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An Artificial Environment for Simulating Corporate Strategy

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Abstract

The paper introduces an environment for agent-based simulation of corporate strategy. The environment consists of specifications for internal and external factors like cost or market structures that influence corporate strategy, as well as a framework for operational and strategic decisions made by the agents. The entire system is implemented in MATLAB and will be used in a first set of experiments to test the fit of diversification and core competence-based strategies to various types of environment.

1 Introduction

The relationship between research on corporate strategy and economic theory has always been a delicate one (Besanko, Danove, & Shanley, 1996; Khanna, Gulati, & Nohria, 2000). On one hand, in neoclassical economic theory, most problems and phenomena that characterize corporate strategy simply do not exist. At the focus of corporate strategy, there is the quest for sustainable, above average profit. This quest is, of course, a direct contradiction to the neoclassical equilibrium, in which only the most efficient firms survive, and even those firms have zero profit.

On the other hand, the fact that neoclassical economics renders strategy more or less obsolete has directed researchers on corporate strategy to focus their attention, and thus base their strategy recommendations, on the differences between the assumptions of economic theory and economic reality.

Apart from the bounded rationality of actors (Schoemaker, 1990; Amit & Schoemaker, 1993; Greve, 1998), one obvious source of such differences is the lack of perfect markets. Consequently, much of the current literature on strategy can be interpreted as a search for market imperfections. This is clearly evident by the literature on strategy inspired by Porter's five competitive forces (Porter, 1998a), which more or less describe imperfections of product markets and leads to the conclusion that a firm (or, more in line with Porter's arguments, an industry) is able to achieve sustained profits only if its product markets are imperfect. Similarly, the resource based view of strategy (Barney, 1986; Peteraf, 1993; Wernerfelt, 1984, 1995; Spanos & Lioukas, 2001) can be seen as a quest for imperfections in factor markets.

However, in their quest to exploit the differences between the assumptions of economic theory and existing markets, strategy research with a few notable exceptions (Karnani, 1984; Khanna et al., 2000;

Vining & Meredith, 2000; Bruggeman & Nuallain, 2000) has abandoned much of the analytical rigor that characterizes economic models. This development is quite natural, since most of the market imperfections that play a dominant role in strategy result from the dynamics and the complexity of the systems involved, which defy most of the analytical tools available today.

While complex, dynamic systems cannot be analyzed with models that generate nice, closed form solutions, they still might be amenable to quantitative studies using simulation models. Simulation models, often employing agent-based approaches, are increasingly being used to analyze complex, dynamic systems in areas as economics (Holland & Miller, 1991; Judd, 1997; Tesfatsion, 2000) or organization theory (Carley, 1995), which obviously share many common traits with problems in corporate strategy. Thus we propose that simulation models using agent technology might also be useful tools for analyzing corporate strategy.

Several benefits can be expected from this approach. First of all, while most of the strategy literature commonly refers to economic concepts like productivity, demand, preferences etc., most of these concepts and even more their relationships are only ambiguously defined. Incorporating these concepts into simulation models will force us to provide a precise definition of the concepts and their interactions. There is of course no guarantee that our definitions will be correct in whatever sense. But by explicitly stating them in formal ways, they can be subject to analysis and criticism by others in ways that the more ambiguous concepts from the traditional strategy literature never are.

The ambiguity of concepts and verbal methods of analysis leads traditional strategy research to consider only relationships between a limited number of variables, thus ignoring the very complexity of economic systems that invalidates many of the assumptions of economic theory. Consequently, traditional strategy literature tends to overestimate the generalizability of results obtained, leading to "one size fits all" types of solutions for strategic problems. By embedding many different concepts in simulation models, we expect to be able to gain insight into the particular settings in which our results are applicable, and those settings where they are not.

By providing a precise, formal definition of concepts, modeling undertaken to develop computer simulations might also form an excellent docking point for empirical research. While there has always been a tendency in the strategy literature to perform empirical studies on hypotheses derived from theory, this empirical research often has lead to inconclusive results. One reason for obtaining mixed results is that different studies operationalize ambiguous concepts from the strategy literature in different ways.

In the present paper, we present a first step towards an artificial environment to analyze corporate strategy. We develop specifications for external and internal factors like cost structures or markets, in which artificial "strategy agents" will operate, as well as basic functionalities of such agents. The simulation environment described here has been implemented and tested for one specific research question, the fit of diversification and core competence strategies to different types of environment. In the present paper, we will not provide detailed results concerning this question, but rather focus on the specification of the environment and the agents in order to create a reference about the artificial strategy environment, on which future applications can be based.

The present paper is structured as follows: in section two, we give an overview of the research question studied in the pilot project and the global structure of the artificial strategy environment. Section three provides detailed information about the various components and section four describes the technical implementation. Section five gives an outlook on possible uses of the environment.

2 Overview

2.1 Research Goals

Strategy is a complex, multidimensional concept that can be analyzed at several levels (Hax & Majluf, 1988; Venkatraman, 1989). One important distinction differentiates between strategy at the corporate, business, and functional levels (Wheelwright, 1984; Varadarajan & Clark, 1994). Corporate strategy deals with the management of a portfolio of individual business units, its composition and the allocation of resources to business units. Business strategy describes how a single business unit tries to achieve competitive advantage versus its competitors, and functional strategies refer to single functional areas within one business unit.

Our main research question is located at the corporate level. While there has been some discussion about the importance of strategy at this level, there is convincing evidence that economic results cannot be explained by taking into account just data at the business unit level, and that strategy at the corporate level is indeed an important factor (Bowman & Helfat, 2001).

One important strategic question at the corporate level is the composition of the portfolio of business units of a company. There has been a long debate in the strategy literature on the benefits of diversification into a broad range of different businesses vs. following a more focussed, core-competence oriented (Gorman & Thomas, 1997) strategy. While some authors (Keats & Hitt, 1988; Wiggins & Ruefli, 2002) found only weak empirical evidence for benefits of a diversification strategy, others argued that diversification is indeed beneficial provided that a firm diversifies into products that react differently to business cycles (Amit & Livnat, 1989), or products that use similar resources (Markides & Williamson, 1996) and when possible synergies are adequately managed (Hill, 1995). Others argued that rather than following a pure diversification or pure core competence strategy, firms should aim for a modest amount of diversification to find an optimum balance between reducing competition by differentiating and maintaining legitimacy by similarity to other firms (Deephouse, 1999).

