International Journal of Innovation and Technology Management
Vol. 9, No. 2 (2012) 1250012 (38 pages)

DOI: 10.1142/S0219877012500125

TIMELY RESOURCE ALLOCATION BETWEEN R&D AND MARKETING: A SYSTEM DYNAMICS VIEW

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Received 12 May 2009
Accepted 5 April 2010

Trade-off between marketing and research and development (R&D) has always been a dilemma in management science for many years. Allocating the budget to departments and estimating the future profits and customer base as a result of this action has remained a "challenging task." Developing products faster, better, and cheaper than competitors has become critical to success in many markets. This may require huge initial investments in underlying processes resulting in over-investment in marketing and/or R&D in spite of insufficient purchasing power and market saturation for new products.

Using a system dynamics (SD) model, this paper aims to understand the dynamics of a complex market where demand fluctuates annually. The problem contains severe difficulties in terms of planning and strategy for marketing and R&D. The budgets to be shared by R&D and marketing vary every period. The market includes feedback and dynamic issues to consider. This brings in the problem of understanding and controlling complexity in the market structure by understanding the cyclical causal relationships.

The paper indicates that SD modeling is very useful in investigating and finding sustainable allocation trends in marketing and R&D, so that a firm can keep a sustainable level of customers. While searching for these trends, special attention is paid to the timing of these decisions to synchronize two activities. The paper shows an understanding of the management of a complex problem via policy design and analysis using SD modeling.

Keywords: Marketing, R&D; system dynamics; budget allocation; modeling; simulation.

1. Introduction

Trade-off between marketing and research-development has always been a dilemma for most managers. Balancing the budgets between different departments and estimating the future profits and customer base as a result of this action has remained a "challenging task" throughout the contemporary business history.

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Managers and researchers have come up with many tools to enhance their understanding of the business/market structure and to ease the strategy formulation process [e.g., [Scherer (1967); Souder (1972); Baker and Freeland (1975); Zoltners and Sinha (1980); Lee (1985); Gill (1992); Rink *et al.* (1999); Shapiro (2003); Jenkins (2005); Joglekar and Levesque (2009)]. However, these tools have fallen short in some periods due to difficulties in their applicability.

The importance of standard strategic management tools and their inadequacy have been stressed by Graham and Ariza [2003] because of not only communication and execution, but also fundamental limitations of methodology. Complexity often determines the tools to be used. In a highly complex demand estimation projects, system dynamics (SD) proves quite useful to analyze the problem. In the model structure of Graham and Ariza [2003] one sees the quite intensive and complex interaction of marketing and research and development (R&D).

The purpose of the paper is to investigate and find the sustainable allocation between marketing and R&D, so that a firm can keep a sustainable level of customers and create sufficient amount of revenue. While searching for allocation policies, special attention is paid to the timing of these decisions to synchronize the two activities. The paper attempts to contribute to the understanding and the management of a complex problem via policy design and analysis.

The paper is structured as follows: The next section reviews the relevant literature to extract the model variables. Section 3 gives the methodology. Section 4 introduces the proposed causal loop diagrams and identified stock and flow variables. Testing and validation of the model is done in Sec. 5. Section 6 discusses simulations and resulting behaviors. Policy design and evaluation are covered by Sec. 7. Finally, Sec. 8 concludes the paper.

2. Literature Review

In this section, we briefly review literature on R&D resource allocation from the different perspectives in order to identify and decide on the components of our model.

Company managers and scholars have increasingly come to realize that design and engineering play an important role in delivering products to the final customer [Repenning (2000)]. Hauser [1997] mentioned that R&D provides the science and technology that firms use to serve tomorrow's customers profitably. Many managers, consultants, and researchers have argued that to succeed in the 21st century, R&D should be market-driven [Becker and Lillemark (2006)]. The increasing integration of marketing and R&D has been shown to bring increasing success, especially on new product performances [Leenders and Wierenga (2008)]. This should be done after acquiring the required level of resources, so that building the integration would make sense and effect on business value.

The phenomenon of R&D rivalry in a dynamic profit maximization framework was analyzed by Scherer [1967] who predicted the market structural conditions most conducive to rapid technological progress by formulating models of the firm's optimal R&D resource allocation problem. The author listed the factors that affect the revenues from successful R&D project completion as the date of completion, the quality of the end product (related to its ability to satisfy existing or latent demands), obsolescence time, and the reactions of rivals. Factors that affect the costs of an R&D project were listed as the state of technology, the quality of the end product, and the speed of the development. Given the parameters assumed in the model, a period of three years was reported as the minimum time to product introduction (with infinitely high development costs), while a period of 8.5 years was the development schedule that minimizes undiscounted total costs.

Developing products faster, better, and cheaper than competitors has become critical to success in many markets [Ford and Sterman (1998)]. However, in order to do this, there should be adequate tools and mechanisms to forecast the demand for the product, so that quality and awareness can be adjusted accordingly. In addition, to develop products faster, better, and cheaper may require huge initial investments in the underlying business processes. Integration of marketing and manufacturing has been shown to impact new product development time and competitive advantage [Swink and Song (2007); Song and Swink (2009)]. This process also depends on the sector that the company is operating in. Obviously, sectoral and national characteristics define the need for innovations and marketing [Blankley (2007)].

