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Schumpeterian Dynamics in Semi-Artificial Automobile Market

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Abstract

The paper presents a simulation model in the tradition of the contributions of R. R. Nelson and S. G. Winter. In contrast to their initial work and many subsequent contributions in the last twenty years we formulate a model which is, on the one hand, strongly related to empirical studies. On the other hand, the presented model has a more ≫realistic≪ foundation on the - not necessarily neoclassical - theory of oligopoly and production theory.

In particular, we will analyse the relation between R&D and market structure, which is widely discussed in both mainstream economics and Evolutionary Economics. But in this paper we will not only take market concentration into consideration. We will also analyse some aspects of market exit which, of course, concerns market structure.

Evolutionary models should be reconsidered on the basis of real economic phenomena, but until now there are only a few contributions which have a substantial empirical content. In our paper we try to combine an evolutionary simulation model and data from the automobile market.

Until now the paper is under construction. Consequently, we have run only a few simulations. Nevertheless, the results show a very strong concentration process which is rare in economic literature.

JEL-Classifications

L13, L62, O31

Key words

R&D, innovation, market structure, market exit, Nelson-Winter models, automobile industry

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1 Introduction

In this paper we will present a simulation model in the tradition of the contributions of R. R. Nelson and S. G. Winter. (e. g. NELSON/WINTER [1974,1982]). In contrast to their initial work and many subsequent contributions in the last twenty years we formulate a model which is, on the one hand, strongly related to empirical studies. On the other hand, in our opinion the presented model has a more ≫realistic≪ foundation on the - not necessarily neoclassical - theory of oligopoly and production theory.

In particular, we will analyse the relation between R&D and market structure, which is widely discussed in both mainstream economics and Evolutionary Economics. But in this paper we will not only take market concentration into consideration. We will also analyse some aspects of market exit which, of course, concerns market structure.

Evolutionary models should be reconsidered on the basis of real economic phenomena, but until now there are only a few contributions which have a substantial empirical content. In our paper we try to combine an evolutionary simulation model and data from the automobile market.

The paper is organized as follows. In Section 2 we present some important features of the international and the German automobile market. Afterwards we will make some remarks on the theoretical questions we deal with and the methodological frame we will use.

In Section 4 we present the theoretical model, which follows the tradition of the Nelson-Winter type models. Three important features of the model differ from most of the simulation models dealing with the Schumpeterian hypothesis. Firstly, we assume production functions with four inputs: technological knowledge, labor, capital and intermediates. Secondly, we assume a system of demand functions which brings a structure of a heterogeneous oligopoly into the model. Thirdly, we assume R&D behavioral rules which can be observed for the manufacturers on the automobile market.

The theoretical structure allows some short-run analysis, which we will present in Section 5. We discuss the Cournot-Nash-solution of the model. This analysis is quite neoclassical, but is very helpful in order to classify the simulation results. In Section 6 we will motivate the assumed R&D behavioral rules. Therefore we show some results which we take from a study of the R&D behavior of the 16 largest world automobile manufacturers. That study shows, that, both satisficing rules and rules of thumb can be observed in the automobile market. In Section 7 we present the simulation results. We run 15 simulations, varying both, the average R&D intensity and the share of firms which follow a satisficing rule respectively a rule of thumb. Finally, the last section will summarize the results, and we will give an outlook on the opportunities towards evolutionary simulation models which are founded on empirical studies.

2 Some Theoretical and Methodological Remarks

In this paper we will analyse the interdependencies between R&D, market concentration and market exit. First of all, neoclassical and mainstream economics have provided many contributions in this research field - as always (see e. g.MARTIN [1993]). But the contributions are from a point of view of Evolutionary Economics more or less to be critised - as always.

The main shortcomings of neoclassical modeling are due to the basic assumptions. It is not necessary to discuss the following points in detail:

- rational behavior,
- long-run equilibria,
- identical individuals and
- no ≫remarkable≪ Schumpeterian competition.

In contrast to these features evolutionary economists have developed several approaches. The most important work was contributed by R. R. Nelson and S. G. Winter (NELSON/WINTER [1974,1978,1982]). Their work was the initial starting-point of many other contributions (see NELSON [1995]). In comparison with traditional models, these models show advantages and disavantages. On the one hand, these models are able to represent real economies more ≫realisticly≪. On the other hand, such models tend to become very complex, so that analytical methods cannot be applied. Normally, simulation techniques are used.