From a more theoretical perspective, the dichotomy between diversification and focussed strategies was extended by (Miles, Snow, Meyer, & Coleman, 1978), who added the frequency of new product introductions as an additional parameter and thus distinguished four basic strategies:

- The *prospector* strategy has a strong focus on diversification and innovation. Firms following this strategy are characterized by high rates of innovation and introduce highly diversified products.
- The *analyzer* strategy is also characterized by high innovation rates, but unlike in the prospector strategy, new products are more similar and build on common core competencies.
- The *defender* strategy combines a core competence focus with low innovation rates. Firms using this strategy focus on continuous development and refinement of existing core products.

- The fourth strategy combines low innovation rates with a high degree of diversification between products. It was labelled *reactor* by Miles and Snow, who attributed the wide diversification to a lack of clear focus rather than a conscious strategic choice.

Miles and Snow further proposed that these strategies would fit to different environments. A prospector strategy should be most appropriate in a dynamic, growing environment, while a defender strategy would be more suitable in a stable environment and the analyzer strategy takes a middle position.

There are several possibilities how an artificial strategy environment can be used to test these propositions. In a direct approach, which is used in the current set of experiments, agents follow a predetermined strategy that corresponds to one of the prototypical strategies identified by Miles and Snow. A group of agents using different strategies competes in a given environment. According to the theory, agents using a strategy that is particularly well suited to the environment selected, should, in the long run, perform better than other agents. By performing systematical experiments using different types of environments, the match of strategies to environment types can be validated.

A more elaborate type of analysis would consider strategy as an endogenous variable and allow agents to adapt their strategies using a suitably type of optimization method, for example genetic algorithms. Over time, agents should develop strategies that are best suited to their respective environments according to the theoretical predictions.

2.2 Components of the Environment

The competitive position and thus the long-term profits of a firms are influenced by (Keats & Hitt, 1988):

- its strategy,
- its structure,
- internal factors and
- external factors.

Strategy in our framework is associated with the breadth of a firm's value creating activities, i.e. the number and similarity of its product. Following earlier research (Natter, Mild, Feurstein, Dorffner, & Taudes, 2001; Krishnan & Ulrich, 2001), we characterize products by n-dimensional feature vectors. The similarity of products can thus be measured by their distance in feature space. This distance can be considered as a measure of product diversification similar to the spread in industry classification codes that is often used in the empirical literature (Amit & Livnat, 1989). While other approaches to measure diversification like discrete classifications (Keats & Hitt, 1988), concentric indices (Davis & Thomas, 1993) or entropy (Kim, 1989; Hoskisson, Hitt, Johnson, & Moesel, 1993) are used in the empirical literature, this measure is directly linked to the representation of product characteristics used in our simulation and thus most consistent with our approach.

The most prominent internal factor mentioned in the strategy literature is the cost position of a firm. In the strategy literature, the cost position is usually not considered as static, but in a dynamic context. Changes in the cost position of a firm occur for two reasons: as the result of a conscious strategic effort by the firm leading to investment in more efficient equipment, cost reduction programs etc. The cost position also changes more or less automatically over time due to learning effects, which are commonly modeled by learning curves (Belkaoui, 1986). Learning curves relate efficiency of production (measured usually by unit costs) to the cumulated output of a firm. Diversification on the other hand is often expected to increase the costs of a firm (Kekre & Srinivasan, 1990).

The cost position of a firm, as well as its capability to exploit possible synergies between products, is also influenced by the organizational structure (Hill, 1995). In the present model, firms are viewed as homogenous entities without an internal structure, so this aspect is not represented.

External factors which influence a company's long run profits are related to the market(s) in which the firm operates. Research on corporate strategy has always been aware of the fact that markets are not static, but evolve over time (Amit & Schoemaker, 1993). Consequently, the concept of product life-cycles has always played a prominent role in the strategy literature (Onkvisit & Shaw, 1989; Porter, 1998b). More recent research has stressed that development of markets does not necessarily follow such a clear-cut pattern, but rather might be characterized by unexpected disruptions like the emergence of new technologies, which make existing product obsolete and thus cut short their life cycle (D'Aveni, 1999).

3 Component Descriptions

3.1 Internal Factors

3.1.1 Products and costs

In economic theory, cost functions are derived from production functions, which represent the transformation process by which inputs (factors) are transformed into outputs (goods or services). Thus, one can define a cost function for every product a firm manufactures, and the firm's total costs are the sum of costs for all its products. Products in such a framework are discrete entities, which could be identified by indices.

Our notion of strategy is based on the composition of the product portfolio of a firm. This product portfolio changes over time, and the way in which the product portfolio is changed is an important strategic decision. Thus we need a more elaborate representation of different products, their similarities and possible synergies, than just indices. Following much of the product innovation as well as the marketing literature (Krishnan & Ulrich, 2001), we characterize products by a vector of features, which are measured on a metric scale.

In the literature, sometimes a distinction is made between technical features and perceptional features of a product (Natter et al., 2001). Technical features are physical characteristics of a product, e.g. the power of a car's engine. Perceptional features represent concepts the customers use in evaluating a product, e.g. whether it is a "sporty" car. While perceptions are influenced by technical features, they might also be influenced by other factors like advertisement. Since we do not, at the present time, model this kind of activities, we use only one kind of feature vector.

It is possible to represent product innovations in this framework as long as these innovations concern features already contained in the vector. This does not consist a restriction in the generality of the model, since at the beginning of the simulation, all products available in the market might have a value of zero in some attributes. The first product with a non-zero value in an attribute is then a technological innovation introducing "new" features.

We denote a firm's product portfolio at time t by S_t. Each product $k \in S_t$ is characterized by its feature vector $f_k = (f_{k,1}, f_{k,2}, \ldots, f_{k,N})$, where N is a constant throughout the simulation. The number of units of product k produced in period t is $x_{k,t}$.

One important aspect which the cost function needs to capture is the development of core competencies and the effect of synergies when related products are manufactured using the same core competencies. We therefore use a formulation in which the costs of manufacturing a given product depend on its similarity to products manufactured in both the current and past periods.

