Working Paper Series

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Working Paper No. 68
Mai 2000

Working Paper Series

Mai 2000

SFB
'Adaptive Information Systems and Modelling in Economics and Management Science'

Vienna University of Economics
and Business Administration
Augasse 2–6, 1090 Wien, Austria

in cooperation with
University of Vienna
Vienna University of Technology

http://www.wu-wien.ac.at/am

This piece of research was supported by the Austrian Science Foundation (FWF) under grant SFB#010 ('Adaptive Information Systems and Modelling in Economics and Management Science').

To Innovate or Not To Innovate*

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May 22, 2000

Abstract

In this paper we analyze the evolution of output decisions of adaptive firms in an environment of oligopolistic competition. The firm might either choose to produce one of several existing product variants or try to establish a new product variant on the market. The demand for each individual product variant is subject to a life-cycle, but aggregate demand for product variants is constant over time. Every period each firm has to decide whether to produce the product again, to introduce a new product variant itself (which generates an initial advantage on that market), or to follow another firm and change to the production of an already established product. Different firms have heterogeneous abilities to develop products respectively imitate existing designs, and therefore the effects of the decision whether to imitate existing designs or to innovate differ between firms. We examine the evolution of behavior in this market using an agent based simulation model. The firms are endowed with simple rules to estimate market potentials and market founding potentials of all firms including themselves, and make their decisions using a stochastic learning rule. Furthermore, the characteristics of the firms change dynamically due to 'learning by doing' effects. The main questions discussed are how the success and the optimal strategy of a firm depend on the interplay between characteristics of the industry and properties of the firm.

1 Introduction

Technology Strategy has been pointed out as a predominant predictor of survival of firms in fast changing environments (Christensen et al. (1998)). Bower and Christensen (1995) provide a number of examples where well-known firms failed to keep up with the technological progress in their industries, just because they were too narrowly focused on their key customers and thus assessed new opportunities wrongly. Their inertia lead them to miss new trends. On the other hand, innovativeness is associated with uncertainty and the risk of failure (Leonard-Barton (1988)). Thus, while innovation increases the risk of failure in the short run, it enhances the growth of firms in the long run. These effects lead to the 'innovator's dilemma' (Christensen (1997)), the question, under which circumstances firms should stick to a certain product and reap efficiency gains through learning-by-doing and in which situation they should explore new technologies or markets. The large body of research in this area can mainly be categorized into two groups. The first one adheres to an internal view and examines the impact of a firm's internal capabilities on its strategies (e.g. Cooper and Schendel (1976), Cooper (2000)). Cooper (2000) provides a benchmark study of 160 businesses and reports results which show that in addition to a firm's capabilities a corresponding new product and technology

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strategy is also needed for high performance. The second group focuses on external forces that influence a firm's strategies (Willard and Cooper (1985), Clark and Guy(1998)). In this line of research the impact of market structures and government policies on firm's behaviour is studied (Dawid and Reimann(1999)). In this context also timing decisions are examined (Christensen et al. (1998)) and it is argued that innovation success crucially depends on the timing of action.

However, Dosi (1988) reviewed the extensive literature on the effects of innovation and found that the success of innovation and the adoption of technologies depends on the attributes of the particular firm as well as on the environment and the timing of action. The overall firm strategy has to include appropriate decision rules for innovation.

Building on this finding, in our paper we study the impact of qualitatively different innovation strategies by taking the internal characteristics of the firm as well as the properties and strategies of the industry into account. In particular, we focus on the question of the determination of a firms product innovation policy. Thus, we have to find an answer to the 'innovator's dilemma', which is a complex task under uncertainty about market response (demand), industry response (pricing policy, product imitation) but also development and production costs.

Our approach follows the large stream of literature in the fields of evolutionary economics and organization theory, 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 neoclassical paradigm 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. Most of the work in this field where market interaction of firms is taken into account focuses on the effect of certain individual behavioral rules on market development, price dynamics, industry structure or economic growth (e.g. Arthur et al. (1997), Beltrati and Margarita (1993), Dawid (2000), Nelson and Winter (1982), Vriend (1995)). The organizational theory literature on the other hand stresses the impact of the firms organizational structure on its adaptive behavior and the ability for successful innovation, however in general without explicitly studying the interaction with other companies in the market (e.g. Cohen and Levinthal (1994), Ayers et al. (1997)).

We use a rather stylized agent based model, where the innovation policy of the firm is determined by a simple decision rule, to explore the question for which combination of individual firm and industry properties rules with high respectively low levels of inertia and innovation propensities are more profitable for the firm. The answers to the innovator's dilemma differ significantly and depend on the focus of the study (see Meeus and Oerlemans (2000) for a literature review) and thus an approach which links firm and industry development is of large interest. Using an agent based simulation model seems to us a very sensible way to explore this important question. The complexity of the interplay of heterogeneous firms in an industry seem to prohibit realistic and tractable mathematical models. The idea to use 'artificial agents' with rule based behavior in economic modeling has been explored with large success in the last two decades (see e.g. Conte (1997), Dawid (1999), Moss and Rae (1992)) especially to gain insights in problems like this, where analytical solutions are hard to obtain. We will show here that the agent based approach is extremely helpful to derive insights which yield actual policy implications for the individual firm.

