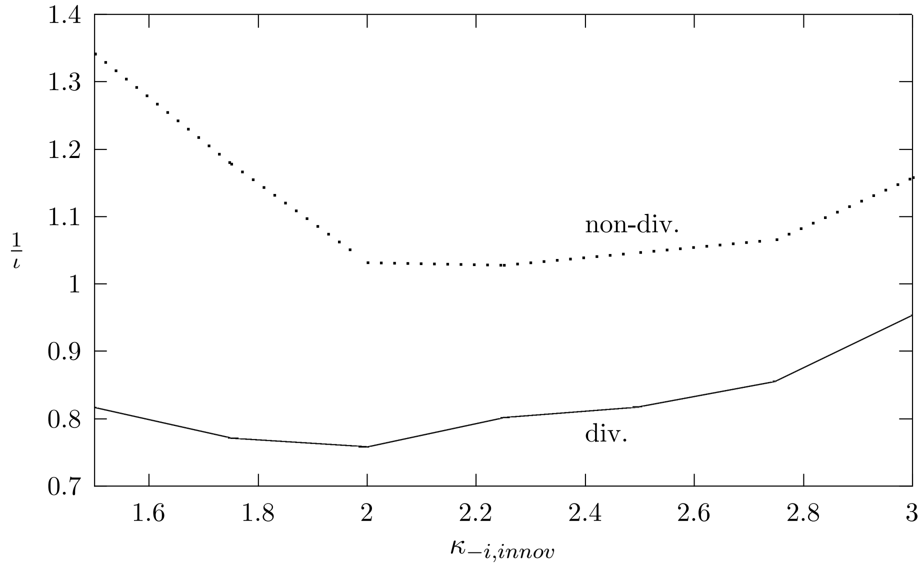

Figure 4: Incentives to choose $\kappa_{innov} = \kappa_{innov}^H$ depending on the quality requirements on innovations used by the competitors.

complementarities between the relevant strategy parameters of the individual companies and that of the surrounding industry. It is well known that in the presence of strategic complementarities adaptive dynamics tend to lead to Pareto inefficient outcomes if the group of players is relatively large (see Van Huyck et al. (1990), Crawford (1995)). In any case, the incentive analysis makes clear that an increase in diversification does not only jeopardize quality standards for technical reasons, but that in a dynamic market framework it is **individually rational** for companies to reduce the level of quality required for an innovation to be introduced to the market.

As we have seen in section 4, the total effect of the emergence of individual incentives for quality reduction are in the long run quite negative for the industry as a whole. This raises the question which properties of the market environment increase such incentives. The following section addresses this issue.

6 Industry Structure and Quality Incentives

In this section we present the influence of four key parameters describing the industry structure on the incentives to reduce κ_{innov}. The four key parameters we have chosen are the number of firms, N_F, the extent of appropriability for innovators, d_p, the maximal amount of money spent by consumers for output of this industry, $msize$, and the average duration of a product life-cycle, L. In all these cases we have considered an industry with heterogeneous κ_{innov} profile, where the firms were equally distributed over the κ_{innov} values $\kappa_{innov}^L = 1.5, 2, 2.5, 3 = \kappa_{innov}^H$. As above, the profit ratio ι gives the average profit of firms with $\kappa_{innov} = \kappa_{innov}^L$ divided by the average profit of