To model this effect, we introduce the firm's current "focus of knowledge", which we denote by E_t. E_t is a point in the feature space, its location is determined over time as

$$E_t = \lambda E_{t-1} + (1 - \lambda) F_t \tag{1}$$

where

$$F_t = \left(\frac{\sum_{k \in S_t} x_{k,s} \cdot f_{k,1}}{\sum_{k \in S_t} x_{k,s}}, \ldots, \frac{\sum_{k \in S_t} x_{k,s} \cdot f_{k,N}}{\sum_{k \in S_t} x_{k,s}} \right) \tag{2}$$

is the weighted average of features of all products manufactured in the current period. Parameter λ represents the relative importance of current vs. past experience on costs. For $\lambda = 1$, costs depend only on past experience, for $\lambda = 0$, only the present period is of importance.

Each unit of product k enters the firm's cost function with a weight of

$$c_{k,t} = 1 + \gamma_{k,t} \cdot d_{k,t} \tag{3}$$

where

$$d_{k,t} = \sqrt{\sum_n (f_{k,n} - E_{n,t})^2} \tag{4}$$

is the Euclidean distance of a product's feature vector to the firm's current focus of knowledge, and $\gamma_{k,t}$ is a scaling parameter. Thus a product located exactly at the firm's "focus of knowledge" is a standard product, which is used as a reference value for manufacturing costs. The more a product differs from this (hypothetical) standard product, the higher are its unit costs.

To allow for (dis-)economies of scale, we specify the firm's total costs in period t similar to (Karnani, 1984) as :

$$K_t = \beta_t \left(\sum_{k \in S_t} x_{k,t} \cdot c_{k,t} \right)^{\alpha} \tag{5}$$

where β_t is a parameter denoting the overall efficiency of the firm in period t. It should be noted that for $\alpha \neq 1$, cost function (5) makes it impossible to allocate costs correctly to products. Thus any production decision which the agent makes will necessarily be based on approximate unit costs and estimates about the consequences of production decisions will only be approximations of the true changes.

In addition to these variable costs, we also consider fixed costs at two levels: fixed costs of individual products Kp_k are incurred whenever product k is manufactured at all, and corporate fixed costs Kc are always incurred. The value of Kp_k is determined as a random number when product k is introduced and remains constant over time. Kc is generated at the beginning of the simulation and is also constant.

3.1.2 Cash Flow

The cash flow of each firm for period t is given by :

$$CF_t = \sum_{k \in S_t} xd_{k,t} p_{k,t} - \beta_t \left(\sum_{k \in S_t} x_{k,t} \cdot c_{k,t} \right)^{\alpha} - \sum_{k \in S_t} Kp_k - Kc \tag{6}$$

The cash flow consists of a revenue component and a cost component. The revenue component is based on the prices ($p_{k,t}$) set by the firm, and the actual sales ($xd_{k,t}$) of each product k. Actual sales are determined by the market model described in section 3.2 and might be less than the amount produced. Products are assumed to be not storable, so any units produced but not sold constitute a loss to the firm.

Cash outflows result from variable costs according to (5) as well as the various types of fixed costs.

Free cash flows are used by the firm to implement its strategy. Specifically, they can be used to

- introduce new products,
- extend production capacity, or
- improve the efficiency of production.

The frequency of new product introductions is determined by the (given) strategy of an agent. Investments into production capacity or efficency improvements are set autonomously by the agent.

3.1.3 Learning and investment effects

Over time, the cost position of a firm will change due to learning and productivity enhancing investments. Both effects can take place at the aggregate firm level as well as the level of individual products. In our model, this corresponds to changes in parameters β and γ. Since relationships between the different products are an important part of our model, we only consider effects at the firm level and thus influences on parameter β, which is varied over time according to the following equation:

$$\beta_t = \beta_0 \cdot \left(\sum_{\tau < t} \sum_{k \in S_\tau} \frac{x_{k,\tau}}{1 + d_{k,\tau}} \right)^{\beta_1} \cdot \frac{1}{1 + \ln \left(1 + \sum_{\tau < t} Inv_\tau \right)} \tag{7}$$

In equation (7), the first term represents learning effects and the second represents the effects from productivity enhancing investments. Learning is modeled as a standard learning curve (Belkaoui, 1986) with a learning rate of

$$r = 2^{\beta_1} \tag{8}$$

where $\beta_1 < 0$. By weighting the amount manufactured of each product by its distance to the focus of knowledge, we take into account that products which are dissimilar to other products also contribute less to organizational learning.

The second factor represents the effects of productivity enhancing investments, for which we assume decreasing returns. The expression

$$\sum_{\tau<t} Inv_\tau \tag{9}$$

represents the cumulated investment in productivity enhancements of previous periods. Thus we assume that effects on productivity of earlier investments will continue, even when new investments are made.

3.1.4 Short run production and marketing decisions

In each time period, the agent has to make short run decisions on the amount to be manufactured of each product and the price to be asked for each product. Products can not be stored between periods, so no inventory decisions need to be made.

In this planning process, the agent takes the following information into account:

- the plan of the previous period,
- a demand forecast for the next period,
- cost information,
- the total production capacity.

The plans of the previous period are stored in the agent's memory. The actual amount sold, on which the forecast is based, is determined by the market model, which will be explained in section 3.2. We do not assume that the agent has perfect information about the cost function (5), but that the agent uses a standard cost accounting system which allocates the observable total costs to the products. The production capacity at the beginning of the simulation is exogenously given. During the simulation, the agent can increase this capacity by investments.

The production and sales plans of an agent are developed in two stages. At the first stage, the agent considers each product individually. At the second stage, all products are considered simultaneously to take into account capacity restrictions.

In the first stage, the agent determines a target volume and a target price for each product. Both target volume and target price are dynamically adjusted using data of the previous period, forecasts for the demand of the current period and simple heuristics:

Firms can forecast demand for one period using the method of exponential smoothing. The forecast $\widehat{xd}_{k,t+1}$ is calculated as

$$\widehat{xd}_{k,t+1} = (1-\varphi)\widehat{xd}_{k,t} + \varphi xd_{k,t} \tag{10}$$

where parameter φ controls the speed of adjustment.