In a classification of high, medium, and low technologies [OECD (1996)], one would expect that marketing and R&D budgets for a high-tech industry firm (e.g., airplane, medical industry, R&D-intensive start-ups, etc.), for a low-tech industry firm (e.g., tobacco, leather, etc.), and for a mid-tech industry firm (e.g., chemical, plastics, etc.) would be different depending on their elasticities of price, demand, and supply. Trott [2002] gave a useful classification scheme of NPD activities across different industries. New product quality level goals have been argued to differ depending on the technology level of the sector [Scherer (1967)]. Joglekar and Levesque [2009] developed a model to study resource acquisition and allocation decisions between R&D (to improve product quality) and marketing (to increase sales) across successive stages of start-up (a manufacturer of electronic design automation) growth and discussed the robustness and application of optimal strategies for optimal capping of R&D and marketing expenses as percentage of revenues.

One may also expect that R&D triggers the company growth due to increased demand in the market. Kameoka and Takayanagi [1999] demonstrated that R&D became one of the most essential driving forces for corporate growth as well as survival in crisis periods. They claimed that R&D expenditures as input resources were gradually converted into technology stock with a certain time delay. Anderson and Reynolds [1997] pointed out that demand articulation was a process of converting the customer's vague wants into a set of R&D projects. This theory, they said, is completely nonlinear, market-driven, and involves foreseeable targets as Dickinson [1999] stressed manager's obligation to allocate resources to diverse financial instruments in the proper proportions to meet the customer's needs. One has to balance risk and reward for this portfolio management.

In a dynamic R&D decision process, the impact produced by a firm's R&D expenditure at a given period may produce both positive and negative impacts on the stream of firm's success [Confessore and Mancuso (2002)]. The total R&D expenditures and government subsidies including basic research in universities build up the national R&D competitiveness. It becomes crucial when these budgets are allocated in the companies that constitute the micro-economy. Investigating the link between national competitiveness and R&D, Papadakis [1995] found out that R&D intensive industries have high competitiveness when compared to the others and that the level of R&D investment has an impact on economic/competitive performance. She also stressed the fact that technology push forces radical innovations in new emerging markets and demand pull generates an emphasis on process innovation in markets with proven demand. It is of benefit to notice that there is a virtuous cycle where more investment in R&D makes nations, brands, and companies more competitive in the next time around.

Resource allocation decisions between exploration (research) and exploitation (development) were examined by Garcia *et al.* [2003] with the help of a SD model by focusing on four different factors: resource availability, exogenous competition, aging of knowledge bases, and adaptive capacity. They made three normative suggestions for new product development management in the proportional choice decision making for explorative and exploitative activities. They also pointed out to the fact that a healthy institution always should allocate some slack resource into the exploration activities even in the turbulent periods. This is due to the erosion of the knowledge stock with time and eventually one needs to feed in new investments.

The endogenous structure for the R&D pro-cyclical behavior in G7 countries was investigated by Wälde and Woitek [2004]. They tested the prediction that resource allocation to R&D should be negatively correlated to economic growth in terms of GDP. They found that some of the R&D activities were accelerated during the economy's downturns during which marketing budgets are pruned. In the present study, the opposite of this was tested.

3. Methodology

3.1. *Applicability of SD to the problem*

In order to satisfy the human psychic need of the desire to know the future [Sherden (1998); cited in Lyneis (2000)], managers use(d) many tools. SD is one of the most powerful tools for forecasting in complex structures.

One of the major advantages of SD over the other methodologies is its ability to help the modeler understand the underlying structure of the current problem at hand. The reason that SD becomes superior to the other methods is that it deals with causalities and nonlinearities that are neglected, ignored, or even feared by most of the static analysis [Forrester (1961)]. By applying SD, one can enhance the usefulness of the model to address and analyze problems to provide more significant, rational, and pertinent policy recommendations. The real value of an SD model is to eliminate problems by changing the underlying structure of the system rather than anticipating and reacting to the environment. A SD model, this way, interacts with the environment and gives/alerts feedback for structure changes [Sterman (2000)]. An SD model provides more reliable forecasts than the statistical (nonstructural) models and tries to understand the underlying structure that creates the data stream [Lyneis (2000)].

The problem discussed in the present paper is a dynamic problem because the trade-off between the marketing and R&D fractions may change each and every year. This leads to different sales figures that would lead to different profitability figures. The firms have to have new products to attract customers as well as marketing to support these products and the old ones. However, the budget of a firm is not limitless. Therefore, they need to have a policy mix for these issues.

3.2. *Problem definition, scope, time horizon, and purpose*

Companies may suffer from excess resource allocation, such as over-investment in the market expenditures though people who do not have sufficient purchasing power and over-investment in R&D though the market is satisfied with the new products. The compromise and harmony between the marketing and R&D determines the success of the firm in terms of customers who would bring revenue.

The electro market demand fluctuates year by year due to GDP growth that brings severe planning and strategy formulation difficulty in terms of marketing and R&D. Therefore, the budget fractions to be shared by R&D and marketing are expected to change annually. Depending on the changes in the effectiveness of resource use, one can say that over — and under-allocation is a widely faced situation.