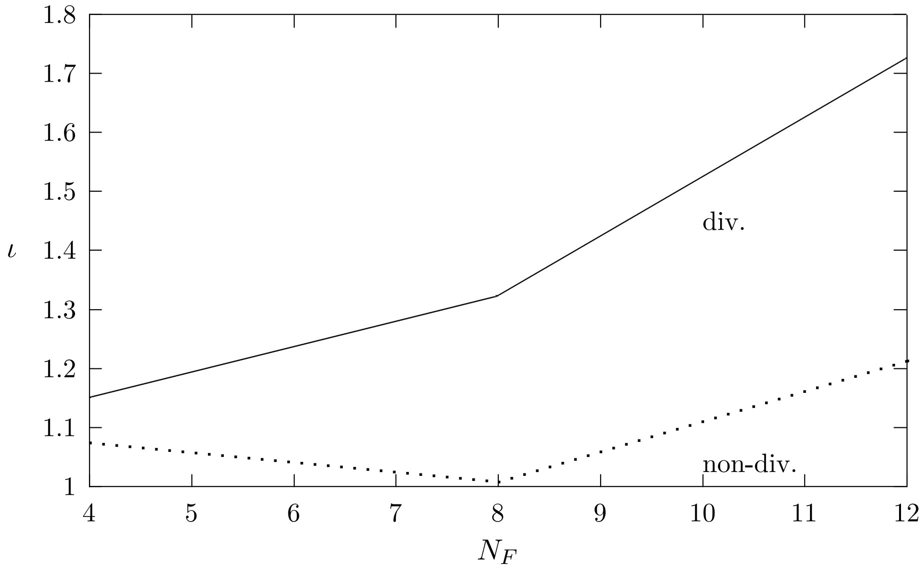

Figure 5: Incentives to choose $\kappa_{innov} = \kappa^L_{innov}$ depending on the number of firms in the industry.

firms with $\kappa_{innov} = \kappa^H_{innov}$.

6.1 Effects of the number of firms on quality incentives

Concerning the number of firms N_F we have compared our standard scenario of $N_F = 8$ with the cases $N_F = 4$ and $N_F = 12$. The intention is to check whether increased market concentration facilitates the development of high quality product innovations, a claim often made by brand-name producers in their fight against discount competitors which is also vaguely consistent with Schumpeter's famous hypotheses about the relationship between market concentration and innovative activity (see e.g. Kamien and Schwartz, 1982). In Figure 5 we depict the average ι values in dependence of the number of firms again for a diversified and a non-diversified industry. High ι values induce large incentives to reduce quality requirements.

For a diversified industry the claim made above is strongly supported. Incentives to reduce quality go up as the number of competitors in the industry increases. For a non-diversified industry almost no effect can be observed when comparing $N_F = 4$ with $N_F = 8$ but a further increase to $N_F = 12$ leads to a clearly distinguishable increase in ι. So, overall the model confirms claims that a higher degree of market concentration reduces the incentives for firms to speed to the market and introduce innovations of lower quality. The intuition for this effect is very similar to that explaining the complementarity between κ_{innov} and κ_{ex}. If competition is too strong introducing outstanding product variants attracts a large number of imitators and the innovator's rents vanish quickly. This result was also tested for statistical significance (see Appendix B, Hypothesis 4) and was found to be fully supported.

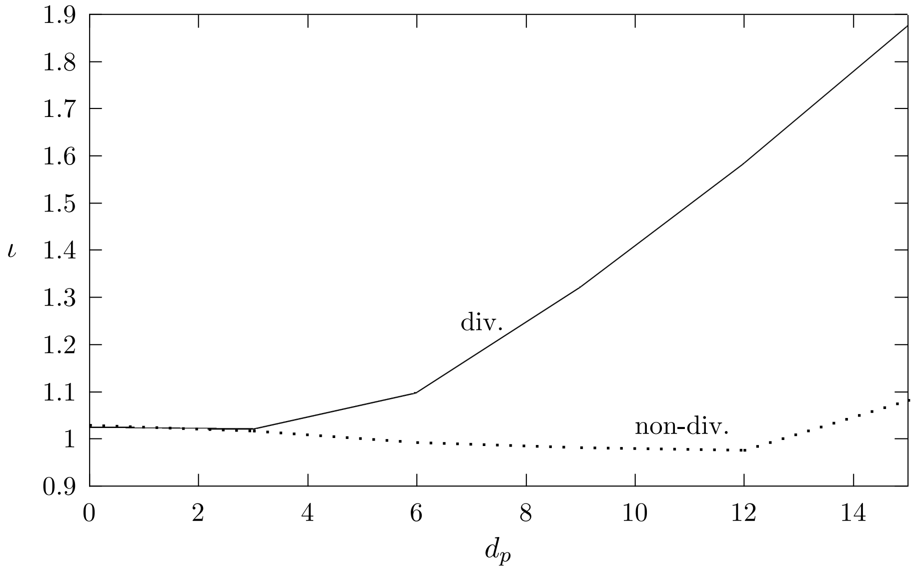

Figure 6: Incentives to choose $\kappa_{innov} = \kappa_{innov}^L$ depending on the duration of patent protection.