When the sales forecast for $t+1$ exceeds the target level x_t set for the previous period, the agent increases the target volume by a (small) random amount. At randomly selected periods, the target price is also increased.

When a sales forecast fall below the target volume of the previous period, the action taken by the agent depends on the cost situation. If the current target price exceeds the unit costs by a sufficient margin, the target price is lowered. Otherwise, the target volume is lowered. Thus, the agent will eventually cease to manufacture a product which cannot be sold at a price recovering the agent's (estimated) costs.

For new products, the initial production volume is set to a fixed level, and the target price is set to the estimated variable costs of the product, multiplied by a constant markup factor.

In the second stage, production capacity is allocated to products based on their estimated contribution margins. For simplicity, we assume that each product manufactured utilizes one unit of available capacity C_t. Let $p_{k,t+1}$ denote the target price of product k and $\overline{x_k}$ the target volume as determined in stage one. The firms are not aware of their true cost function (5) but only know the total costs K_t and the "standard product equivalents" $c_{k,t}$ of each product when planning for period $t+1$. Historical unit costs of each products are thus estimated as

$$\hat{u}_{k,t} = K_t \cdot \frac{c_{k,t}}{\sum_k c_{k,t} x_{k,t}} \tag{11}$$

The contribution margin for product k is then calculated as

$$d_{k,t+1} = p_{k,t+1} - \hat{u}_{k,t} \tag{12}$$

The firm thus assumes that it will actually be able to sell the product for the target price, and that costs will not change in the next period. The products are ranked in descending order of their contribution margins. The marginal product m is then identified according to the following conditions:

$$\sum_{k:d_k>d_m} \overline{x_k} < C_t \tag{13}$$

and

$$\sum_{k:d_k>d_m} \overline{x_k} + \overline{x_m} \geq C_t \tag{14}$$

Production volumes x_k are then set as follows:

$$\begin{aligned} x_k &= \overline{x_k} && \text{for } k : d_k > d_m \\ x_m &= C_t - \sum_{k:d_k>d_m} x_k && \\ x_k &= 0 && \text{for } k : d_k < d_m \end{aligned} \tag{15}$$

Thus products with a contribution margin less than the marginal product are not manufactured at all. This decision can however be reversed in the following periods, since the product is still in the firm's product portfolio and has a positive target volume.

3.1.5 Introduction of new products

The frequency of new product introductions and the types of innovation depend on the type of the firm. Since Miles and Snow do not assign the reactor strategy to any type of environment and because empirical findings show that this strategy is of little relevance in practice (Slater & Olson, 2001), we only consider three distinct types of strategies:

- diversifier,
- variator,
- core competence firm.

Diversifying firms have a very high probability for developing new products and they try to launch very different products to ensure the coverage of the complete feature space as far as possible. In contrast, variators have the same rate of innovation, but their products are less dispersed in feature space. Core competence focused firms are exactly the opposite of diversifiers. They focus only on a small sector of the feature space and hardly ever launch a new product (Figure 1). The competitive advantage of this strategy is a very high conformity of product features with desired features of consumers and lower costs for production and product development.

On the other hand, a core competence focus causes firms to compete in few closely related markets and therefore they have a higher operating risk (Amit & Livnat, 1989) as markets may break away instantly due to disruption or a change in consumer preferences (D'Aveni, 1999). Figure 2 shows the movement of the knowledge focus in feature space depending on the firm type. The plot indicates that diversifiers can react much better to changing customer requirements than core competence firms.

The distinction between diversifiers and variators reflects the cost advantages due to related diversification (Wernerfelt, 1984) where we assume that similarity of products is correlated with similarity of resources needed to manufacture those products (D'Aveni, 1999).

For the positioning of products in feature space at the beginning of the simulation, we assume that firms have a vague idea about consumer preferences. Core competence focused firms and variators launch their products between the two markets that have the smallest distance in feature space so that they have a chance to compete in at least two markets with their narrow product portfolio. Diversifiers on the opposite determine the most extreme consumer preferences that exist in the market and try to cover all preferences between these coordinates.

After creating their initial product portfolios, firms adapt them to the market situation according to their strategies. Variators take the past product performance into account each time they develop a new product. They determine the new product features by moving a predefined distance from their knowledge focus into the direction of the two most successful products of their portfolio. The exact direction depends on the ratio of the turnovers of the two products. This way they can move around

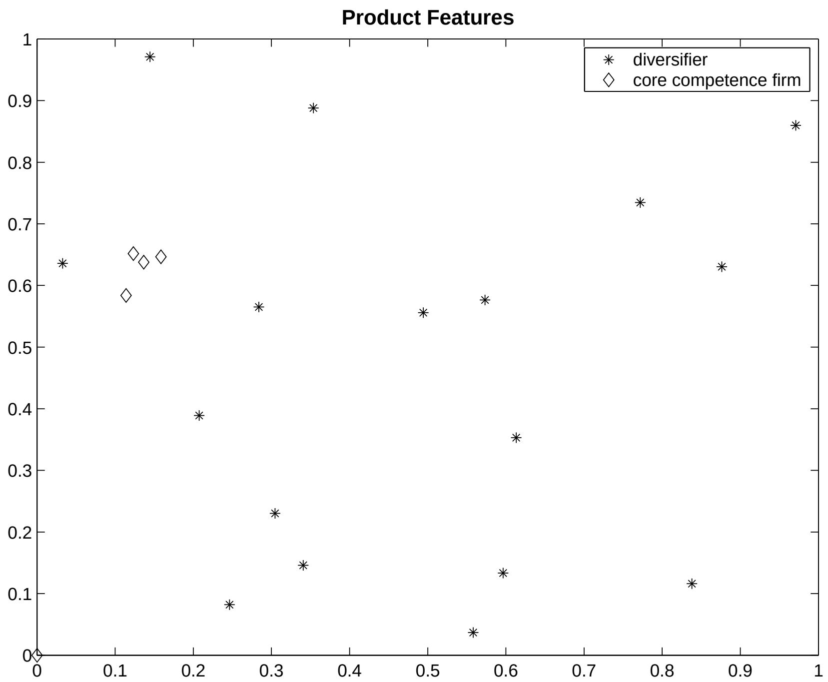

Figure 1: Product features of different firm types

in feature space and adopt their products according to consumer preferences without increasing the dispersion of their portfolio.