But many economists do not understand what happens in simulation models. BALWIN/SCOTT [1987] call such models *hurley-burly worlds.* To disprove such strange arguments, we will present a simulation model of a semi-artifical automobile market. We use the term *semi*, because empirical data of the ≫real≪ automobile market will be included in the model. We use data from a data set which was provided by VOGT [1997]. This data set contains information about 16 automobile manufacturers. Data from other data sets we use to determine different parameters of the model. For example, for the partial elasticities of production we take input-output tables into consideration. In doing so we follow some authors who try to come from artificial models to econometric analysis (SILVERBERG/VERSPAGEN [1996]).

To bring some more structure into the ≫hurly-burly world≪ of simulation models we also use a theoretical basis which can be analysed with well-known methods of oligopoly theory. The price and quality competition involved in the model was first presented by VOSSKAMP [1996]. But in contrast to the model presented in this paper, VOSSKAMP [1996] dicussed only short-run solutions. In Section 5 we will repeat some of these results.

Finally, the model follows the bottom-up principle (VOSSKAMP [1996,1998]) and is designed to be a part of a micro-to-macro-model. Therefore, we take intermediate flows into consideration. The possibilities of linking the model presented in this paper and a micro-to-macro-model are discussed in VOSSKAMP [1998].

In Figure 1 the ingredients of our model are arranged.

– – – Figure 1 – – –

3 The Theoretical Model

In this section we present the theoretical model. The names and the descriptions of all variables and parameters can be found in Appendix A and B. We assume time t to be discrete. We analyse a heterogeneous oligopoly with m suppliers. Each firm produces one heterogeneous good which is characterized by its quality.

At the begin of every period all firms k determine their investment $I_k(t)$ and R&D expenditures $R_k(t)$. We assume:

$$R_k(t) = \rho_k(t) \cdot y_k(t-1), \tag{1}$$

whereby $y_k(t-1)$ denotes the sales of firm k in period $t-1$. In Section 5 we will discuss Equation (1) in detail.

In this paper we will focus on the impact of R&D behavior on market structure, and vice versa. Therefore, we assume simple investment functions:

$$I_k(t) = \sigma \cdot (y_k(t-1) - y_k(t-2)) + d^K \cdot p_K \cdot K_k. \tag{2}$$

R&D expenditures and investment lead to the accumulation of stocks of capital and stocks of R&D taking depreciation into consideration:

$$K_k(t) = (1 - d^K) \cdot K_k(t-1) + I_k(t)/p_K \tag{3}$$

$$T_k(t) = (1 - d^T) \cdot T_k(t-1) + R_k(t)/p_T. \tag{4}$$

We assume that the stocks of R&D have a random impact on technological knowledge $M_k(t)$ and on the quality of the products $q_k(t)$:

$$M_k(t) = (1 + \mu \cdot Z_k^M(t)) \cdot M_k(t-1) \tag{5}$$

$$q_k(t) = (1 + \nu \cdot Z_k^q(t)) \cdot q_k(t-1). \tag{6}$$

Furthermore, we assume that the random variables $Z_k^M(t)$ and $Z_k^q(t)$ are distributed as follows:

$$P(Z_k^M(t) \leq z) = 1 - e^{-1/T_k(t) \cdot z} \tag{7}$$

$$P(Z_k^q(t) \leq z) = 1 - e^{-1/T_k(t) \cdot z}, \tag{8}$$

with

$$\begin{aligned} \mathrm{E}\left[Z_k^M(t)\right] &= T_k(t) & (9)\\ \mathrm{E}\left[Z_k^q(t)\right] &= T_k(t). & (10) \end{aligned}$$

We assume the following production functions:

$$x_k(t) = h \cdot M_k(t)^{\omega} \cdot L_k(t)^{\alpha} \cdot K_k(t)^{\beta} \cdot X_k(t)^{\gamma}. \tag{11}$$

Using traditional neoclassical production theory and taking into consideration that capital and technological knowledge are not subject to cost minimization this leads to the following cost functions (VOSSKAMP [1996]):

$$\begin{aligned} C_k(x_k) &= (1-\omega-\beta) \cdot h^{-1/(1-\omega-\beta)} \cdot \left(\frac{w}{\alpha}\right)^{\alpha/(1-\omega-\beta)} \cdot \left(\frac{p_X}{\gamma}\right)^{\gamma/(1-\omega-\beta)} \\ &\quad \cdot M_k^{-\omega/(1-\omega-\beta)} \cdot K_k^{-\beta/(1-\omega-\beta)} \cdot x_k^{1/(1-\omega-\beta)}, \end{aligned} \tag{12}$$

where w and p_X are the wage rate and the price for the intermediate goods.