The market environment we use in our simulation study is that of a group of markets 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. Examples for industries we had in mind, include the automobile industry (sedans, convertibles, mini-vans, SUVs) , the soft-drink industry (recently introduced variants are ice tea, energy drinks or ice-coffee) or magazine publishers. Since a main property of a real market which makes innovation essential and inertia dangerous is the stagnation and decline of the product demand after some time we use a dynamic market framework where product demands develop according to a life cycle.

The paper is organized as follows. We introduce the model in section 2 and discuss our simulation results in section 3 by first examining the impact of firm and industry properties on individual payoffs for a fixed strategy, then characterizing the optimal innovation strategies under different constellations and finally examine the impact of firm and industry properties on individual payoffs if firms always adapt their strategy to the circumstances. In section 4 we present some managerial implications and conclude in section 5 with some final remarks.

2 The Model

2.1 Market Evolution

We consider a population I of firms who produce for a certain sector of goods consisting of several markets for different variants of a consumer good. As pointed out above examples we have in mind would be markets like those for cars or soft drinks. In every time period t a certain number of such markets exists and there is a certain demand for the product variant traded on each market. New markets occur only if they are founded by one of the firms introducing a new product variant and existing markets die after a stochastic time period (see below). The demand function on an existing market j is given by

$$D_{j,t} = \frac{\tilde{a}_{j,t}}{(1+\beta p_{j,t})^{\gamma}},$$

where p_{jt} is the current market price on this market, $\beta,\ \gamma > 0$ are parameters determining the price elasticity of demand and its rate of decrease and $\tilde{a}_{jt}$ is the market size of market j at time t. Note that the elasticity of demand does not depend on the market size $\tilde{a}_{j,t}$ and we assume that the elasticity for a given price is identical for product variants under consideration, thus the parameters β and γ are identical for all product variants j. The market size changes over time in a stochastic way. At the time a market is founded the market potential of the market is fixed. This market potential should describe the basic appeal the newly developed product variant has for consumers. The market potential of the market is determined by the ability for new product design of the firm who has founded the new market. This should model the fact that some firms in the industry might have better market research and product design departments than others and therefore the products introduced by these companies are on average more successful. We denote the market potential of market j by B_j. The size of market j evolves according to a (non-stationary) Markov process of the form:

$$a_{j,t} = \begin{cases} 0 & t < t_j^{ini} \\ a_{j,t-1} + \epsilon_{j,t-1} & t \geq t_j^{ini} \end{cases}$$

where $\epsilon_{j,t}$ is normally distributed with expected value $(\frac{L}{2} - (t - t_j^{ini}))B_j$ and variance σ_ϵ. Here t_j^{ini} denotes the period where market j was founded and the parameter L determines the expected life-span of a market.

The form of this stochastic process should model the life cycle of a product (see Bass (1969)). Initially demand is small but the expected increase is large. Expected increases in demand decrease as the market becomes more saturated and eventually the expected change of market size becomes negative. As soon as $a_{j,t}$ becomes negative the market vanishes and all firms which have been in this market have to enter some other market. We carry out our analysis under the assumption that the total market size for all variants of products we consider is constant over time. Thus, we assume that the sum of the sizes of all active markets stays constant over time. The actual market size for a market j is then given by

$$\tilde{a}_{j,t} = \frac{a_{j,t} A}{\sum_{k \in \Delta_t} a_{k,t}},$$

where Δ_t is the set of all active markets in period ti and A is the total market size. This condition induces cross substitution effects and in particular the founding of a new market implies a decrease of demand for already existing product variations.

It is assumed that the prices for all the product variations are determined by the market clearing conditions. This implies that the price on market j at time t is given by

$$p_{j,t} = \max \left[0, \frac{1}{\beta} \left(\frac{\tilde{a}_{j,t}}{X_{j,t}} \right)^{1/\gamma} - 1 \right], \tag{1}$$

where $X_{j,t} = \sum_{i \in I} x_{i,j}^t$. Here $x_{i,j}^t$ is the amount supplied by firm i on market j. Let us now turn to the question how these output quantities are determined.

2.2 The Firms

We model the producing firms in a quite simplified way. It is assumed that all firms have identical amounts of variable input factors at their disposal every period and always produce the largest technically possible output quantity given their current production technology. Every firm chooses exactly one of the active markets and produces only for this market. If firm i has chosen to produce for market j at time t the production quantity is determined by

$$x_{i,j}^t = x_{i,j}^{ini} \frac{1 + \lambda_i u_{i,j}^t}{1 + u_{i,j}^t},$$

where $x_{i,j}^{ini}$ is the initial productivity of firm i for product j, $u_{i,j}^t$ is a counter of the number of periods firm i has already produced good j and $\lambda_i \geq 1$ is a parameter expressing firm i's ability for technological improvement through learning by doing. The larger λ_i is, the more firm i can increase its output per period it stays in a given market. A parameter value of $\lambda_i = 1$ corresponds to a case of no technological improvements at all. We call λ_i the rate of productivity increase. The initial productivity $x_{i,j}^t$ is determined the first time the firm decides to produce good j. To model the effect that there are differences in how suitable certain product variations are for different firms[1] we assume that this initial productivity is individually determined for each firm. The value $x_{i,j}^*$ is the realization of a normally distributed stochastic variable with expected value $\bar{X}_j$ and variance σ_f^2. The average productivity in a market, $\bar{X}_j$, is determined when a market is founded (see below) as the realization of a normally distributed random variable with expected value 1 and variance σ_m^2. So, we incorporate two different sources of heterogeneity in the output quantities here. On one hand some product variations are in general easier to produce than others and on the other hand not all firms are equally well suited for the production of a certain product implying that also the productivities of firms in the same market might differ. Note however that a priori the expected initial productivity of all firms in a given market is identical. Differences in the parameter λ_i may however yield different expected productivities of firms after they have stayed in a market for a certain number of periods.