Keeping the customer base at a sustainable level and the market share for the electro-business can be handled via the marketing or R&D activities such as quality improvement or new product launches. GDP growth can also affect the market and decisions drastically. In the present study, GDP is not an endogenous variable.

The general framework of the model includes decisions such as marketing and R&D (for both the average quality of the products and aging new product launches). Production, inventory, backlog, and issues such as delivery delay, competitors' reactions, and licensing are not considered.

On the other hand, product attractiveness, quality, and customer awareness are other variables impacting company success. One can see that there are many trade-offs that a CEO should consider. This brings up the problem of understanding and controlling complexity in the market structure.

Considering the delay of R&D expenses on R&D know-how, it can be noticed that it takes five or so years to form or add to such a stock. Hence, we decided to use a time horizon of 20 years to study the impact of different product generations.

The purpose of the model is to investigate and find the sustainable allocation trends in marketing and R&D, so that a firm can keep at a sustainable level of customers. Customers are assumed to be the main resource on which the firm builds all of the success indicators. While looking for these allocation trends, special attention is paid to the timing of these allocation decisions, namely the harmony between these two departments. One can see the model boundary chart in Fig. 1.

The model comprises of mainly the following issues:

(1) Customer accounting management,
(2) Product portfolio management,
(3) New product development, and
(4) R&D quality and manufacturing.

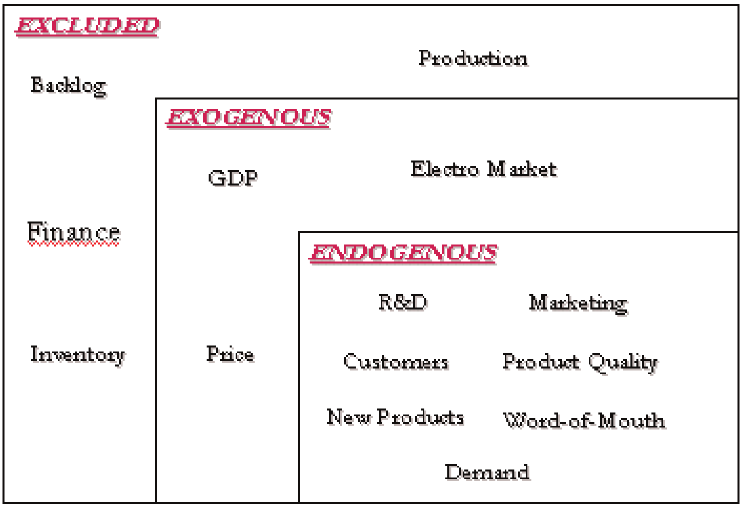


Fig. 1. Model boundary chart.

One can find relevant sectors and variables in the model related with these topics. In the next sections, the dynamic formulation of the hypotheses in both causal diagram and stock-flow representations will be explained. Following this, validation tests are done and then the policy design will be clarified. Finally, we will conclude with results and further research.

3.3. *Formulation of dynamic hypotheses*

The main aim of the model is to provide and explanation for the allocation trends in marketing and R&D departments of a high-tech firm to achieve a long-term success in customer base and revenue. We target to explain and investigate the reasons behind these investment patterns in details. In particular, the lack of harmony and timing of the investments in these functions are believed to create the problems concerned in this project that is the departure point for the dynamic hypotheses.

One way to evaluate these hypotheses is through a look at the timings of the allocation and its effect on the relevant stock. Marketing may have a short-term effect, whereas R&D has a longer-term effect. Especially in terms of R&D, it takes specific longer times to create an R&D know-how and functionality in the department. One should not expect to get a quick response from R&D that is ignored by most of the business environments. Time delays should be taken into consideration.

4. Simulation Model

The model in this paper is intended to represent the development of resource (budget) allocation of a high-tech company. The goal of the paper is to be a guide for a manager of the firm to constitute healthy investment actions for marketing and R&D. This would be via changing and controlling certain values of certain parameters in the system. When we change these values, we should see an effect on the

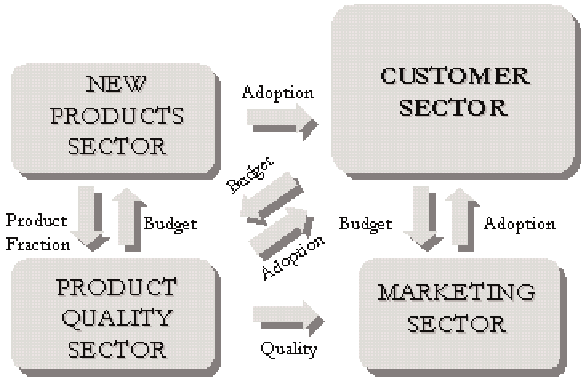


Fig. 2. Bird-eye view of the model in terms of sectors.

objective targets of the model. After observing the effects of decisions taken to different types of allocation trends, the user would help improve his/her understanding of the situation and structure that exists on his/her mental model.

The modeling process starts with determining some relevant key variables in the model to be explored for the problem at hand. The previous sections give an insight about these variables. The model boundary chart is developed to identify what is exogenous, endogenous, and excluded to determine the scope and boundary of the model. One can see a rough sketch of the sector relations reflecting the model structure in Fig. 2.