We are now turning to the demand side of the model. Clearly, an increase of the quality of a product which we will interpret as a product innovation will have a positive impact on the innovator and a negative impact on the competitors. To represent these oligopolistic impacts of quality improvements we define a demand variable $a_k(t)$, which measures the quality of a product in comparison to all other products:

$$a_k(t) = \frac{q_k(t)}{\prod_{l=1}^{m} q_l(t)^{1/m}}. \tag{13}$$

Both oligopolistic quality competition and oligopolistic price competition are represented in the model. Choosing $p_k(t)$ for the price of good k we assume the following demand functions:

$$x_k^D(t) = b \cdot a_k(t) \cdot \left(\prod_{l=1}^{m} a_l(t)^{-1/m}\right) \cdot \left(\prod_{l=1, l\neq k} p_l(t)^{1/(m-1)}\right) \cdot p_k(t)^{-\varepsilon}. \tag{14}$$

On the basis of these functions firms are able to maximize their short-run profits. We assume that they fix their price calculated by this maximization procedure for the whole period. There are no changes of prices within one period. Also they have to make a decision on supply $x_k^S(t)$.

The demand depends on the vector of all demand variables $\mathbf{a} := (a_1, \cdots, a_m)^T$ and all prices $\mathbf{p} := (p_1, \cdots, p_m)^T$. We assume that in period t firms do not know the extent of innovation of their competitors in period t. Also, we assume that no firm k knows the price p_l which a competitor sets in period t. Consequently, each firm k has to form expectations on the prices and demand variables of all competitors l. We assume Cournot behavior which is assumed to be identical for all firms:

$$
\begin{aligned}
{}^k p_l^E(t) &= p_l(t-1) && (15)\\
{}^k a_l^E(t) &= a_l(t-1) && (16)\\
{}^k m^E(t) &= m(t-1). && (17)
\end{aligned}
$$

Clearly, firms also have to think about the number of suppliers. In general, we assume that they expect that all firms which supplied in the period $t-1$ do so in period t, too.

On the basis of these assumptions the firm k determines the price $p_k(t)$ and production $x_k^S(t)$:

$$
\begin{aligned}
p_k(t) &= p_k(a_k, M_k, K_k, \mathbf{a}(t-1), \mathbf{p}(t-1)) && (18)\\
x_k^S(t) &= x_k^S(a_k, M_k, K_k, \mathbf{a}(t-1), \mathbf{p}(t-1)). && (19)
\end{aligned}
$$

Obviously, market supply and market demand are not necessarily equivalent. Two cases are possible. Supply can be larger than demand: In the case of unexpected price decreases of the competitors, for example due to process innovations, supply is higher than expected. Demand is larger than supply (c.p̃.): For example, one firm left the market.

Demand $x_k^D(t)$ is calculated by using the demand functions (14) and the actual prices and actual qualities. Clearly, the market »uses« the prices $p_k(t)$ and not the expected values $p_k(t-1)$. As mentioned above, in nearly all cases we have:

$$x_k^S(t) \neq x_k^D(t). \tag{20}$$

In the first version of the model we do not model stocks. Consequently, market demand will not be satisfied in the case that demand is larger than supply. In the case that demand is smaller than supply we assume that the firm has to destroy excess supply. We define:

$$x_k(t) := \min(x_k^D(t), x_k^S(t)). \tag{21}$$

At the end of the period, firms calculate their profits and profit rates based on $x_k(t)$. We take different variables into account:

$$
\begin{aligned}
\Xi_k(t) &= y_k(t) - C_k(t) && (22)\\
\Pi_k(t) &= y_k(t) - C_k(t) - R_k(t) - (r + d^K) \cdot p_K \cdot K_k(t) && (23)
\end{aligned}
$$

and

$$\xi_k^K(t) = \frac{\Xi_k(t)}{K_k(t)} \qquad \xi_k^y(t) = \frac{\Xi_k(t)}{y_k(t)} \tag{24}$$

$$\pi_k^K(t) = \frac{\Pi_k(t)}{K_k(t)} \qquad \pi_k^y(t) = \frac{\Pi_k(t)}{y_k(t)}. \tag{25}$$

According to MEYER/VOGT/VOSSKAMP [1996] we assume that a firm will leave the market at the end of period s, if

- the rate of return $\pi_k^K(t)$ is smaller than π_{min}^K for T periods ($s = t-(T-1), \cdots, s = t$, or,
- the market share becomes smaller than s_{min}^x.