[1] See Bullnheimer et al. (1998) for a more thorough discussion of the effect of heterogeneity on the optimal choice of production technologies.

Since it is assumed that all firms use a given fixed amount of labor input the overall production costs per period do not depend on the good the firm is producing and they are identical for all firms. We denote these per period production costs by c. The profit of firm i in period t is then given by

$$\pi_{i,t} = p_{\alpha_{i,t},t} x^t_{i,\alpha_{i,t}} - c.$$

where $\alpha_{i,t} \in J$ denotes the product firm i produces in period t.

As pointed out above, the main focus of our analysis lies on the question how the firm should decide which good to produce and how frequently the firm should try to introduce new product variants. Basically we assume that at the beginning of every period each firm has to decide which product variant to produce in the subsequent period (there are some exceptions we will discuss below). Every firm can only produce one single product variant. The decision process as such is modeled as a reinforcement learning type process: using information the firm can observe the firm builds estimates of the profitability of all the currently active markets. All information used to build these estimates is public, and therefore these estimates coincide for all firms. We denote by $\chi_{j,t} \geq 0$ the estimate of the profitability of market j. The estimate of the profitability of founding a new market is denoted by $\chi^{new}_{i,t} \geq 0$. This estimate depends on the properties of firm i since different firms have different abilities to develop successful new products. All the estimates take into account the observed past success of the firm which founded a market, past observed potentials of the market, but also the age of the market and the number of current competitors. The exact specification of these is quite complicated and thus we provide it only in the Appendix. The firm uses a stochastic decision rule to choose its product for the subsequent period. It might either decide to produce one of the goods in Δ_t which are already traded on one of the active markets or try to establish a new product $j_{new} \notin \Delta_t$. The probability for firm i to produce good $j \in \Delta_t \cup \{j_{new}\}$ is given by

$$\mathbb{P}(\alpha_{i,t+1} = j) = \begin{cases} \frac{R_i \chi_{j,t}}{\Sigma} & j = \alpha_{i,t} \\ \frac{\chi_{j,t}}{\Sigma} & j \in \Delta_t \setminus \{\alpha_{i,t}\} \\ \frac{S_i \chi^{new}_{i,t}}{\Sigma} & j = j_{new} \notin \Delta_t \end{cases}$$

The normalization constant $\Sigma = \sum_{j \in \Delta_t \setminus \{\alpha_{i,t}\}} \chi_{j,t} + R_i \chi_{\alpha_{i,t},t} + S_i \chi^{new}_{i,t}$ guarantees that this is indeed a probability distribution. Reinforcement learning models of similar type have been frequently used in recent work to describe the decision process of agents in a discrete choice framework with a high degree of uncertainty (see for example Arthur (1993) or Arthur et al. (1997)).

The parameters R_i and S_i characterize the production choice strategy of firm i. Parameter R_i describes the inertia of the firm. The larger this parameter is the less likely it is in general that the firm changes its production decision from the previous period. On the other hand, a large value of S_i corresponds to a large readiness to introduce new products. Using different combinations of these two parameters several different types of strategies may be described: small values of R_i and S_i correspond to an 'imitator' who is willing to change to any successful active market but does not develop own products. A large R_i but small S_i describes a very conservative firm which is reluctant to change its production decision and also is not interested in exploring the potential of new markets. On the other hand, very flexible innovative firms are described by a small R_i and a large S_i. Finally, large values of both R_i and S_i describe a strategy of a firm which tries to exploit the market it is in as long as possible but, if it has to leave, it is very likely to introduce a new product itself rather than entering an existing market. To avoid unrealistic jumping behavior of firms between markets we further impose the restriction that a firm which changes to a different market at time t does not consider a market change for the following τ periods. An exception here is a change back to the product the firm was previously producing. Since here only negligible switching costs would occur such a change back can occur at any time.

When a firm decides to introduce a new product, a new market is found and the set Δ_t is enlarged by this new element. As explained above the two key parameters which characterize this new market are the market potential, B_j, and the average productivity in this market, $\bar{X}_j$. The market potential B_j depends on the ability of the firm who introduces the new product to carry out a good market analysis and product design process. This ability of the firm is expressed by the parameter $q_{i,t} \in [0, 1]$ and the market potential is simply given by $B_j = q_{i,t}$. It is assumed that the innovative abilities of a firm increase via learning by doing effects and thus whenever firm i introduces a new product in period t we have

$$q_{i,t+1} = q_{i,t} + \rho(1 - q_{i,t}), \quad \rho \in [0, 1]$$

for a given $\rho \in [0, 1]$. For reasons of simplicity we assume that this parameter is identical among firms. The reason why we choose $q_{i,0}$ rather than ρ as the firm specific indicator of innovative ability is that it is much easier to make a connection between this parameter and a certain part of the firm, like the quality of the production design department. The way human capital builds in such a department - which might be responsible for differences in ρ - depends on more general properties of the firm structure and it is beyond the scope of this paper to deal with them. Summarizing, firm i capabilities are characterized by its initial ability to develop new products, $q_{i,0}$ and by its rate of productivity increase λ_i. The strategy of the firm is defined by the pair (R_i, S_i) giving the inertia and the willingness to introduce new products. A main point of this analysis is to determine good values of the strategy parameters in dependence not only on the characteristics of the firm itself but also on the strategies and characteristics of the other firms in the industry.