Customer sector works like a big engine for the model and provides revenue for the survival and development of the other sectors. Product quality sector provides the quality for the products and feeds this back to the marketing sector for increasing awareness that would bring more adoption of customers. New product sector sustains the R&D budget by the help of its feedback to the product quality sector where the main R&D budget is determined.

Given the dynamic hypotheses and these sub-system charts, the model should represent a situation in which allocation gets an equilibrium value that is in fact the sustainable level for each department that ought to work in harmony. The underlying feedback and stock-flow structure would help in capturing the model (i.e., the main causalities and equations).

The model assumes a laboratory environment where the data for the model are fictive, but close the reality. The next step in this model should be applying this to a real case with the actual data. However, as a starting point, this paper would build confidence and ability to control the variables, so that the next step gets much easier to handle. After the stock-flow structure is introduced, some policy designs would be created and analyzed for different situations.

4.1. *Causal loop diagrams*

The causal loop diagram gives the general structure based on causalities and feedback loops. The interpretation of these loops and their combined complexity can be

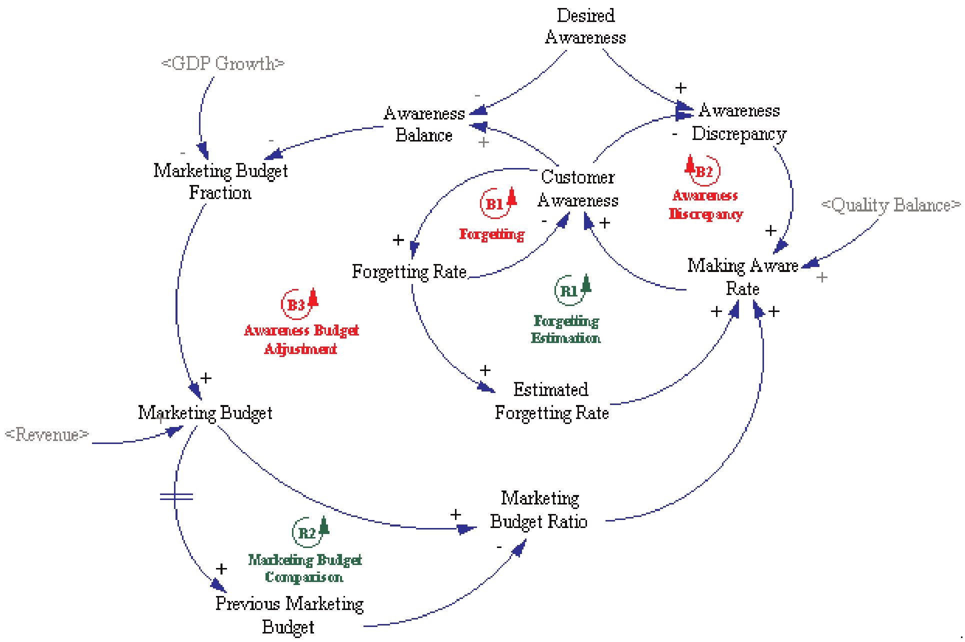


Fig. 3. Causal loop diagram of the marketing sector.

recognized easily. It may help separate the loops to two groups, namely reinforcing and balancing loops. The red arrows show the balancing loops and the green ones show the reinforcing loops. One can see the schema of causalities starting from Fig. 3 and in the following figures. The storytelling can be made both ways. In other words, if there is a (+) causality between two variables, it is possible to say that "X increases Y" if X increases and "X decreases Y" if X decreases. Each one of the loops are explained and described in the following pages due the sector analysis.

It is relevant to start explaining the story behind a resource because of the fact that a resource has a meaning when time is frozen, as it is at the beginning of the story. The selection of the stocks would be easier for the reader to understand in the following sections.

There are four sectors, marketing, R&D quality, R&D new products, and customers, containing the major variables of the proposed model.

4.1.1. *Marketing sector*

It is assumed that the company has a customer base that forms the sales and revenue figures for the survival of the company. The formation of the revenue and customers will be explained in detail later. The more revenue we have, the more marketing budget we would get. As the marketing budget increases, marketing budget ratio is also increased because the ratio is the comparison of the current budget with the previous quarter's budget. When the company realizes that the marketing budget ratio is increased, there occurs more opportunity for improvement in the customer awareness. This rate of making aware is also affected by the quality balance that is another variable in another sector. As the quality balance is increased, making aware rate is increased too. When customers see that the quality of the product is high, they get aware of it more. The more aware the customers are, the more forgetting there occurs. This forgetting rate is estimated within a time period and added to the making aware rate, so that the managers replace the depreciated awareness with the new amount.

There is also a desired awareness that the company seeks for. awareness discrepancy is the difference between the actual and desired value for the awareness. The more awareness discrepancy, the more addition to the making aware rate. In addition, the company can see its awareness by dividing customer awareness by the desired awareness that is called awareness balance. As the awareness balance gets bigger, the budget gets smaller each time. The reason is that a customer can be maximum 100% aware of the product or service. Therefore, this balance ratio and also the GDP growth feed back to the budgeting decisions. Finally, we come up with the new budget for marketing where we have started.