Core competence focused firms use the same algorithm for launching a new product, but as their innovation rate is per definition much lower, they can hardly react to changing external influences. In contrast, diversifiers try deliberately to increase dispersion and calculate the direction that allows them to move as far as possible away from their knowledge focus. The ideal outcome of this behaviour would be heterogenous products spread all about the feature space with a knowledge focus in the middle of the feature space.

3.1.6 Investment decisions

Depending on the firm type (3.1.5) there are four actions a firm can undertake to allocate its cash-flows:

- new product development,
- investment in productivity,
- investment in capacity,
- saving of cash flows.

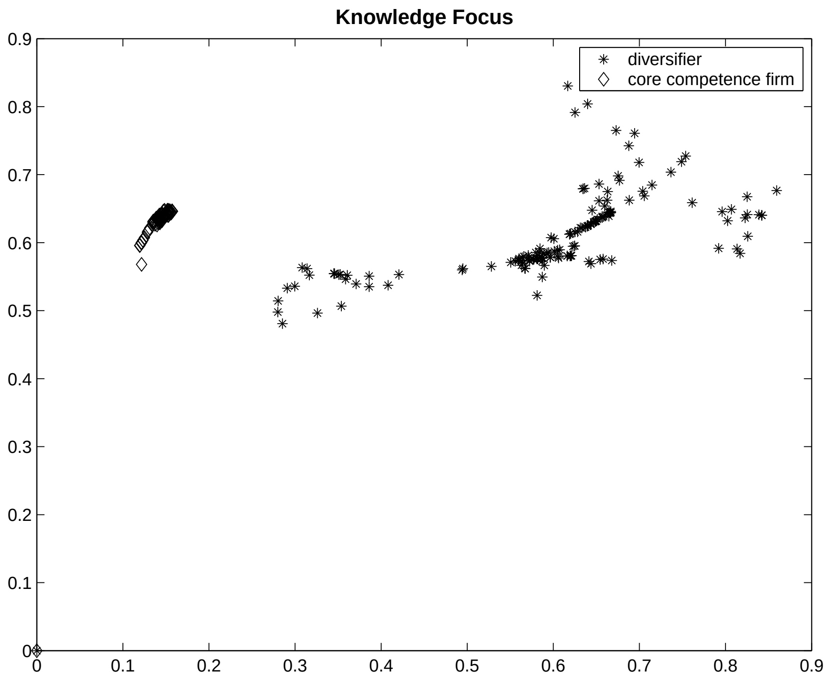

Figure 2: Change of knowledge focus over time

New product development is the only investment alternative that firms can not decide autonomously in the current model. The probability for product development is exogenously given for every firm type (cf. section 3.1.5). If a firm is about to develop a new product in a randomly selected time period, it must use its free cash flow for that purpose and thus cannot realize one of the three remaining alternatives. This enables us to observe the impact of stable firm strategies on the cash flows (or other measure of success) under different environmental settings. It could be a possible enhancement for future research to model firms that can switch between strategies depending on environmental influences. This step of course presumes validated results of strategy impact from the current model.

For the other investment decisions, firms calculate the impact of their investment alternatives on the total cash flow for the next period and select the investment which will lead to the highest revenues.

Productivity improving investments will reduce costs. Their effect can be estimated by differentiating the efficiency parameter $\hat{\beta}_{t+1}$ which is expected by the firm for the next period. Using (7), this parameter can be written as:

$$\begin{aligned}\hat{\beta}_{t+1} &= \beta_0 \cdot \left(\sum_{\tau \leq t} \sum_{k \in S_\tau} \frac{x_{k,\tau}}{1 + d_{k,\tau}} \right)^{\beta_1} \cdot \frac{1}{1 + \ln\left(1 + \sum_{\tau \leq t} Inv_\tau\right)} \qquad (16)\\ &= A \cdot \frac{1}{1 + \ln\left(1 + \sum_{\tau \leq t} Inv_\tau\right)}\end{aligned}$$

$$\frac{\partial \hat{\beta}_{t+1}}{\partial Inv} = A \cdot \frac{1}{\left(1 + \ln(1 + \sum_{\tau \leq t} Inv_\tau)\right)^2} \cdot (-1) \cdot \frac{1}{1 + \sum_{\tau \leq t} Inv_\tau} < 0 \qquad (17)$$

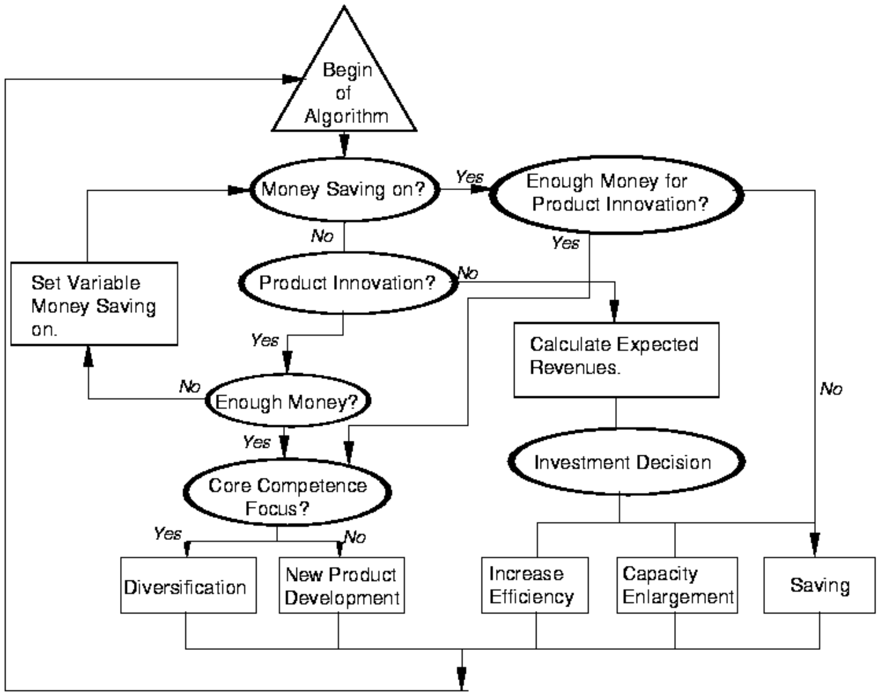

Figure 3: Investment decision

and since

$$\frac{\partial K}{\partial \beta} > 0 \tag{18}$$

an investment into productivity enhancements will indeed reduce costs. In the first period, this will also increase the free cash flow, in later periods, the firm can pass on the cost reduction to the consumers by lowering its prices.