3 Simulation Results

3.1 A Close Look on Firm and Industry Properties

In this section we will present an extensive numerical analysis of the profits earned by firms in the market for different constellations of parameter values and individual strategies. This will enable us to draw some general conclusions about the interplay of market conditions and individual firm properties and its implications for the individual firm's success. To be able to get a complete picture of this interplay we systematically examined 32 different parameter constellations. We always use a setup with $N = 12$ firms where 10 firms are identical in properties and strategies and comprise the 'industry' whereas the remaining 2 firms are the individual firms we are investigating. The 32 different constellations result from the following distinctions: the 'industry' may or may not experience productivity increases ($\lambda = 2$ or $\lambda = 1$ respectively), it may have large ($q = 0.8$) or small ($q = 0.2$) initial ability for new product developments. Apart from that we consider two qualitatively different strategy types for the industry: A 'non-innovative' firm ($R = 50, S = 1$) tends to stay with the product it has been producing and is not particularly willing to develop new products. An 'innovative' firm ($R = 50, S = 50$) is highly self sustained. It frequently develops its own products and tends to stay in the market. We will discuss the choice of these particular values for R and S in more detail in the next subsection. What matters for the considerations in this section is the qualitative distinction between high and low levels of inertia respectively innovation rates. Altogether, we therefore have 8 different possible industry states. Furthermore we have to distinguish between cases where the firms individual rate of productivity increase and its initial ability for new product developments are high or low. Thus, there are 32 different scenarios the individual firm might be faced with. For each of these settings we have compared the two different strategies described above. We have run 100 simulation runs for each individual strategy in each setting. This resulted in 64 batches of 100 simulation runs. The results reported here are the average values over the 100 runs in each batch. When discussing our findings, for the sake of readability we will present only representative subgroups of the table.

Although we were trying to keep the model as simple as possible while at the same time capturing the basic features like life cycles governing the development of this type of market, the number of model parameters is relatively large. Most of these parameters will be kept constant over all the simulation runs presented here. This set of parameter values is given by

$$\beta = \gamma = 1,\ \rho = 0.5,\ c = 1,\ \sigma_f^2 = \sigma_m^2 = 0.1,\ \sigma_\epsilon = 1.$$

After an initiation period where markets are randomly generated with random ages and firms randomly assigned to markets, the system is run for 36 additional periods. It should be kept in mind that the production decisions we are considering here are rather long term decisions which are not made on a day to day basis. Thus one period in our model might correspond to time intervals of at least a quarter of a year. In this case a run corresponds to a time period of at least 9 years. The expected length of the life cycle of a product is $L = 16$. The total market size is $A = 5N$ and the number of periods a firm does not reconsider changing markets immediately after a change is $\tau = 2$. This parameter constellation has been determined such that the model basically works and yields reasonable outcomes in a sense that the number of active markets over time remains larger than one but smaller than the number of firms and prices on the markets are such that the firms can in general make positive profits. Whereas it turned out that this restricts the set of 'reasonable' parameter constellations quite significantly there is still quite a bit of freedom concerning the choice of the parameter values. The qualitative results we will report below seem to be very robust with respect to variations of parameters in the range of 'reasonable' constellations. The most sensible assumption seems to be the one about the value of τ. We plan to look more closely at the exact effects of a change of this parameter in future work.

Using simulation data generated in this setup we will first discuss the implications of different individual firm's properties for a given strategy of the individual firm. This will provide some first general insights into the structure of the model. We will then go on to examine the optimal strategies of the firm under the different scenarios and finally reevaluate the impact of firm and industry properties and the firm's success under the assumption that the firm chooses its optimal strategy.

Let us first look at the impact of a firm's ability to introduce new products on its average profits. To demonstrate the effect a change in $q_{i,0}$ has, let us first use the case where both the industry and the individual firm are non-innovative. Intuitively one would assume that a higher ability to develop new products should be advantageous for the firm regardless of the industry condition and the firm's strategy. This intuition is indeed supported by the results presented in Table 1. We can clearly see that the firm is always better off if its ability for new product development initially is large. We can also see that this effect is larger if the ability of the industry is low. Whereas the fact that a large $q_{i,0}$ is advantageous seems to be obvious, a closer look at our results for other individual strategies reveals that it is not in general true. Assuming that the individual firm under consideration uses the innovative strategy we get the results presented in Table 2 (still assuming that the industry is conservative):

This shows that for a firm which uses an innovative strategy in a conservative industry a higher ability for product development is detrimental. This result is quite surprising, it can however be understood. Due to the fact that the total market size for all existing product variations is assumed to be fixed, for the demand on a given market only the relative size of the potential of a market, B_j, compared to those of the other existing markets is important. This potential is however determined

		Ind. Firm	
Industry		$q_{i,0} = 0.8$	$q_{i,0} = 0.2$
$q_{ma,0} = 0.8$	$\lambda_{ma} = 2$	$62/43$	$55/34$
	$\lambda_{ma} = 1$	$128/96$	$120/87$
$q_{ma,0} = 0.2$	$\lambda_{ma} = 2$	$77/52$	$62/41$
	$\lambda_{ma} = 1$	$152/110$	$129/97$

Table 1: Comparison of the average profits of individual firms if individual firms as well as all firms in the industry use the strategy $R = 50, S = 1$. The first number gives the profit for $\lambda_i = 2$ the second for $\lambda_i = 1$.