The decision of the firms, whether or not to supply in the next period is the last step in period t.

4 A Neoclassical Interpretation of the Model

For a short moment we will turn to neoclassical theory. In the case of exogenous stocks of technological knowledge $M_k(t)$ and capital stocks $K_k(t)$ we can derive the Cournot-Nash solution of the model. This gives one fixed point for the interpretation of the simulation results. The details and the derivation are presented in VOSSKAMP [1996].

The vector of prices $\mathbf{p} := (p_1, \cdots p_m)^T$ holds:

$$\ln \mathbf{p} = (\mathbf{I} - \mathcal{A}\mathbf{\Phi})^{-1} \cdot \mathbf{z}, \tag{26}$$

with

$$\mathbf{z} := \mathcal{B} + (\mathbf{I} - \mathbf{\Theta}) \cdot \ln \mathbf{a} - \mathcal{C} \cdot \ln \mathbf{M} - \mathcal{D} \cdot \ln \mathbf{K}. \tag{27}$$

The parameters have the following properties:

$$\mathcal{A} = \mathcal{A}(\varepsilon, \omega, \beta) > 0 \tag{28}$$

$$\mathcal{B} = \mathcal{B}(\varepsilon, \omega, \alpha, \beta, \gamma, b, h, w, p_X) \gtreqless 0 \tag{29}$$

$$\mathcal{C} = \mathcal{C}(\varepsilon, \omega, \beta) > 0 \tag{30}$$

$$\mathcal{D} = \mathcal{D}(\varepsilon, \omega, \beta) > 0. \tag{31}$$

Also, we use the following definitions:

$$\mathbf{I} := \begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & 1 \end{pmatrix} \in \mathbb{R}^{m \times m} \tag{32}$$

$$\mathbf{\Phi} := \begin{pmatrix} 0 & 1/(m-1) & \cdots & 1/(m-1) \\ 1/(m-1) & 0 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 1/(m-1) \\ 1/(m-1) & \cdots & 1/(m-1) & 0 \end{pmatrix} \in \mathbb{R}^{m \times m} \tag{33}$$

$$\mathbf{\Theta} := \begin{pmatrix} 1/m & \cdots & 1/m \\ \vdots & \ddots & \vdots \\ 1/m & \cdots & 1/m \end{pmatrix} \in \mathbb{R}^{m \times m}. \tag{34}$$

The model also allows to derive the market shares. We have:

$$s_k := \frac{x_k}{\sum_{l=1}^{m} x_l} = \frac{a_k^{1+(\omega+\beta)\cdot\mathcal{X}} \cdot M_k^{\omega\cdot\mathcal{X}} \cdot K_k^{\beta\cdot\mathcal{X}}}{\sum_{l=1}^{m} a_l^{1+(\omega+\beta)\cdot\mathcal{X}} \cdot M_l^{\omega\cdot\mathcal{X}} \cdot K_l^{\beta\cdot\mathcal{X}}}. \tag{35}$$

Obviously, the market share of firm k depends on its demand variable a_k, the stock of technological knowledge M_k and the capital stock K_k and on the corresponding variables of all competitors. The parameter $\mathcal{X}$ depends on some elasticities and the number of firms:

$$\mathcal{X} = \mathcal{X}(\varepsilon, \omega, \beta, m). \tag{36}$$

The derivation and the discussion of Equation (35) is presented in detail in VOSSKAMP [1996].

5 The Estimation of the R&D Behavioral Rules

In this section we discuss the R&D behavior of the automobile manufacturers. On the basis of the data set described in Appendix C VOGT [1997] analyzed the R&D behavior of the firms listed in Appendix D. She showed that two different behavioral rules can represent the R&D behavior very well. These in Evolutionary Economics well-known rules are:

- rules of thumb;
- satisficing behavior.