Capacity enhancing investments influence total costs and turnover at the same time:

$$K_{t+1} = \beta_{t+1} \left(\sum_k x_{k,t+1} c_{k,t+1} \right)^{\alpha} \tag{19}$$

$$\frac{\partial K_{t+1}}{\partial x_{k,t+1}} = \beta_{t+1} \alpha \left(\sum_k x_{k,t+1} c_{k,t+1} \right)^{\alpha - 1} c_{k,t+1} > 0 \tag{20}$$

$$U_{t+1} = \sum_{k \in S_{t+1}} x d_{k,t+1} p_{k,t+1} \tag{21}$$

$$\frac{\partial U_{t+1}}{\partial x d_{k,t+1}} = p_{k,t+1} > 0 \tag{22}$$

The results in (20) and (22) indicate that a marginal unit of output increases both costs and turnover. As firms only sell products with a positive contribution margin, additional output has a positive effect on the firm's cash flow if the demand forecast is appropriate. For the case of an overestimation of demand this might be not true. As a short term impact firms with this approximation error will generate sunk costs through overproduction and in the long run excess supply causes firms to decrease prices and therefore reduce the contribution margin of their products.

3.2 External Factors

3.2.1 Product lifecycles

Firms do not offer their products on specific markets, but rather manufacture products with specific features and offer them to all consumers. Consumers from various markets may demand a firm's products, but the firm does not perform a segmentation of consumers via market research. Thus the firm is not aware that different markets do exists, but only observes cumulated demand for its products. Each product of a firm can be sold on different markets and it is possible that several products of one firm compete against each other in the same market.

Markets are modeled at the aggregate level, not at the level of individual consumers. While it would be possible to link the strategy agents described here to consumer-based market simulations like SIMSEG (Baier & Mazanec, 1999), this is not the aim of this first stage of development. At the aggregate level, each market is characterized by a point in feature space, which can be considered as the ideal product for a group of consumers. These ideal points are not known to firms and can move in feature space in the course of the simulation. During the simulation, new markets are created, while existing markets may decline and eventually vanish.

A market follows a product lifecycle as it is commonly assumed in the corporate strategy literature (Porter, 1998b; Onkvisit & Shaw, 1989). We denote the maximum size of market m by g_m and the relative size at time t with respect to its maximum size by z_t. Product lifecycles correspond to a certain pattern of the relative market size over time.

In the corporate strategy literature, product lifecycles are usually defined in terms of four phases: an introduction phase characterized by slow growth, a growth phase in which sales rapidly increase, a maturity phase in which sales stabilize at a high level and a phase of decline, in which the market deteriorates. The first three phases thus form an s-shaped curve.

The pattern of the first three phases corresponds to a diffusion process as it is studied in the context of new product introduction (Bass, 1969). Such diffusion processes can be modeled by a differential equation describing the development of the relative size of the market as:

$$z'_t = \delta_0 \cdot z_t + \delta_1 \cdot z_t \cdot (1 - z_t) \tag{23}$$

where δ_0 represents the adoption rate of innovators and δ_1 the adoption rate among imitating users of the product.

While the parameters δ_0 and δ_1 have a convenient interpretation in terms of the diffusion process, they cannot be related directly to the duration of the product lifecycle. Solving equation (23) under the starting condition $z_0 = 0$, we obtain the time path for z_t as

$$z_t = \frac{\delta_0 \left(e^{(\delta_0+\delta_1)t} - 1\right)}{\delta_0 e^{(\delta_0+\delta_1)t} - \delta_1} \tag{24}$$

Using equation (24), the point in time at which the market reaches a certain fraction q of its ultimate size g_m can be determined as

$$t(q) = \frac{ln\left((\delta_0 - \delta_1 q)/(\delta_0(1-q))\right)}{\delta_0 + \delta_1} \tag{25}$$

This relationship can be used to calibrate the product lifecycle in the simulation. Although it is not possible to solve (25) analytically for the parameters, we note from (25) that if both parameters are changed by the same factor, $t(q)$ changes by the inverse of that factor. Thus, starting from a randomly generated value, the parameters can easily be adjusted to generate product lifecycles of a desired length.

For the last phase of the product lifecycle, a progressive decline in a product's market size is generated by the differential equation

$$z'_t = -\delta_2(1 - z_t) \tag{26}$$

Variable z_t measures the size of a market relative to its maximum possible size g_m. In the simulations, a maximum size g_m is randomly generated whenever a new market m is created.

3.2.2 Market location

Apart from its current and maximum size, each market is also characterized by an *ideal point* in feature space. This ideal point may change over time. Both the probability and maximum distance of a movement are exogenously given parameters of the simulation. By changing these parameters, the experimenter can deliberately expose firms to different environmental scenarios and observe the impact of their strategies under various conditions.

Apart from this continuous movement an ideal point in feature space can suddenly break away if it belongs to a disruptive market or it may expire due to the end of a market lifecycle.

3.2.3 Market shares

Firms offer their products to all customers. The function of the market share submodel is to determine how many units of its products each firm sells on each market. The total demand observed by a firm is the aggregated demand for a product on all markets.

Corporate strategy is a meaningful concept only if there are market imperfections. Thus the market's reaction towards the offers made by a supplier cannot be determined using equilibrium concepts. We therefore assume that it is possible for different firms to sell similar products at different prices in one market, although the number of items they sell will be influenced by their price. The quantity sold of each product is also influenced by the fit of the product's features to the market's ideal point.

The basic idea of the demand structure is that consumers are not maximizing their utility, but follow a satisficing strategy. They perform only a limited, random search among suppliers and make their purchase at the first supplier who meets their aspirations with respect to price and product features.