		Ind. Firm	
Industry		$q_{i,0} = 0.8$	$q_{i,0} = 0.2$
$q_{ma,0} = 0.8$	$\lambda_{ma} = 2$	$50/50$	$53/40$
	$\lambda_{ma} = 1$	$68/68$	$97/83$
$q_{ma,0} = 0.2$	$\lambda_{ma} = 2$	$57/56$	$67/57$
	$\lambda_{ma} = 1$	$84/79$	$126/97$

Table 2: Comparison of the average profits of individual firms which use the strategy $R = 50, S = 50$ whereas the rest of the industry use the strategy $R = 50, S = 1$. The first number gives the profit for $\lambda_i = 2$ the second for $\lambda_i = 1$.

by the ability of the firm which developed the corresponding product. In a situation where the other firms in the industry are very reluctant to introduce new products most of the existing markets have been founded by the individual innovative firm. Thus, if the firm already initially has a high ability for product development – which leaves little room for improvements – the potential of all existing markets is fairly equal and the firm gains no advantage from frequent product developments. On the contrary, if the initial ability of the firm is rather low – which implies that its ability rises significantly with every new product development – the expected potential of every new market it founds is substantially larger than that of the average existing market and therefore the innovative firm most of the time deals in markets with above average potential. The size of this effect also depends on the rate of productivity increase of the average firm. If this rate is large the incoming firms dampen the price on a new market very quickly and thus the additional profit which can be earned by founding a new market is rather low. This implies that the effect described above is smaller the more efficient the other firms are in increasing their productivity. Looking at the numbers in Table 2 this can be clearly seen.

Comparing the effects of different rates of productivity increase for the individual firm we see from Tables 1 and 2 that it is always favorable for the firm to have a larger rate.

Let us now look at an innovative industry where the majority of firms use $S = 50$. We present the average profits of the individual firm in such an environment in Tables 3 and 4.

We can see that in an innovative industry a larger initial ability for product development is always advantageous. On the other hand, the effect of an increase in λ_i is not so clear anymore. A larger λ seems to be only advantageous if the other firms in the industry have low initial ability for innovation. If the innovative capacity of the industry is large from the beginning, a small value of λ_i yields higher profits. In such an environment many new products are introduced by the other industry firms which

		Ind. Firm	
Industry		$q_{i,0} = 0.8$	$q_{i,0} = 0.2$
$q_{ma,0} = 0.8$	$\lambda_{ma} = 2$	$9/23$	$7/21$
	$\lambda_{ma} = 1$	$9/22$	$9/21$
$q_{ma,0} = 0.2$	$\lambda_{ma} = 2$	$70/57$	$57/50$
	$\lambda_{ma} = 1$	$101/91$	$92/79$

Table 3: Comparison of the average profits of individual firms which use the strategy $R = 50, S = 1$ whereas the rest of the industry use the strategy $R = 50, S = 50$. The first number gives the profit for $\lambda_i = 2$ the second for $\lambda_i = 1$.

		Ind. Firm	
Industry		$q_{i,0} = 0.8$	$q_{i,0} = 0.2$
$q_{ma,0} = 0.8$	$\lambda_{ma} = 2$	$2/12$	$-5/8$
	$\lambda_{ma} = 1$	$-4/4$	$-5/7$
$q_{ma,0} = 0.2$	$\lambda_{ma} = 2$	$59/62$	$42/45$
	$\lambda_{ma} = 1$	$67/68$	$68/63$

Table 4: Comparison of the average profits of individual firms if all firms use the strategy $R = 50, S = 50$. The first number gives the profit for $\lambda_i = 2$ the second for $\lambda_i = 1$.

have a high ability to do so. Thus, a large number of markets exist in each period and the market sizes are small (remember that total market size is fixed). This leads to small prices in each market, hence profits are also small. Even if a firm is alone in its market, the push strategy makes it not desirable to improve productivity as supply exceeds demand and thus prices and profits will fall even more. Also, a firm that is less productive has less incentives to stay in one market for too long and thus will not miss too many good opportunities in markets founded by other firms. While this seems to imply that inertia should be low in such a scenario, the opposite is true. Low inertia would lead a firm to change markets frequently. The price effect of such frequent changes is negative and thus profits will be smaller than under a higher level of inertia.

Very clear statements can be made regarding the effect of the properties prevailing on the industry on the individual firm's profit. For an individual firm with arbitrary but fixed properties it is always advantageous if the industry's ability for innovation and rate of production improvement are low. Generally speaking it is also advantageous for a firm if the other industry members are non-innovative, although a few exceptions can be found in Table 4.

3.2 Implications for Firm Strategies

In the previous section we have examined the effects of different properties of the firm and its environment on the firm's profit for different given strategies. Now that we have a better understanding of the effects at work in the interplay between the firm and the industry we return to the main question of this paper, namely how a firm should choose its optimal strategy given its properties and a certain state of the industry.