6.2 Effects of the degree of appropriability on quality incentives

Next we examine the impact of the parameter d_p determining the number of periods a newly found sub-market is closed for all potential entrants other than the innovator. The optimal design of the patent policy has been one of the central and most discussed themes in economics of innovation research. There is a large theoretical literature on the effects of patent length and scope on innovation incentives (see Gallini and Scotchmer (2002)). Most of these studies focus on the effects of patent protection on prices, R&D activities and technology diffusion in a single market framework. Our dynamic multi-product setting allows to incorporate also indirect effects of patent protection in a sense that long patent durations increase intensity of competition on older non-protected markets, which again influences the incentives of firms to introduce new products in order to generate a protected market. Also, to our knowledge the effect of patent duration on the quality of product innovations so far has not been considered. Hence, the question arises whether strong patent protection is helpful in avoiding the incentives for low quality in product innovations.

We consider a range of d_p between zero (no appropriability) and a patent duration slightly above half the expected product life-cycle. Results are depicted in Figure 6.

In a concentrated industry incentive effects of an increase in appropriability are almost non-existent for a large range of d_p values. Only for durations above $L/2$ does the incentive to decrease quality suddenly go up. In a diversified industry the increase in ι starts at lower values of d_p and is much more pronounced. While it seems somewhat counter-intuitive that increasing appropriability decreases the incentives for a high-quality strategy, one has to consider the indirect effects of increasing d_p. If d_p is high, all markets are closed for imitators for a long time. Once these markets

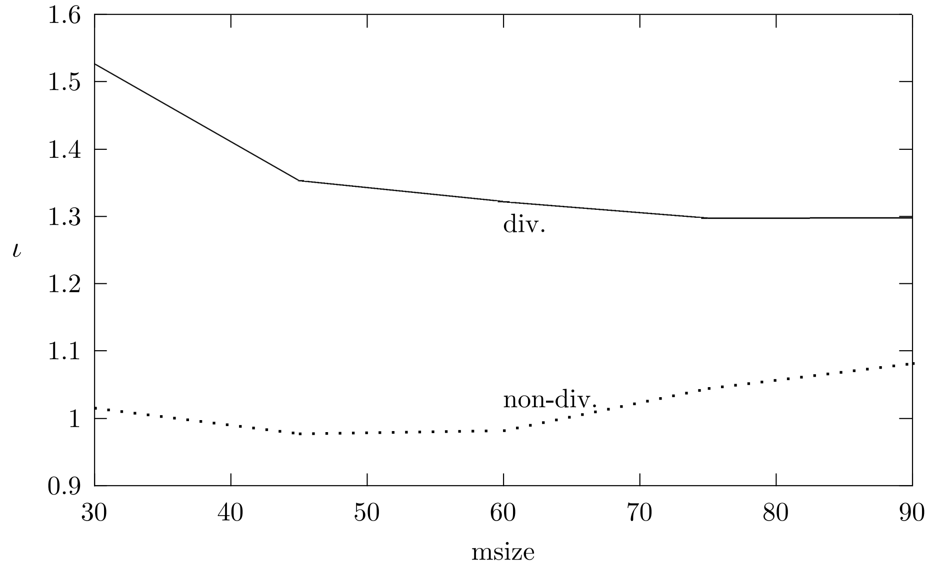

Figure 7: Incentives to choose $\kappa_{innov} = \kappa_{innov}^{L}$ depending on the maximal available consumer budget.

are open, entrants will find it difficult to catch up with the incumbent and profits will be low. A firm with a strategy to diversify thus has to do this by introducing its own products. High quality innovations take both, more investment and more time, such that the firm is better off by frequently introducing innovations with low quality. Looked at it this way, our results show that in industries where product imitation – either due to patent protection or some other reason – takes a long time a strategy aiming at high levels of diversification is not compatible with strategies of high quality requirements for product innovation. To strengthen this finding, we formulated two hypotheses (Hyp. 5 and 6, App. B) and the statistical test fully supports the result discussed above.

From a patent policy point of view these observations add to other arguments, like the slow diffusion of new technological developments, which have been used against extensive patent protection.