To simplify our exposition, we first explain the market mechanism assuming homogenous products, and then discuss the extensions necessary to take into account different product features. We denote the aggregate demand function of market m by $D_m(p)$. This function represents the number of consumers who are willing to purchase the product if its price does not exceed p. For the simulations, we use a simple specification

$$D(p) = s_t \cdot (ln(\overline{p}) - ln(p)) \tag{27}$$

where $\overline{p}$ is a limit price and $s_t = g \cdot z_t$ is a scale factor expressing the current size of the market. This demand function is valid in each time period of the simulation. Our products can thus be considered as commodities, which every customer (who is part of the relevant market) purchases exactly once in every period, provided that he finds a supplier offering the product at a price which the customer is ready to pay. A similar situation of repeated purchases was used in the model of (Adner & Levinthal, 2001).

The price asked by firm i is denoted by p_i. Without loss of generality, we assume that firms are numbered in ascending order of prices, i.e. $p_1 < p_2 < \ldots < p_I$ when there are I firms offering the product.

There are

$$v_i = D(p_i) - D(p_{i+1)} \tag{28}$$

customers who have a reservation price between p_i and p_{i+1}. These customers would buy the product from any of the firms $1, \ldots, i$, but are not willing to buy the product from firms $i + 1, \ldots I$, since the prices of these firms are above their reservation price. Assuming that these customers are randomly split among those firms that offer their product cheaply enough, each of those firms can sell its product to

$$N_i = \frac{D(p_i) - D(p_{i+1})}{i} \tag{29}$$

customers in this segment. To extend the model to the firm asking for the highest price, we define

$$D(p_{I+1}) = 0 \tag{30}$$

Thus firm i can sell at most

$$y_i = \sum_{j \geq i} \frac{D(p_j) - D(p_{j+1})}{j} \tag{31}$$

units. The actual number of product sold by firm i is then given by $min(x_i, y_i)$, since a firm cannot sell more products than it has produced, assuming that the product cannot be stored across time periods.

The demand function (31) has some plausible properties. As

$$\frac{\partial y_i}{\partial p_i} = \frac{D'(p_i)}{i} < 0 \tag{32}$$

increasing its own price will decrease the potential sales of a firm. To study the effects of price changes by competitors, we have to distinguish two cases. For $j > i$, we have

$$\frac{\partial y_i}{p_j} = -\frac{D'(p_j)}{j-1} + \frac{D'(p_j)}{j} = -\frac{D'(p_j)}{j(j-1)} > 0 \tag{33}$$

thus an increase in the price of a more expensive competitor will increase the potential sales of a firm. On the other hand, price changes by cheaper competitors will only induce a shift in those cheap market segments where the firm does not compete and thus will not influence the sales potential.

There are several possibilities how this framework can be extended to take into account different product features. One approach, which was used in the simulation model of (Prietula & Watson, 2000), is to consider a mismatch between a product's features and the market's ideal point as a kind of opportunity cost to customers and correspondingly increase the product's price when calculating demand (but of course not when calculating the firm's revenue).

We use a different approach, which is more consistent with the demand structure defined above and which also makes it possible to introduce the notion of an aspiration level in terms of product features in a natural way.

Denote the Euclidean distance of the feature vector of product k to the ideal point of the market by d_k. We then define a coefficient g_k for product k as

$$g_k = \max\left(1 - \frac{d_k}{d_{\max}}; 0\right) \tag{34}$$

where $d_{\max}$ is a model parameter which represents the maximum distance of a product's feature vector to the ideal point which a customer will accept. This distance thus corresponds to a "functionality threshold" as used e.g. in the model of (Adner & Levinthal, 2001). Customers in each segment are not split evenly among firms competing for each segment, but in proportion to g_k. Thus the number of potential buyers of product k in segment i is given by

$$N_i \cdot \frac{g_k}{\sum_{\kappa \le i} g_\kappa} \tag{35}$$

3.2.4 Substitution between markets

An important stylized fact that characterizes the current strategic environment is the emergence of disruptive technologies (D'Aveni, 1999). A disruptive technology is a technology which erodes the market base of an incumbent product, for example by offering new features which have not been available in previous products.

Whenever a new market is created, it can be of two types:

- An *independent market*, which consist of entirely new customers and does not directly effect the size or structure of existing markets.
- A *disruptive market*, which reduces the customer base of existing markets.

Of course, over time in the simulation, an independent market might also have some effect on sales on existing markets, for example, when competitors start to focus on the new market and thus competition in the other markets decreases.

A disruptive market will divert a fraction of an existing market's potential size g_m towards itself. Whenever a new market is created, it is randomly designated to be either an independent or a disruptive market according to a prespecified probability. By increasing the probability of disruptive markets, the experimenter can create a more turbulent environment for the firms. If the new market is a disruptive market, an existing market is randomly selected and a randomly determined fraction of that market's total size is transferred to the new market. It should be noted that this diversion takes place at the level of potential, not actual customers. Thus the actual loss of sales will depend on the stage of the affected market as described by variable z_t.

4 Implementation

The simulation is implemented in Matlab R12, a technical computing language with numerous builtin mathematical, statistical and engineering functions. In the following flow chart, the most important function calls and their dependencies are listed in chronological order. For giving a better overview the flow chart is strongly simplified and therefore doesn‘t correspond with the implementation in all details.

The function "Main" contains all history variables and executes the main simulation loop. Calculations for each simulated time period are based on existing production plans and prices set by the firms. Based on this data, costs are computed according to the cost function (5) and market shares and sales according to the market model described in section 3.2. From sales revenues and costs, the cash flow is determined. Then the market sizes and ideal points are updated.

In the second part of the main simulation loop, the firms are making their decisions for the next period. First they perform a short-run production planning using given capacities and efficiency to obtain a projected baseline cash-flow against which the various investment alternatives are then evaluated. Depending on the firm type, new products may be introduced. If according to its strategy, a firm should introduce a new product, but the current cash flow is insufficient to finance its development, the firm enters a "save mode", in which cash flows are accumulated until the new product can be developed.

When no new products are introduced, the firm can use its free cash flow for investments. It calculates a cash flow forecast for each alternative and selects the alternative with the highest projected cash flow.