First, we will treat the question whether it is advantageous for a firm to have a low or high level

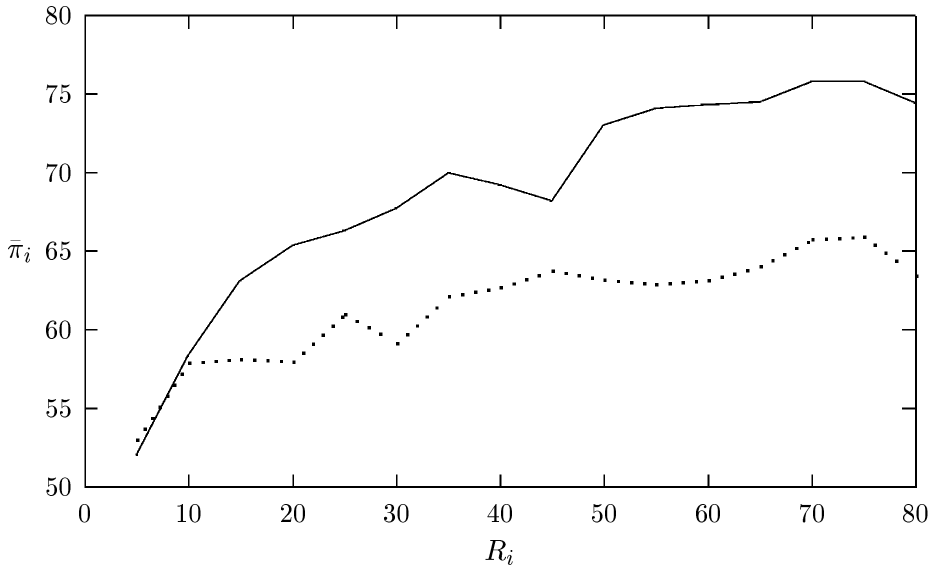

Figure 1: Average profits for different levels of inertia in a highly inert environment $R = 50, S = 1$ (dotted line) and a dynamic environment $R = 5, S = 1$ ($q_{0,i} = 0.5, \lambda_i = 2$).

of inertia. We start by comparing the effects of different levels of inertia for the individual firm in two different industry settings: one in which the average level of inertia in the industry is low, the other one where it is high. The average results for 200 runs in each setting can be seen in Figure 1.

The Figure shows mainly two interesting facts. First, it can be seen that the effect of the individual firm's level of inertia is larger the less inertia there is in the industry. This can be easily understood, if one considers the effect inertia has on the predictability of the future market development. If the average level of inertia in the industry is high, the number of firms in each market is rather stable and therefore future market prices can be better forecasted. Second, a larger level of inertia is favorable for the individual firm in both settings. This is quite understandable if the rate of productivity increase is large since then changing the market implies a loss of acquired technological know how. However, the effect is also present in the absence of productivity gains. Although this result is a little bit surprising one possible explanation might be that the fact that a firm is in a certain market is a signal that the market potential of the market is not very low, since it not only survived for a number of periods but also the firm did not choose to leave the market immediately after it entered.

To check whether these findings are robust with respect to changes in the other parameters of the individual firm and the industry conditions we compare the results for given high and low levels of R and S. To model high and low levels of inertia we chose $R = 50$ and $R = 5$ respectively. A level of $R = 50$ corresponds to the case where a firm which produces for a market with average profitability stays there with a probability of 50% - 80% depending on the value of S. On the other hand $R = 5$ implies that the firm stays in an average market with a probability of less than 25%. Since we are primarily interested in qualitative insights rather than in the actual level of R and S it does not seem to be essential for our argument to use exactly optimal levels of these parameters under all different circumstances. In Table 5 we show the profits for the individual firm for high and low levels of inertia in a large number of different settings. Clearly, our findings from above are confirmed by these additional numerical results. A large level of inertia is always advantageous for the firm. Furthermore

		Ind. Firm							
		$S_i = 1$				$S_i = 50$			
		$q_{i,0} = 0.8$		$q_{i,0} = 0.2$		$q_{i,0} = 0.8$		$q_{i,0} = 0.2$	
Industry		$\lambda_i = 2$	$\lambda_i = 1$	$\lambda_i = 2$	$\lambda_i = 1$	$\lambda_i = 2$	$\lambda_i = 1$	$\lambda_i = 2$	$\lambda_i = 1$
$q_{ma,0} = 0.8$	$\lambda_{ma} = 2$	$62/53$	$43/41$	$55/43$	$34/32$	$50/38$	$50/40$	$53/42$	$40/38$
	$\lambda_{ma} = 1$	$128/109$	$96/90$	$120/104$	$87/80$	$67/57$	$70/54$	$97/82$	$83/74$
$q_{ma,0} = 0.2$	$\lambda_{ma} = 2$	$77/68$	$52/52$	$62/55$	$41/37$	$56/44$	$57/45$	$67/62$	$57/49$
	$\lambda_{ma} = 1$	$152/132$	$110/103$	$129/117$	$97/90$	$84/63$	$79/60$	$126/100$	$97/84$

Table 5: Comparison of the average profits of an individual firm if all other firms use the strategy $R = 50, S = 1$. The first number gives the profit for $R = 50$ the second for $R = 5$.

the industry's level of inertia has no qualitative influence on the individual firm's strategic decision on R. Also, we see again that the difference in the individual firm's profits associated with high and low levels of inertia is much smaller if the average level of inertia in the industry is high. Thus, the implications of the numerical findings as far as the choice of the level of inertia is concerned are quite clear cut.