For illustration we present the regression results for the German manufacturers Volkswagen and Porsche. The other estimates are shown in Vogt [1997]. For k = Volkswagen we found a rule of thumb for the R&D behavior, as the estimates show (t-value in parantheses):

$$R_k(t) = \underset{(119.9)}{0.035} \cdot y_k(t) \tag{37}$$

$$n = 15,\ \mathrm{R}^2 = 0.99,\ \mathrm{DW} = 2.08.$$

With

$$\bar{\pi}^y(t-1) := \frac{1}{m} \cdot \sum_{l=1}^{m} \pi_l^y(t-1) \tag{38}$$

$$s_k^y(t) := \frac{y_k(t)}{\sum_{l=1}^{m} y_l(t)} \tag{39}$$

for Porsche the following satisficing result was estimated:

$$\begin{aligned}\rho_k(t) = {} & \underset{(1.27)}{0.049} - \underset{(-2.41)}{0.228} \cdot (\pi_k^y(t) - \bar{\pi}^y(t-1)) \\ & - \underset{(-1.71)}{0.073} \cdot s_k^y(t-1) + \underset{(+4.43)}{0.213 \cdot 10^{-6}} \cdot y_k(t-1)\end{aligned} \tag{40}$$

$$n = 14,\ \mathrm{R}^2 = 0.92,\ \mathrm{DW} = 2.76.$$

Due to the evidence of rules of thumb and satisficing behavior we choose the following specification for the Equation (1):

$$\rho_k(t) = \rho - \tau(\pi_k^K(t-1) - \bar{\pi}^K(t-1)). \tag{41}$$

6 Some Simulation Results

The theoretical model was translated in a C++ code. The simulations were run on a personal computer. The analysis of the results was done with both, EXCEL and C++ routines. In this paper we will present only a few results, based on 15 simulations, which underline the importance of the R&D behavior of firms. Point of attachment is Equation (41). On the one hand we will vary the parameter ρ from 0.04 to 0.12. On the other hand we will analyse three different scenarios **R**, **S** and **RS** for τ:

R All m firms use a rule of thumb: $\tau = 0$.
S All m firms use a satisficing rule: $\tau = 0.5$.
RS The fims $k = 1, \cdots, m/2$ apply the rule of thumb mentioned in scenario **R**. The firms $k = m/2 + 1, \cdots, m$ use the satisficing rule mentioned in scenario **S**.

Consequently, with respect to the chosen scenarios, this paper is close to NELSON/WINTER [1982] and MEYER/VOGT/VOSSKAMP [1996]. We only analyse $m = 12$ firms motivated by the facts of the world automobile market. Furthermore, we assume that in the starting period $t = 0$ all firms are identical. In this period the price vector $\mathbf{p}$ represents the Cournot-Nash solution of the model (see Section 5).

We analysed the model for a very large parameter space. In all cases - and that is the first important result - we got a strong tendency towards monopoly. Of course, this is a result which is only possible, because we represent capital stocks and stocks of technological knowledge. Models, which apply linear demand and supply functions cannot generate a tendency towards monopoly in such an extent (see e. g.MEYER/VOGT/VOSSKAMP [1996] or NELSON/WINTER [1982]). The impact of the investment function and the market entry and exit conditions are, of course, important as well. Nevertheless, in the economic literature in general and in particular on (evolutionary) simulation models results which show such strong concentration processes are rare.

In particular for the subset of parameters, which represents the automobile market, we always get monopolies after a short period of time. In Table 1 the period t is presented in which a monopoly is established.

– – – Table 1 – – –

With respect to the period of the establishment of monopoly the results are not surprising. In the scenarios R concentration is quicker than in the scenarios S. Yet, another result is very interesting: In the case of low (high) values for ρ a firm which applies the satisficing rule (rule of thumb) always becomes monopolist.

For the comparison of the simulations we choose period $t = 50$. First of all, we will show some impacts on market structure. Table 2 shows the calculated values for the concentration ratio CR4, Table 3 the values for the Herfindahl-index and Table 4 the largest market share we get in period 50.

– – – Table 2, Table 3, Table 4 – – –

These results are really uniform. Market concentration is positively correlated with the R&D intensity ρ. Satisficing reduces concentration. Furthermore, Table 5 shows that in the case of high R&D intensities in the RS scenario the firms which apply the satisficing rule are already on the path of loosers in period 50.

– – – Table 5 – – –

The next two tables (Table 6 and Table 7) show the average R&D intensities and the sum of all R&D expenditures in period 50. Clearly, in the R scenarios the average R&D intensities are equal to the assumed R&D intensity. In the S and RS scenarios the average R&D intensities are almost the same: they are only a little bit larger. But that is not the whole story with respect to R&D. A look at Table 7 shows that the absolute amount of R&D expenditures in R is much higher than in S. These results show a risk associated with successful R&D and innovation. High R&D intensities might lead to competitive advantages which the competitors are not able to make up. It might be an interesting discussion, whether the dominance of Microsoft in the software market is a good example for these facts or not.