6.3 Effects of industry size on quality incentives

Let us now turn to the effects of the size of the industry on the innovation strategy. Figure 7 presents the incentives for low κ_{innov} depending on the maximum market size $msize$. Two effects can be observed here. First, for small markets the incentives to speed to the market are relatively high. This is quite intuitive, since in such a market framework profits and therefore also R & D investments are small, and therefore κ_{innov} values significantly higher than that of the competitors lead to very long development circles and the danger of becoming a pure imitator. The second effect is that for very large market sizes (boom-markets), where R & D projects are easily financed, there

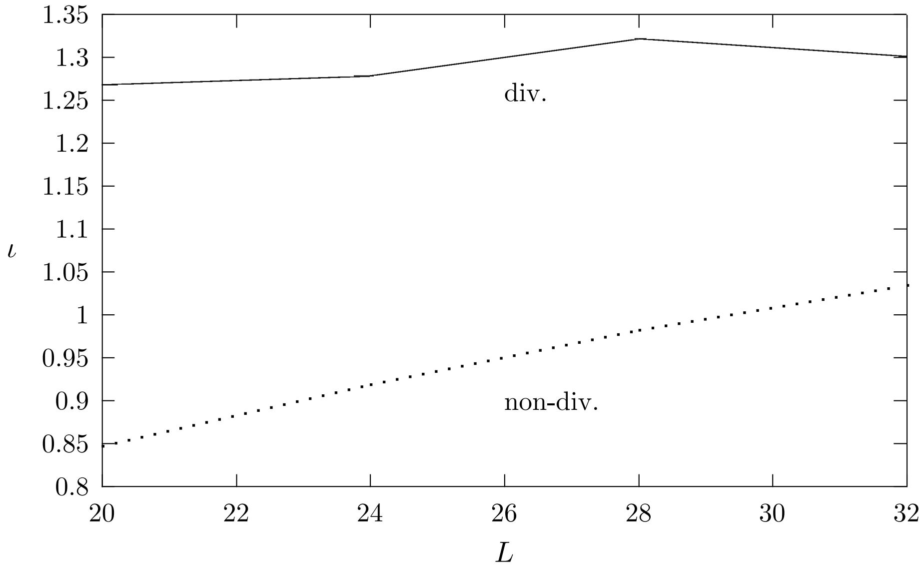

Figure 8: Incentives to choose $\kappa_{innov} = \kappa_{innov}^{L}$ depending on the expected length of the product life-cycle.

is again an increase in incentives to offer low quality innovations if the market entry behavior in the industry is not aggressive. The rationale seems to be that with such strong overall demand also relatively unattractive niche-markets are able to generate sufficient revenues to cover the allocated fixed costs. With non-diversified competitors there is almost no competition on these markets and hence founding many weak sub-markets becomes particularly attractive. No such effect can be observed if entry behavior is aggressive. These findings were analyzed statistically through Hypotheses 7 and 8. In this case only the increased incentives to reduce quality in larger, non-diversified industries were found to be statistically significant.

6.4 Effects of life cycle length on quality incentives

Finally, we concentrate on the effect of the average length of the life-cycle. It has been argued e.g. in Bayus (1997) that in the case of short product lifetimes speeding to the market with low quality products may be optimal as there is limited time in which to obtain revenues. As this result is based on the assumption that the target market is already supplied by a competing firm, we are interested whether we can observe a similar result in our model, where an innovation will induce a new life cycle for the developed product variant. We considered values of of the average length of the life-cycle L between $L = 20$ and $L = 32$. In order not to pick-up any hidden effects of changes in appropriability the value of d_p was adapted proportional to that of L. The results are shown in Figure 8.

Whereas there is no effect in an industry with aggressive diversification strategies, in a non-diversified industry incentives to choose low κ_{innov} go down (respectively incentives to choose κ_{innov}^H go up) if the expected duration of the life-cycle becomes smaller. Hence, maybe surprisingly, fast changing consumer preferences do not strengthen incentives to speed to the market but at least in industries with a low degree of diversification make innovation with high quality requirements attractive. The above mentioned result for diversified industries was tested and supported by our results for Hyp. 9, whereas for non-diversified industries our statistical results indeed show that shorter life-cycles reduce incentives to lower quality. Clearly, this result is in contrast with the observation of Bayus (1997) as discussed above. However, it can be understood in terms of the different assumptions of the two models. In our setting innovations are always horizontally differentiated from the existing products and sales are only indirectly influenced by the life-cycles of the incumbent products. The main effect of short life-cycles is that there is less time for imitators to catch up to the innovator with respect to costs and market share before the demand for this variant reaches its peak. This makes high-quality innovations more attractive.