Thus, we will now turn to the impact of different levels of the propensity for new product development, S. We will see that here the results are less clear cut and more interesting. The basic question we address is under which conditions a firm should introduce its own products and take the role of a industry leader, and under which it should mainly imitate other firm's products and go into existing markets. Analogous to our analysis above we compare the effects of two different levels of S, namely $S = 50$ and $S = 1$. In the first case ($S = 50$) a firm will introduce a new product variant, which it expects to be as good as the existing ones, with a probability of 50% to 75%. The case $S = 1$ means that the firm chooses to introduce a new product variant with a probability of less than 15%. It turns out that the fact whether a high S is preferable to a low one or not indeed crucially depends on the environment. In the following table we show which of the two is preferable in different settings and also provide the corresponding average profit if the optimal strategy is used. Whereas this table

			Ind. Firm			
			$q_{i,0} = 0.8$		$q_{i,0} = 0.2$	
Industry			$\lambda_i = 2$	$\lambda_i = 1$	$\lambda_i = 2$	$\lambda_i = 1$
$S_{ma} = 1$	$q_{ma,0} = 0.8$	$\lambda_{ma} = 2$	$L/62$	$H/50$	$L/55$	$H/40$
		$\lambda_{ma} = 1$	$L/128$	$L/96$	$L/120$	$L/87$
	$q_{ma,0} = 0.2$	$\lambda_{ma} = 2$	$L/77$	$H/57$	$H/67$	$H/57$
		$\lambda_{ma} = 1$	$L/152$	$L/110$	$L/129$	$L/97$
$S_{ma} = 50$	$q_{ma,0} = 0.8$	$\lambda_{ma} = 2$	$L/9$	$L/23$	$L/7$	$L/21$
		$\lambda_{ma} = 1$	$L/9$	$L/22$	$L/9$	$L/21$
	$q_{ma,0} = 0.2$	$\lambda_{ma} = 2$	$L/70$	$H/62$	$L/57$	$L/50$
		$\lambda_{ma} = 1$	$L/101$	$L/91$	$L/92$	$L/79$

Table 6: Optimal levels of the propensity to innovate under different scenarios if the level of inertia in the industry is $R = 50$.

was generated for a case where $R = 50$ for all firms we have run identical batches of simulations for different levels of R and have observed that the patterns of 'L' and 'H' in this table are remarkably robust. These results imply that in most scenarios a low propensity to innovate is advantageous. In particular, it is always advantageous if the firm has a large initial potential for innovations but also has a large rate of productivity increase. This shows that high abilities concerning technological improvement is the dominant factor and thus the firm prefers a strategy with high inertia and little new development even if the ability to develop new products is high. In some sense this means that risk averse behavior of the firm is more profitable (note that of course product innovation is always more risky than technological improvements, even if abilities in both areas are high). Another indicator that the value of λ is actually more crucial for the determination of the innovation strategy than the value of q_{ini} is that a small value of S is always preferable for the firm if the rate of productivity increase in the industry is small. Only if the rate of production increase in the industry is large, which implies that prices in a successful market with a large number of firms goes down fast, a very innovative strategy is successful. In particular, such a strategy tends to be successful if the other firms in the industry are not innovative themselves. In an industry where the other firms use $S = 50$ there is a strong general tendency in favor of a non-innovative strategy. The only exception here is the case where the firms own properties are such that it has a high ability for innovation but a low ability for technological learning. These results very nicely highlight the fact that the qualitative characteristics of the optimal strategy of a firm can not be explained solely by the properties of the firm nor by the industry environment. An understanding of the interplay between the two is crucial to develop such a strategy. Generally speaking an innovative strategy pays off if the other firms in the industry are reluctant to introduce new products and the own abilities for technological learning are below average. It is further interesting to note that the initial ability for innovation plays a minor role.

3.3 Firm and Industry Properties Revisited

Having characterized the strategies a firm should use under different circumstances we will now return to the relationship between firm properties, industry conditions and the firm's profit. In contrast to subsection 3.1 we will now assume that a firm indeed uses the best strategy available. Under this assumption some of our findings in subsection 3.1 have to be reevaluated. Using again Table 6 we realize that for an optimally acting firm increases in λ_i and $q_{0,i}$ are always favorable. The strategies where such increases have negative effects turn out to be inferior. The non-ambiguous results concerning the effects of changes in the industry's rate of productivity increase and ability for innovation still hold under our optimizing assumption.

4 Managerial Implications

Survival in fast changing industries crucially depends on the strategy a firm employs. Managers have to make strategic decisions without having all the necessary information to behave optimally. Thus, they have to estimate the quality of different strategies and choose the one appropriate to achieve the long-run goals. While our results presented in the previous section can't be viewed as ultimate solutions to this decision problem they provide valuable insights in the dynamics that affect a firm's profitability. Our findings enable us to give the following guidelines to managers:

(i) A firm should adopt an innovative strategy only if its technical abilities are below the industry average. If a firm has a competitive advantage on the job-floor it should try to exploit this advantage.

(ii) A firm should try to deviate from the general industry strategy as far as innovation is concerned (i.e. be innovative if the industry is not but rather imitative if the industry is innovative).

(iii) A certain degree of inertia in the production decision is always advantageous (even though there are no explicit switching costs in the model).

(iv) Improvements in the firms technical and innovation abilities might have detrimental effects if the firm does not adapt the product choice strategy accordingly.

From these guidelines it is quite obvious that internal as well as external forces influence a firm's strategic decision to innovate and the profit associated with this decision. The last item stresses the importance of a good fit between a firm's strategy and internal as well as external factors. Thus not only abilities and environmental scenarios affect a firm's long run success, but the interplay between those two factors together with the right strategy choice. A final remark we want to make is, that while the innovation ability of a firm is related with a firm's profitability it has only minor importance for the choice of the appropriate innovation strategy.