– – – Table 6, Table 7, Table 8 – – –

We finish the presentation of the results with the presentation of the performance. Table 8 contains the average rate of return in period 50. It shows a second fact which is - from the firm's point of view - contradictory. On the one hand, high R&D intensities lead to market concentration. On the other hand, R&D is not costless so that the rate of return will be affected negatively which leads to higher prices. In our model R&D is not worthwhile - from an indivual point of view. But due to the fact that all firms spend on R&D each firm has to do the same. Consequently, there could be a tendency to a kind of cartel which agrees upon low R&D activities which stops technological change. A firm's single alternative might be to march through. Only a monopoly allows a high rate of return for a long time.

Summarizing the main results we have to mention three points again:

- In all cases we get a monopoly after a small number of periods.
- The larger the R&D intensities, the faster the process of concentration.
- A higher degree of concentration does not permit to raise prices which compensate for higher R&D expenditures.

Finally, we have to underline that in this paper we run each simulation only one time. Also, we only analyse the results in period 50. Nevertheless the results show a picture which is in contrast to most of the approaches to the problems we dealt with.

7 Outlook

The paper presented is a paper in progress. The forthcoming developments of the model can be characterized by four points:

- Completion of the theoretical model: We will introduce stocks of goods which will have one more dynamic impact. We try to introduce merging which at the moment is a very important phenomenon on many markets. This will reinforce concentration processes.

- Implementation of further data from markets: In this paper we use only some data from the automobile market. We will include more empirical data into the model as we move towards an (evolutionary) econometric model.

- Improving the analysis of the simulation results: In this paper we presented only a few simulations. Each simulation we ran only one time. Next we will improve this part of the analysis.

- Modelling a system of n interdependent markets: Due to the representation of an intermediate good the model has an interface to other markets. One idea is to use this model as a module in an disaggregated econometric model. For a discussion of this type of model see Vosskamp [1998].

Due to these forthcoming developments we go without a detailed discussion of the results with respect to the automobile market.

A List of Variables

The following subscripts are used:

k	:	firm k
l	:	firm l

The superscripts are applied as follows:

K	:	capital
y	:	sales

The following variables are taken into consideration (always firm k, period t):

$a_k(t)$	:	demand variable
$C_k(t)$	:	costs
$I_k(t)$	:	investment
$K_k(t)$	:	capital stock
$L_k(t)$	:	labor input
$M_k(t)$	:	technological knowledge
$p_k(t)$	:	price
$\Pi_k(t)$	:	profit
$\pi_k^K(t)$	:	rate of return (profit/capital)
$\pi_k^y(t)$	:	profit rate (profit/capital)
$q_k(t)$	:	quality
$R_k(t)$	:	R&D expenditures
$\rho_k(t)$	:	R&D intensity
$\sigma_k(t)$	:	investment intensity
$s_k^x(t)$	:	market share (output share)
$s_k^y(k)$	:	market share (sales share)
$T_k(t)$	:	stock of R&D capital
$X_k(t)$	:	intermediate input
$x_k(t)$	:	output
$x_k^D(t)$	:	demand
$x_k^S(t)$	:	supply
$\Xi_k(t)$	:	short-run profit (operating result)
$\xi_k^K(t)$	:	short-run rate of return (operating profit/capital)
$\xi_k^y(t)$	:	short-run profit rate (operating profit/sales)
$y_k(t)$	:	sales
$Z_k^M(t)$	:	random variable (technological knowledge)
$Z_k^q(t)$	:	random variable (quality)

B List of Parameters

variable	value	source	description
b	2.0	C	parameter in demand functions
d^K	0.07	IO	depreciation rate for capital stocks
d^T	0.2	RD	depreciation rate for R&D stocks
h	1.0	C	parameter in production functions
m	12	A	number of suppliers
p_K	1.5	C	price for capital goods
p_T	1.5	C	price for R&D capital goods
p_X	1.0	C	price for intermediate goods
r	0.05	IO	interest rate
s^x_{min}	0.01	A	critical market share
T	3	A	critical number of periods
w	1.0	C	wage rate
α	0.20	IO	partial elasticity of production of labor
β	0.15	IO	partial elasticity of production of capital
ε	0.5	C	price elasticity of demand
γ	0.60	IO	par. elas. of prod. of intermediate goods
μ	0.02	RD	parameter in process innovation function
ν	0.02	RD	parameter in product innovation function
π^K_{min}	-0.05	A	critical rate of return
ρ	0.04 - 0.12	A	parameter in the R&D expenditure functions
σ	0.1	A	parameter in the investment functions
τ	0.0/0.5	A	parameter in R&D expenditure functions
ω	0.05	IO	par. elas. of prod. of technological knowledge