7 Conclusions

This paper is based on empirical observations that in many industries speeding to the market phenomena associated with quality problems of product innovations seem to become increasingly prevalent. A prominent example in this respect is the car industry where at the same time a trend towards a higher degree of product diversification could be observed for most major producers. The agent-based industry model developed in this paper is able to reproduce these stylized facts and shows that, whereas increasing diversification of producers indeed induces short innovation cycles for the non-coordinated competitors in the market, this development has negative effects on the overall industry profit. Our strategic analysis shows that incentives to speed to the market are indeed increasing as the average level of diversification in the industry increases and that this effect is particularly strong if the competitors also have short development cycles. So, firms following such a strategy are acting perfectly rational, but still have to face decreasing profits in the long run.

As long as firms act non-cooperatively this dilemma seems hard to avoid. Some cooperation and credible commitment to uphold high quality standards in innovations seems necessary. This is particularly feasible in industries with high concentration because on one hand we have shown that for concentrated industries the incentives to introduce a speeding to the market strategy are comparatively weak and on the other hand the coordination problem per se is less pronounced. Extending appropriability, for example by increasing patent lengths, is according to our findings no option to avoid the decrease in the average quality of product innovations but rather counter-productive.

On a methodological level the paper demonstrates how agent-based models can be employed to extend rigorous strategic analyses, which are by now standard in the IO literature, to complex dynamic settings. This seems particularly relevant for studying innovative activities which can only be well understood in terms of dynamic market evolution. In this sense the method proposed here should be seen as complementary both to game-theoretic examinations in more stylized settings and to empirical studies of firm behavior in real markets.

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Appendix A

In this appendix a complete list of our model notation is given.

Indices:

- i ... index for firms
- j ... index for sub-markets
- t, l ... indices for time periods

General Model Parameters:

- $T = 150$ ... time horizon
- $\varepsilon \sim \mathcal{N}(0, 0.1)$ ... noise term
- $\chi = 0.5$ ... uncertainty of new product quality
- $A = 1$ ... parameter governing industry growth due to product variety

Exogenous Industry characteristics:

- $N_F = 8$ ... number of firms
- $m_0 = 6$ ... initial number of sub-markets
- $P_{ini} = 0.25$ ... market potential of initial sub-markets
- $d_p = 9$ ... degree of appropriability
- $b = 0.5$ ... degree of complementarity of sub-markets
- $L = 28$ ... expected length of the life-cycle of sub-markets
- $msize = 60$ ... maximum size of the industry

Endogenous Market and Sub-Market Characteristics:

- m_t ... number of active sub-markets at time t
- B_t ... overall industry size at time t
- $t_{ini}(j)$ ... founding period of sub-market j
- P_j ... market potential of sub-market j

- $a_{j,t}$ ... attractiveness of sub-market j at time t
- $X_{j,t}$ ... total supply in sub-market j at time t
- $p_{j,t}$ ... unit sales price in sub-market j at time t
- $\eta_{j,t}$ ... price elasticity of demand in sub-market j at prices p_t

Exogenous Firm Characteristics and Strategy Parameters:

- S_0 ... initial money stock of firms
- x_{min} ... firms' minimum production quantity in a sub-market
- τ_i ... planning horizon of firm i
- Φ_i ... fixed costs per sub-market served by firm i
- μ_i ... speed of increase in fixed costs with increasing number of sub-markets served by firm i
- $c_{i,j}^{ini}$ ... initial costs of firm i on sub-market j
- c_{min} ... fraction of initial costs that can be reached through process improvements
- α_i^c, β_i^c ... technological expertise and efficiency of process management of firm i
- $\alpha_i^{RD}, \beta_i^{RD}$ ... efficiency of R&D investments of firm i
- q_i^{proc} ... share of profit invested in process improvements by firm i
- q_i^{prod} ... share of profit invested in product innovation by firm i
- $\delta_{i,\pi}, \delta_{i,\xi}, \delta_{i,P}$ ... firm i's weights determining the relative importance of current profits, growth rates and sub-market potential, respectively, during sub-market evaluation
- $\kappa_{i,innov}$ ... required (relative) quality of new product innovations by firm i
- $\kappa_{i,ex}$ ... parameter guiding firm i's inertia concerning market exit
- $\kappa_{i,en}$ ... parameter guiding firm i's inertia concerning market entry

In Table 1 we list the parameters governing the exogenous firm characteristics and strategy, together with their respective ranges given by upper and lower bounds for their values. For each of the 100 profiles we generated, these parameters were independently, uniformly random drawn between these bounds. Note, that we have omitted firm indices in Table 1 as our firms are identical with respect to the listed parameters.