5 Conclusions

In this paper we have used an agent-based simulation model to examine the question how firm properties and industry conditions affect the optimal production strategy of a firm competing in a market where regularly new distinctive product variants are introduced, go through a life-cycle and vanish. The results reported here are based on more than 40000 simulation runs we have carried out. We have shown that the effects of changes in the abilities of an individual firm and the 'industry' firms are in general as should be expected. In particular, assuming that the individual firm always uses an appropriate decision strategy, increasing technical and innovative abilities of the firm itself as well as decreasing abilities of the industry firms increase the firms profit. In the previous section we have given managerial implications of our findings. These are meant to help managers understand the factors that affect their decisions concerning innovation. They are also guidelines for decision makers. We showed that a broad picture has to be drawn to completely understand the dynamics underlying the success or failure of innovativeness.

Besides the implication of this particular model we have demonstrated how an agent based market model can be used to derive abstract although non-trivial insights about how the production and product design decision in a firm should be adapted to the interplay of the properties of the firm and the characteristics of the industry the firm is dealing in. Although it might be difficult to exactly translate the parameters in our model to observable properties of real world markets we hope to have shown that general insights can be obtained using such an approach. Thus, we believe that agent based models have a large potential for successful application not only in economic modeling but also in more management science oriented research.

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Appendix

Calculation of the Estimates $\chi_{j,t}$ and $\chi_{i,t}^{new}$:

Consider first the estimate for the profitability of an existing market j. Since a firm has to stay in this market for at least τ period but can leave without any further switching costs afterwards we assume that the firm is only interested in estimating the profit within this time interval. Firms know the current aggregate output, current prices and therefore the current market size of all active markets. Furthermore, they know for each product variant when it was introduced into the market and also the average life span L. If we denote by $\hat{a}_{j,t}$ the market forecast for market j at a future period t and by $\hat{X}_{j,t}$ the estimated future aggregate output on the market the estimations for future market prices and profits are

$$\begin{aligned} \hat{p}_{j,t} &= [(\frac{\hat{a}_{j,t+l}}{\hat{X}_{j,t+l}})^{1/\gamma} - 1]\frac{1}{\beta} \\ \chi_{j,t} &= max[0, \sum_{s=1}^{\tau}(\frac{\hat{X}_{j,t+s}}{\Psi_{j,t}}\hat{p}_{j,t+s} - c)], \end{aligned}$$

where $\Psi_{j,t}$ is the current number of firms in market j. Note that the only unknown parameter for the firms in the demand function is the market size and thus they can carry out these calculations. To estimate future market sizes the firm has to estimate the market potential. Given an estimated market potential $\hat{B}_j$ and a current market size $a_{j,t}$ the market forecast at time t is given by:

$$\hat{a}_{j,t+l} = a_{j,t} + \alpha\hat{B}_{t+1,j}\sum_{s=1}^{l}(1/2L - (t + s - t_j^{ini})).$$

Note further that the expression $\frac{\tilde{a}_{j,t} - \tilde{a}_{j,t-1}}{(1/2L - (t - t_j^{ini}))}$ gives a signal of B_j. A priori firms estimate the market potential of a market founded by some firm i as the estimated innovation ability of the firm (see below): $\hat{B}_{j,t_j^{ini}} = \hat{q}_{i,t_j^{ini}}$. As soon as developments of the market size can be observed the firm uses the estimator below to update $\hat{B}_{j,t}$:

$$\hat{B}_{j,t+1} = \frac{w_{j,t}}{w_{j,t} + 1}\hat{B}_{j,t} + \frac{1}{w_{j,t} + 1}\frac{\tilde{a}_{j,t} - \tilde{a}_{j,t-1}}{(1/2L - (t - t_j^{ini}))\alpha},$$

where $w_{j,t}$ is a counter indicating the number of observations $\hat{B}_{j,t}$ is based on. The estimator of the innovative potential of a firm is generated in a similar way. It is initialized with the average ability $\hat{q}_{i,0} = 0.5\ \forall i \in I$ and afterwards updated every period as follows:

$$\hat{q}_{i,t+1} = \frac{v_{i,t}}{v_{i,t} + |\Phi_{i,t}|}\hat{q}_{i,t} + \frac{1}{(v_{i,t} + |\Phi_{i,t}|)}\sum_{j \in \Phi_{i,t}}\frac{\tilde{a}_{j,t} - \tilde{a}_{j,t-1}}{(1/2L - (t - t_j^{ini}))},$$

where $\Phi_{i,t}$ is the set of active markets at time t which have been founded by firm i. To understand this estimator it has to be kept in mind that the market potential of a market is an unbiased signal of the innovative ability of the founding firm. Finally, changes in the aggregate output on a market are naively forecasted using the last rate of change:

$$\hat{X}_{j,t+l} = \left(\frac{X_{j,t}}{X_{j,t-1}}\right)^l X_{j,t} \quad l = 1, \ldots, \tau.$$

The profitability of introducing a new product does not only depend on the innovative ability of the firm but also on the other firms estimation of this ability – which determines the expected number of early competitors in the market – and the potential of all other currently active markets. Taking into account all this factors would make the estimation here even more involved than for already existing markets. Therefore we assume that firms estimate the profitability of founding a new market simply as the average profit the firm has earned in the first τ periods of previous foundings of new markets. Before the firm has founded a market for the first time this estimate is always the average value of the profitability estimates of all existing markets.