A	:	data from the automobile market (Vogt [1997])
C	:	calibration
IO	:	input-output tables
RD	:	studies on R&D

C The Data

In contrast to many other theoretical simulation studies we try to base the model on empirical data as far as possible. We use two classes of data: On the one hand, we apply micro data which we got from the annual reports of the most important automobile manufacturers. On the other hand, we take data material from different official and semi-official statistics. The data set was first used in VOGT [1994] and VOGT [1997]. Here you can find a description of the data set in detail. There is also a discussion of all the problems with different accounting and currencies which have to be solved in order to arrive a consistent data set which allows comparisons between manufacturers of different countries.

The micro data set is related to the automobile segment of the most important manufacturers. It is not based on the whole companies. We collect the information for 16 automobile companies with almost 40 manufactures. For example, PSA produces Citroen, Peugeot and Talbot. The most important variables of the data set are:

$x_k(t)$	:	output of firm k in period t
$I_k(t)$	:	investment of firm k in period t
$R_k(t)$	:	R&D expenditures of firm k in period t
$y_k(t)$	:	sales of firm k in period t
$\Xi_k(t)$	:	operating result of firm k in period t
$\Pi_k(t)$	:	profit of firm k in period t

For the operating result and the profit we use the variables used in the theoretical simulation model, although there are some differences. In Appendix D the firms represented in the data set are listed. VOGT [1994] presents which manufactures belong to the different firms.

The data set covers about 90 % of the world automobile production. This might be a good starting-point for an empirical analysis.

Besides the annual reports of the firms, meso data from the following sources were used:

- production of automobiles by countries and firms: VERBAND DER AUTOMOBILINDUSTIE [1980-1994];
- exchange rates: DEUTSCHE BUNDESBANK [1980-1994];
- (sectoral) price indices: National Statistical Officies; provided by INFORUM;
- concentration measures: STATISTISCHES BUNDESAMT [1980-1996];
- input-output data: STATISTISCHES BUNDESAMT [1980-1993];
- (new) car registration: KRAFTFAHRTBUNDESAMT [1997].

D List of Firms Represented in The Micro Data Set

Firm	Location	Country Code	Years
Bayrische Motorenwerke	München	D	80-94
Chrysler Corporation	Highland Park	USA	80-94
Daimler Benz AG	Stuttgart	D	80-88
Fiat S.p.A.	Turin	I	80-94
Ford Werke AG	Dearborn	USA	80-94
General Motors Corporation	Detroit	USA	80-94
Honda Motor Corporation	Tokio	J	84-95
Mazda Motor Corporation		J	80-95
Mercedes Benz AG	Stuttgart	D	89-94
Nissan Motor Corporation	Tokio	J	80-95
PSA Peugeot Citroen	Paris	F	80-94
Renault S. A.	Boulogne	F	80-94
Toyo Kogyo Corporation	Tokio	J	80-83
Toyota Motor Corporation	Toyota City	J	80-95
Volkswagenwerk AG	Wolfsburg	D	80-94
Volvo AB	Göteborg	S	80-94

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Table 1: Period of the Establishment of Monopoly

	R	S	RS
$\rho = 0.12$	58	65	59 (R)
$\rho = 0.10$	69	74	73 (R)
$\rho = 0.08$	80	87	73 (S)
$\rho = 0.06$	99	110	88 (S)
$\rho = 0.04$	136	>140	>140 (S)

Table 2: CR4 in Period 50

	R	S	RS
$\rho = 0.12$	0.81	0.71	0.80
$\rho = 0.10$	0.67	0.61	0.64
$\rho = 0.08$	0.56	0.53	0.54
$\rho = 0.06$	0.48	0.46	0.46
$\rho = 0.04$	0.41	0.40	0.41

Table 3: Herfindahl-Index in Period 50

	R	S	RS
$\rho = 0.12$	0.25	0.15	0.25
$\rho = 0.10$	0.14	0.12	0.13
$\rho = 0.08$	0.11	0.10	0.10
$\rho = 0.06$	0.10	0.09	0.09
$\rho = 0.04$	0.09	0.09	0.09