Endogenous Firm Characteristics:

Parameter	Lower Bound	Upper Bound	Parameter	Lower Bound	Upper Bound
S_0	10		α^{RD}	3	4
x_{min}	0.01		β^{RD}	0.75	0.95
τ	3	10	q^{proc}	0.25	0.35
Φ	0.25	0.35	q^{prod}	0.4-q^{proc}	
μ	0.75	1	δ^P	0.3	0.4
c_{ini}	0.4	0.6	δ^ξ	0.3	0.4
c^{min}	0.2	0.4	κ_{innov}	1.5	3
α^c	1.5	2	κ_{ex}	0.5	1.5
β^c	0.75	0.95	κ_{en}	0	0.5

Table 1: Model parameters and their respective ranges

- $S_{i,t}$ ... capital stock of firm i at time t
- $F_{i,t}$ ... total fixed costs of firm i at time t
- $M_{i,t}$ ... set of sub-markets served by firm i at time t
- $I_{i,t}^{prod}$ ... investment in product innovation by firm i at time t
- $I_{i,j,t}^{proc}$ ... investment in process improvements for sub-market j by firm i at time t
- $\tilde{c}_{i,j,t}$ ... knowledge stock for process improvements by firm i on sub-market j at time t
- $RD_{i,t}$ ... knowledge stock for product innovation by frim i at time t
- $v_{i,j,t}$ ... evaluation function of firm i for sub-market j at time t used for market exit and entry decisions
- $\tilde{v}_{i,j,t}$ ... evaluation function of firm i for sub-market j at time t used for investment decision
- $\Delta_{i,t}^{ex}$ ... savings on total fixed costs of firm i through market exit
- $\Delta_{i,t}^{en}$ ... additional fixed costs of firm i through market entry
- $\bar{v}_{i,t}$ ... average evaluation of sub-markets served by firm i at time t
- $\nu_{i,t}$ ... Lagrange multiplier of firm i's budget constraint at time t

Firm's Estimates:

- $\hat{P}_j^t$ ... estimated market potential of sub-market j at time t
- $\hat{a}_{t+l,j}^t$ ... time t estimate of attractiveness of sub-market j at time $t+l$

- $\lambda_{i,j,t}$ ... firm i's estimate of change in total supply on sub-market j at time t
- $\xi_{i,j,t}$ ... firm i's time t estimate of market growth rate on sub-market j
- $\hat{P}_{av}^{t}$ ... average of estimated market potentials of all existing sub-markets at time t
- $\hat{a}_{i,av}$ ... average of estimated attractiveness of all existing sub-markets at the end of firm i's planning horizon
- $\hat{\pi}_{i,j,t}$ ... firm i's estimate of time t profits on sub-market j
- $\hat{p}_{j,t}, \hat{X}_{j,t}$ ... firm i's estimate of time t prices and total supply on sub-market j

Appendix B

This appendix provides detailed information about the statistical tests we referred to in Sections 5 and 6.

Given the data, which represent an individual firm's incentives to decrease the quality of its innovations under different industry scenarios we used the Mann-Whitney U Test, which is the non-parametric counterpart of the t-test for independent samples. It does not require a particular distribution of the underlying data and tests whether the two samples are from the same distribution. For each hypothesis below we verbally formulate the alternate hypothesis and the data sets used for the tests consist of the results for the different constellations over the 100 random profiles we generated.

The following hypotheses were tested concerning individual firms' incentives.

Hypothesis 1:
Regardless of the prevailing quality standards in the industry, incentives to decrease quality are larger in diversified than in non-diversified industries.
$H_0 : 1/\iota_{div} \geq 1/\iota_{non-div}$
$H_a : 1/\iota_{div} < 1/\iota_{non-div}$

Hypothesis 2:
In a diversified environment, incentives to decrease quality are larger in low-quality than in high-quality industries.
$H_0 : 1/\iota_L \geq 1/\iota_H$
$H_a : 1/\iota_L < 1/\iota_H$

Hypothesis 3:
In a non-diversified setting, incentives to decrease quality are larger in high-quality than in low-quality industries.
$H_0 : 1/\iota_H \geq 1/\iota_L$
$H_a : 1/\iota_H < 1/\iota_L$
The results for the one-sided tests of these hypotheses are summarized in Table 2, where for each Hypothesis the z-value and the 1-sided significance is given.