4.1.2. *R&D-quality sector*

In order to determine the R&D budget, old product fraction and GDP growth are used. As the fraction of old products gets higher, the importance of R&D gets higher and it gets larger values to add more products to the product portfolio. The more R&D-quality budget we get, the bigger the R&D-quality budget ratio gets, which is basically the division of the current budget with the previous quarter's budget. This adds to the quality inflow more.

As quality inflow increases, quality increases and there occurs more quality outflow. Then this affects quality and lowers its value (Loop B4). The more quality outflow, the more estimated quality outflow takes place and the more quality inflow gets (Loop R3). This mechanism works like an adjustment for the quality. The managers are replacing the depreciated quality with the new amount.

There is also the concept of the desired quality that the company seeks to attain. The difference between this value and the actual one gives us the quality discrepancy that would add more to the quality inflow to adjust the quality toward the desired value (Loop B5).

After calculating the quality balance that is the ratio of current quality with the desired quality, this affects the R&D-quality budget. R&D budget is a general budget that is composed of two sub-budgets, namely R&D-quality budget and R&D-new product budget. If we get closer to the desired quality, then there would be less budget allocated next time around. Finally, we come up with the new budget for R&D-quality where we have started (Loop R4 and B6).

4.1.3. *R&D-new product sector*

One would remember that the R&D-new product budget is dependent on the R&D-quality budget. Quality budget is subtracted from the total R&D budget to get the

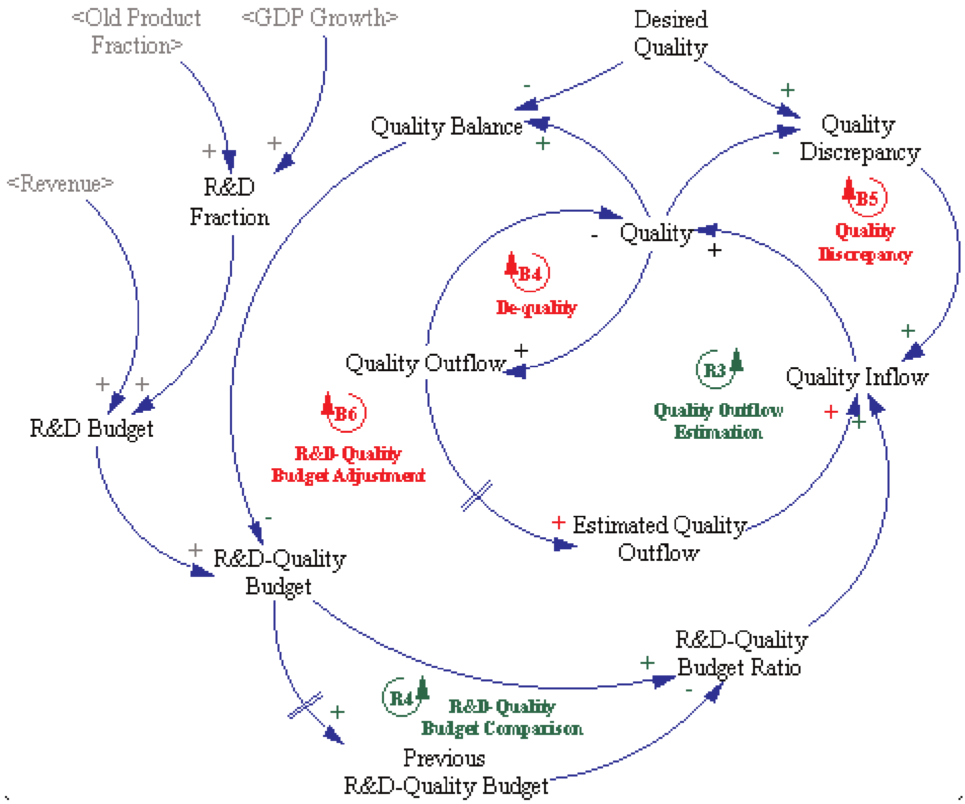


Fig. 4. Causal loop diagram of the R&D-quality sector.

product development budget. By dividing this budget with the value or the cost of a new product, we get the launching rate of new products. The more new products we get, the more obsolete they become.

In this sector, one can see that there is a stream of products from new products to mature products and then to old products. It aims to reflect the "product life cycle" concept in the model. As the new products are increased there would be more transition to the mature products and then to old products. Each phase has its own obsolescence time (Loops B7, B8, and B9). This approach includes imitation by competitors implicitly.

Total products is the sum of all three stages described above, so it is positively affected by these products. We compare this number with a reference number of products available in the market. The target here is to see if the company is lagging the market in terms of product portfolio. The ratio is called product balance ratio, which is used in the next sector. In addition to this availability issue, the products' being too old also is a threat for the company in the competitive arena. If the fraction of old products is increased, the company should allocate more R&D budget and if this ratio is high, customers would begin attrition from the company.

The fractions of the products are also calculated, so that they can be used for the customer sector. They are used for price calculation.

4.1.4. *Customer sector*

This sector may said to be the main engine of the model due to its importance for the customer base. As Warren [2002] also states that customers are the main and crucial stock of the company.

As it was stated earlier, there is a customer base in the market active in transactions with the company and there is also another pool of customers who are called potential customers. As the potential customers are increased, there would be more adoption rate to the actual customers.