Table 4: Largest market share in Period 50

	R	S	RS
$\rho = 0.12$	0.43	0.22	0.45
$\rho = 0.10$	0.21	0.19	0.22
$\rho = 0.08$	0.17	0.16	0.15
$\rho = 0.06$	0.14	0.13	0.13
$\rho = 0.04$	0.11	0.11	0.11

Table 5: Market share of R and S firms in Period 50

	R	S
$\rho = 0.12$	0.70	0.30
$\rho = 0.10$	0.58	0.42
$\rho = 0.08$	0.54	0.46
$\rho = 0.06$	0.52	0.48
$\rho = 0.04$	0.51	0.49

Table 6: Average R&D intensity in Period 50

	R	S	RS
$\rho = 0.12$	0.12	0.1284	0.1237
$\rho = 0.10$	0.10	0.1037	0.1019
$\rho = 0.08$	0.08	0.0816	0.0804
$\rho = 0.06$	0.06	0.0606	0.0602
$\rho = 0.04$	0.04	0.0402	0.0401

Table 7: Sum of R&D expenditures in Period 50

	R	S	RS
$\rho = 0.12$	12.63	9.39	11.93
$\rho = 0.10$	7.46	6.79	7.17
$\rho = 0.08$	5.34	5.15	5.25
$\rho = 0.06$	3.91	3.86	3.89
$\rho = 0.04$	2.69	2.68	2.67

Table 8: Average Rate of return in Period 50 (in percent)

	R	S	RS
$\rho = 0.12$	1.26	-1.12	0.49
$\rho = 0.10$	0.86	0.43	0.46
$\rho = 0.08$	2.62	2.49	2.46
$\rho = 0.06$	4.80	4.75	4.74
$\rho = 0.04$	7.13	7.12	7.11

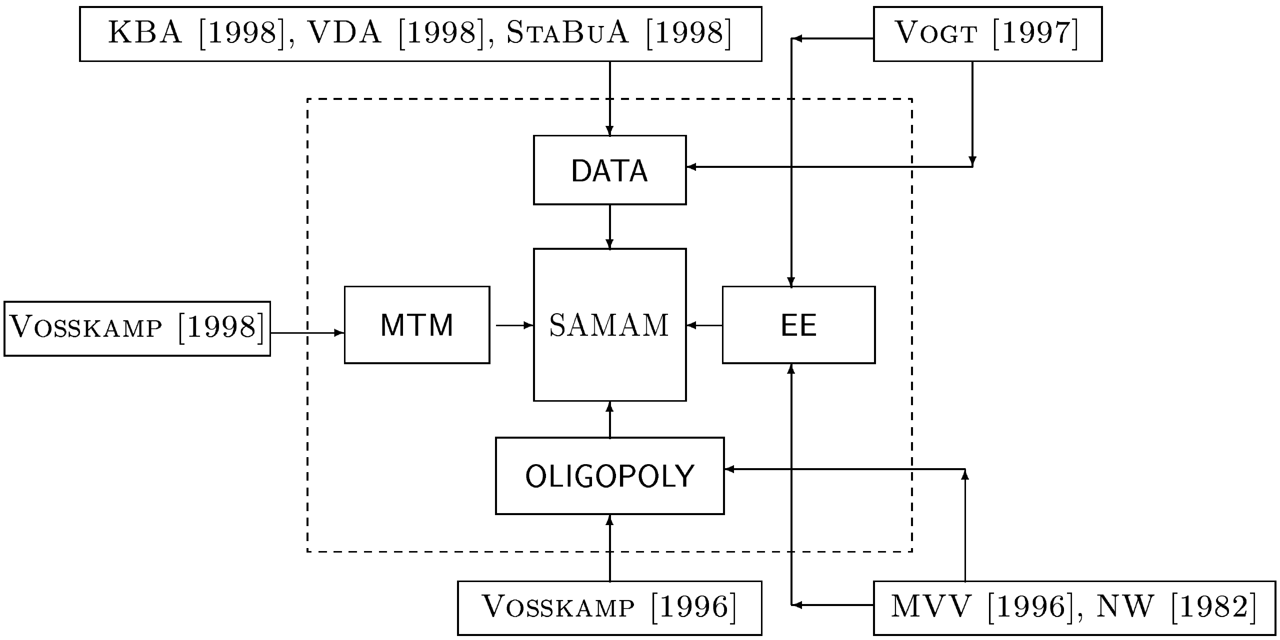

Figure 1: Structure of the Model