In the current setting, each simulation lasts for 250 periods. This cycle is repeated 100 times with identical parameter settings to obtain statistically valid results. The most important parameters, including the number of periods and repetitions, as well as all parameters concerning costs, innovation rates or market dynamics, can freely be set within sensible ranges without endangering the stability of the system or requiring any further changes in the software. The number of products per firm can for example vary between 4 and 250 depending on the innovation rate of the firm that can be set to any value between the permissible limits of zero and one. Table 1 gives an overview of parameters

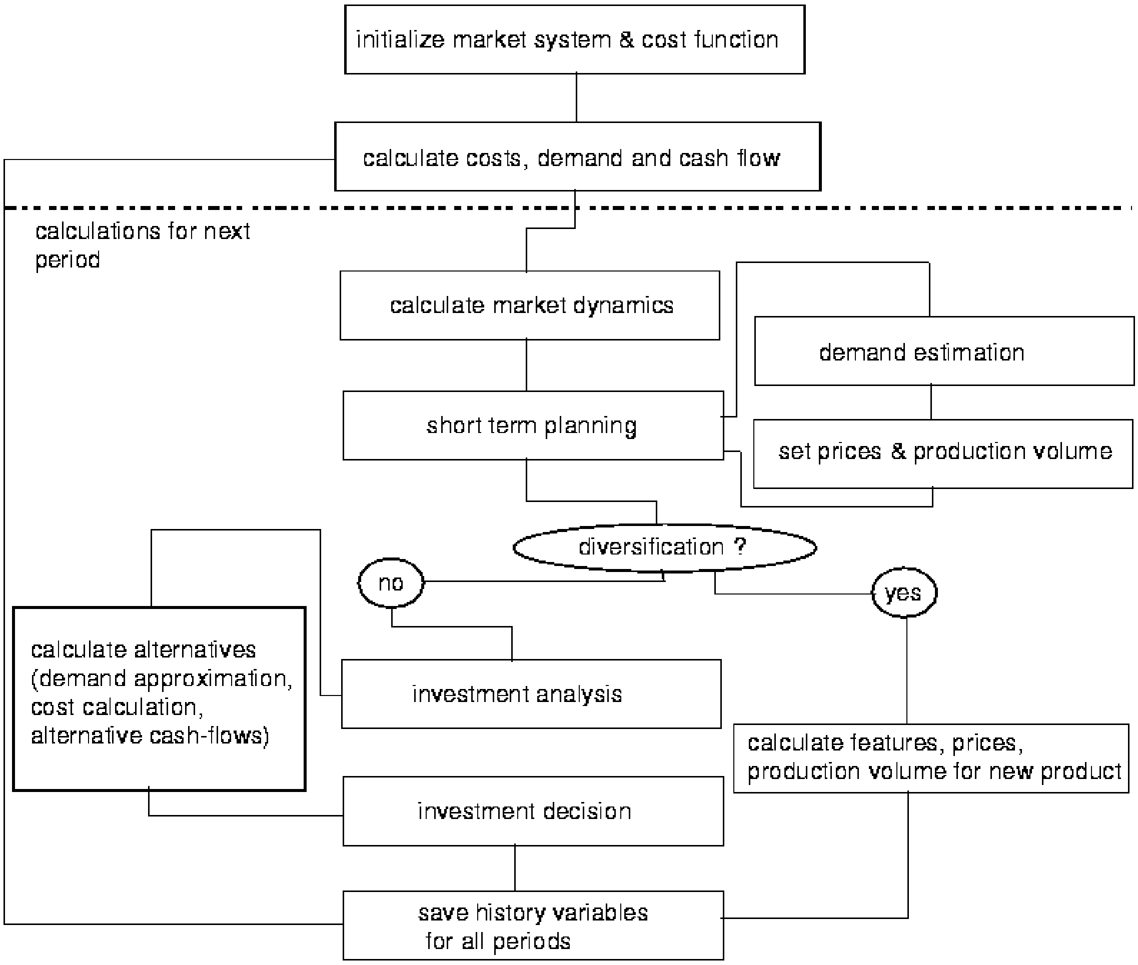

Figure 4: Implementation overview

Parameter	Description	Possible range
Environment parameters		
p_d	Probability of disruptive markets	0 – 1
p_m	Probability of market movement	0 – 1
s_m	Market size	$0 - \infty$
f_n	Number of product features	1 – 99
M_{max}	Maximum number of markets	$0 - \infty$
L_{min}	Minimum length of product lifecycle	$0 - \infty$
L_{max}	Maximum length of product lifecycle	$0 - \infty$
$\overline{p}$	Limit price	$0 - \infty$
δ_0, δ_1	Parameters of diffusion curve	0 – 1
δ_2	Decline during last phase of lifecycle	0 – 1
Parameters describing firm types		
I	Innovation rate	0 – 1
d_{div}	distance of diversification	0 – 1
Parameters for all firm types		
α	Nonlinearity of cost function	$0 - \infty$
λ	Adaption rate of knowledge focus	0 – 1
γ	Scaling parameter for distances	$0 - \infty$
φ	Adaption rate of exponential smoothing	0 – 1
c_i	Fixed diversification costs	$0 - \infty$
c_p	Product fixed costs	$0 - \infty$
c_c	Corporate fixed costs	$0 - \infty$
n_p	Initial number of products	$0 - \infty$

Table 1: Parameters

that can be set by the experimenter to create different types of environment and modify the behavior of agents.

As the complexity of the software makes debugging difficult, frequent review sessions and code inspections are hardly sufficient. Validation of the software is therefore supported by an extensive tracing facility, which allows to observe the time path of all variables for every single time period. The modular architecture allows us to consider extensions like a financial market that would enable us to expand the set of investment decisions available to firms.

5 Conclusions

In this paper, we have introduced an artificial strategy environment, which will allow us to study questions of corporate strategy using agent-based simulation methodology. Developing simulations for the field of corporate strategy is a difficult task requiring a careful balance between different aspects. On one hand, one would like to base the model as far as possible on established economic theory to increase its theoretical validity. On the other hand, many questions and hypotheses discussed in the literature on corporate strategy deal precisely with violations of the assumptions of economic theory.

The behavior we have observed so far from our agents in this environment seems to indicate that we have added the right amount of strategic phenomena to a basic economic framework to provide for a realistic setting, in which strategic research questions can be studied and meaningful results can be obtained.

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