The actual customers may influence the potential customers to adopt the company's products. This happens in the following way: As the number of customers increases, there would be a certain number of contacts that they could do to affect by considering the contact rate. The more customer contacts, the more possible contacts between potentials and customers. However, not all of these contacts are persuasive for the potentials. In other words, there is a word-of-mouth (WoM) probability that this contact would turn into a successful one for the company. The bigger this probability gets, the bigger adoptions would occur. This process is called WoM effect (Loops R6 and R7).

On the other side, the company also has many other adoptions from different features of the product or the company. There are also adoptions from R&D-quality (Loop B14), adoptions from R&D-new products (Loop B13), and adoptions from marketing (Loop B15). They affect the adoption rate in the same direction.

A customer may give up the product permanently or temporarily. He or she may be added to the potentials pool or may be drawn out of the system (Loops B11, B10, and R5).

Potential customers are increased by potential growth rate, which is one of the inflows of the stock. GDP growth also affects the price. GDP growth and indicated price are multiplied basically with an assumption. Then, each customer is believed to bring some revenue to the company. The more customers and price, the more revenue there occurs.

There are also some major loops that are important. As the causal loop diagram is composed of four sectors, it may be difficult to visualize that revenue is allocated to marketing and R&D, roughly speaking. These two departments get customers to the company that would bring more revenue next time around. This structure may be easily visualized by the help of Fig. 5, which is the sector relation figure.

4.2. *Stock-flow diagram*

In the previous section, the causalities between the variables of the model were explained briefly and qualitatively. Readers interested in a more detailed analysis of the model in terms of understanding the underlying structure may contact the authors to request the list of the model equations as well as the stock and flow figures.

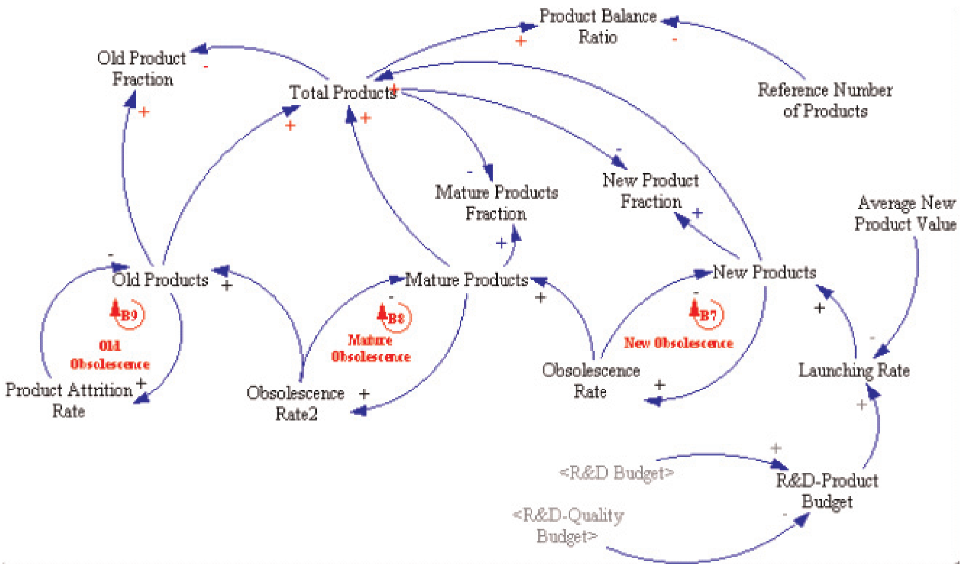


Fig. 5. Causal loop diagram of the R&D-new product sector.

4.2.1. *Selection of stocks*

As Sterman [2000] suggests, the snapshot test is used for the selection of the stocks. The main stocks after this analysis are as follows:

- Customers,
- Potential customers,
- Product quality,
- Customer awareness,
- New products,
- Mature products,
- Old products, and
- Electro market.

These stocks are mentioned in the following sections. The time unit of the model is month and the explanations below are done based on this statement. They are also the resources of the company from the view point of Warren [2002].

These structures were more or less explained in the causal loop diagrams before; however, for space saving purposes, it was decided not to illustrate all equations. Therefore, for the complete stock-flow equations and for input functions, interested readers may contact the authors. The equations described in the text belong to base run.

5. Testing and Validation

In testing a model to see if it is an adequate representation of the reality, Barlas [1996] proposed a sequence of validation tests for formal validation. In this section,