Hypothesis	z-value	sig.
1	-7.11	<0.0001
2	-3.53	0.0002
3	-1.19	0.117

Table 2: Results of the Mann-Whitney U-Test for Hypotheses 1, 2 and 3

As Table 2 shows, for Hypotheses 1 and 2 the null-hypothesis can be rejected at a confidence level beyond 99%. Thus, our findings from Section 5 above are clearly supported. In the case of Hypothesis 3 the null-hypothesis can not be rejected at a confidence level of 90%, such that the industry quality level does not seem to play a significant role for an individual firm's incentives to decrease quality in a non-diversified industry.

Let us now turn to the hypotheses for the effects of the industry structure as studied in Section 6. First, Hypothesis 4 deals with the effect of increased competition as measured by the number of firms in the industry.

Hypothesis 4:
Regardless of the prevailing level of diversification in the industry, an increase in the number of competing firms increases the individual incentives to reduce the quality of innovations.
$H_0 : \iota_{N_F=4} \geq \iota_{N_F=12}$
$H_a : \iota_{N_F=4} < \iota_{N_F=12}$

Turning to the effects of appropriability, Hypotheses 5 and 6 deal with the effects of increasing d_p on the different incentives to reduce quality in diversified versus non-diversified industries.

Hypothesis 5:

Without appropriability, i.e $d_p = 0$ incentives to reduce quality are higher in diversified than in non-diversified industries.

$H_0 : \iota_{div} \leq \iota_{non-div}$

$H_a : \iota_{div} > \iota_{non-div}$

Hypothesis 6:

With high degree of appropriability, i.e $d_p = 9$ incentives to reduce quality are higher in diversified than in non-diversified industries.

$H_0 : \iota_{div} \leq \iota_{non-div}$

$H_a : \iota_{div} > \iota_{non-div}$

Hypotheses 7 and 8 deal with the effects of increasing market size on the incentives to reduce quality in diversified and non-diversified industries, respectively.

Hypothesis 7:

In a diversified industry, incentives to reduce quality fall with increasing market size.

$H_0 : \iota_{msize=90} \geq \iota_{msize=30}$

$H_a : \iota_{msize=90} < \iota_{msize=30}$

Hypothesis 8:

In a non-diversified industry, incentives to reduce quality increase with increasing market size.

$H_0 : \iota_{msize=30} \geq \iota_{msize=90}$

$H_a : \iota_{msize=30} < \iota_{msize=90}$

Finally, Hypothesis 9 and 10 concern the quality incentive effects of varying lengths of the life-cycles.

Hypothesis 9:

In a diversified industry, longer life-cycles induce increasing incentives to reduce quality.

$H_0 : \iota_{L=20} \geq \iota_{L=32}$

$H_a : \iota_{L=20} < \iota_{L=32}$

Hypothesis 10:

In a non-diversified industry, longer life-cycles induce increasing incentives to reduce quality.

$H_0 : \iota_{L=20} \geq \iota_{L=32}$

$H_a : \iota_{L=20} < \iota_{L=32}$

Table 3 summarizes our results for Hypotheses 4 to 10. As in Table 2, for each Hypothesis the z-value and the 1-sided significance is given.

Hypothesis	z-value	sig.
4	-6.91	<0.0001
5	0.77	0.2207
6	6.33	<0.0001
7	-0.55	0.2912
8	1.46	0.0721
9	0.27	0.3936
10	2.79	0.0026

Table 3: Results of the Mann-Whitney U-Test for Hypotheses 4 to 10

The main results from Table 3 can be summarized as follows. First, for Hypotheses 4, 6 and 10 the null hypothesis can be rejected with a 99% level of confidence. Thus, increased competition in terms of an increase in the number of firms indeed induces incentives to reduce quality (Hyp. 4), for settings with high appropriability, diversified industries provide higher incentives to reduce quality than non-diversified industries (Hyp. 6) and longer life-cycles increase incentives to reduce quality in non-diversified industries (Hyp. 10).

Second, in the case of Hypothesis 8 the null hypothesis can be rejected at a level of confidence of 90%. Thus, in a non-diversified industry an increase in market size does induce increasing incentives to reduce quality.

Finally, for Hypotheses 5,7 and 9 the null hypothesis could not be rejected. This implies, that in industries without appropriability of returns from innovation incentives to reduce quality are unaffected by the industry structure in terms of diversification (Hyp. 5). Further, in a diversified industry neither changes in market size (Hyp. 7) nor changes in the length of the life-cycles (Hyp. 9) induce significant effects on quality incentives.