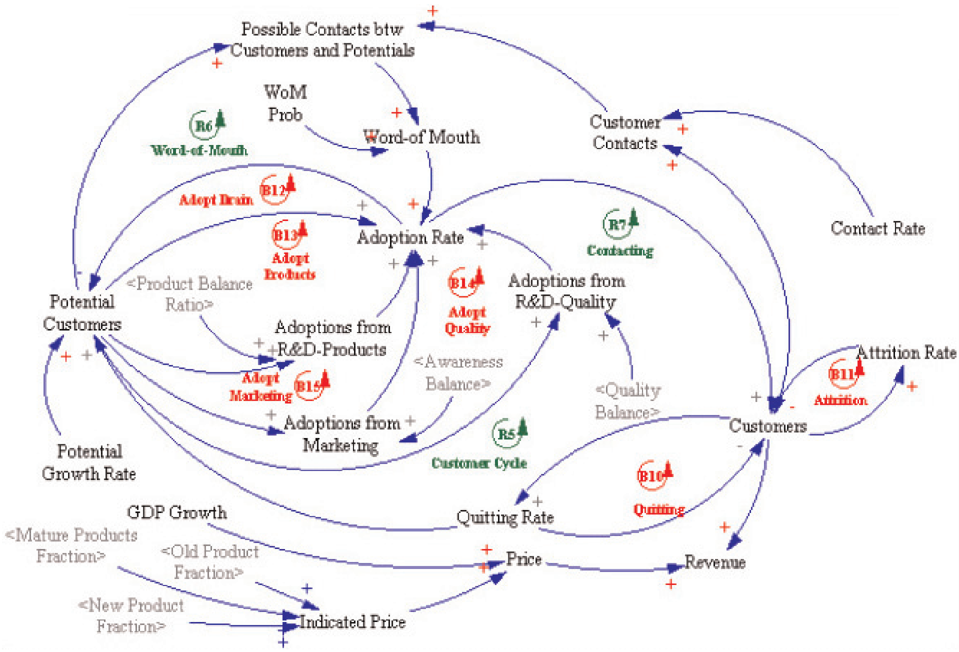


Fig. 6. Causal loop diagram of the customer sector.

this sequence will be followed with the chosen and relevant tests for the model. As the model does not consider raw and actual data, there is no attempt to replicate the history. All tests are concerned on the structure and sensitivity.

5.1. *Direct structure test*

These tests assess the validity of the model structure by direct comparison about real system structure. One will not be able to see a simulation, but rather structure and parameter confirmation with dimensional consistency.

In this part, each equation is considered alone and evaluated with the current knowledge in the literature. This was in fact done with the stock and flow model building at the same time. Each equation was checked and evaluated if it reflects real life. Zero fudge-factoring is aimed at and the units of each side of the equations are checked. For instance while a "stock" has the unit of *item*, a "rate" has the unit of *item/time* since they reflect flows in the system.

5.2. *Structure-oriented behavior tests*

These tests are rather concentrated on testing the behavior of the model with the simulations carried out. One compares the expected mode of behavior with that of the model generated. Then, one concludes that the model is either good enough or needs further work and reverse engineering.

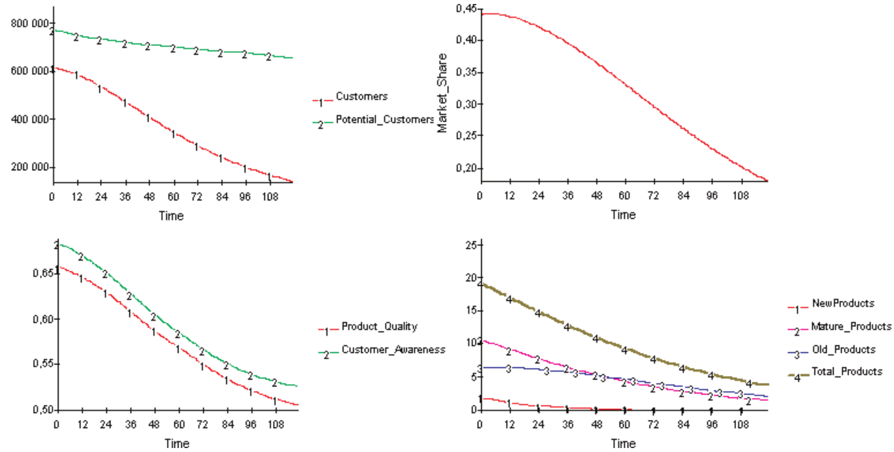


Fig. 7. Main stocks of the model after price = 0.

5.2.1. *Extreme conditions test*

This test includes simulation through time by giving extreme values to the selected variable and comparing the model-generated behavior to the anticipated behavior of the real system under the same extreme condition [Barlas (1996)].

5.2.1.1. *Price*
Price is set at 0 by making

$$\text{Price}_{\text{Mature}} = \text{Price}_{\text{New}} = \text{Price}_{\text{Old}} = 0. \tag{1}$$

Price is chosen to be very close to zero, which is 0.000000001 in order to eliminate the divisibility by zero error. In addition, due to this effect, simulation time has been shifted back to −48 because even this budget affects quality and awareness, so it is filtered for the reader for better understanding the extreme condition (please see Fig. 7 for the results and Run2).

Expectedly, when price goes to zero, revenue goes to zero and as a result there occurs no budget for the departments of the firm for both marketing and R&D. Then, the related measures such as product quality (bottom left), customer awareness (bottom left), and product variety (bottom right) get closer to zero. They are not zero yet at the end of the simulation for 120 months, but it is assured that they go to zero for long period simulations. After these effects customers (top left) begin to quit the company due to lack of pre-mentioned measures and so the market share converges to zero. In addition, the rates related with the customers and potential customers go to zero (bottom left), which is the equilibrium for the system. The company collapses.

The behavior explanation of the model would be done in the next part, so the reason behind the peaks for the product quality and customer awareness would be investigated later.

- Price is set at maximum by making

$$\text{Price}_{\text{Mature}} = \text{Price}_{\text{New}} = \text{Price}_{\text{Old}} = 100, \tag{2}$$

which is a relatively high value (please see Fig. 8 for the results and Run3).

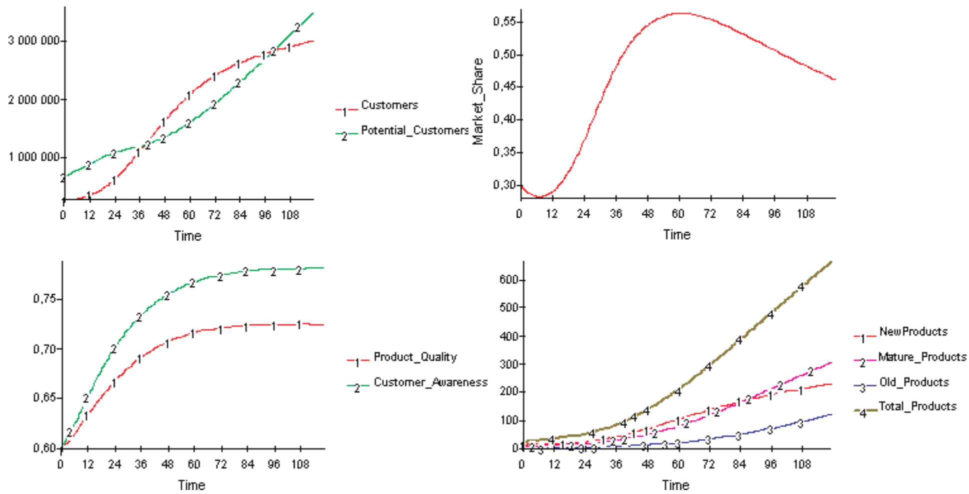


Fig. 8. Main stocks of the model after price =100.

When price goes to 100 that is a relatively high value, revenue goes to a high value in the beginning due to high customer level and as a result there occurs high budget for the departments of the firm for both marketing and R&D. Then, the related measures such as product quality (top right) and customer awareness (top right) experience goal-seeking growth. product variety (bottom right) goes to higher values also. As it is a third-order structure, after the first stock, this response is reflected to the others. As the market share is the ratio of customers to total customers, until time 60, they gain half of the market, which is evident from the figure on top row of Fig. 8.

However, potential growth rate of potentials increases continuously and the net increase in the customers is less than that of the potentials. This may really be the case in reality because after a time when a company gets a large customer base, it shows basically that it is a profitable area. This is an indicator for most of the entrants to get into business there. Therefore, the company has to share this customer base with the rivals. In addition, as the price is on the high extreme, the combined effect — that affects the potential growth rate — really takes high values, so the potential customers reach higher values earlier than it would have got otherwise. This may be the interpretation of the loss of market share.

5.2.1.2. *Average new product value (ANPV)*

- ANPV is set at 4,545, which is a relatively low value (Fig. 9 and Run4).

When ANPV goes to 4,545, which is a relatively low value, there can be made more new products next time around and the transition rates from the new products to the other aging products, go more each time. They grow continuously (bottom right). This brings an "early" success in the product balance, which would affect both product quality and customer awareness in the same way (bottom left). The net increase in the potential customers is again bigger than that of customers (top left) and the market share drops drastically after time 30, because the number of customers stays very low according to the total customers (top right).

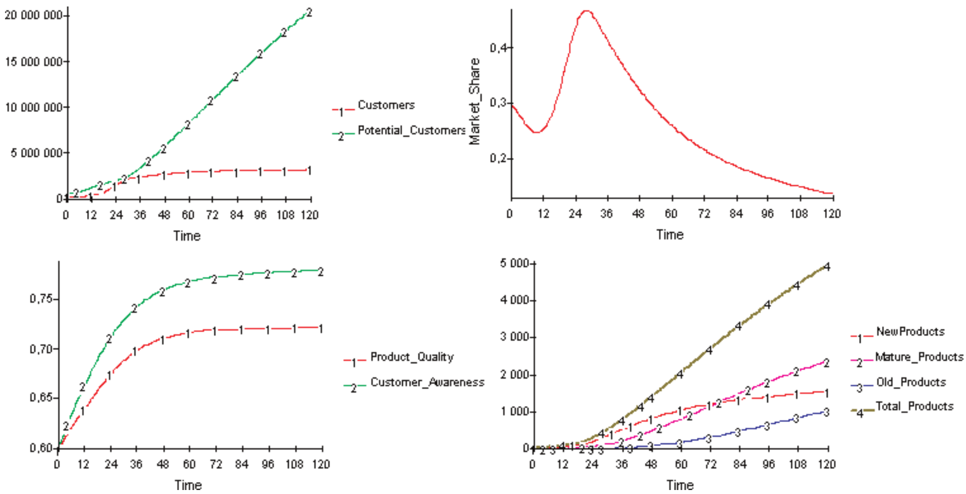


Fig. 9. Main stocks of the model after ANPV =4,545.

- ANPV is set at 1,000,000, which is a relatively high value (cf. Fig. 14 and Run5).

When ANPV goes to 1,000,000, which is a relatively high value, there can be made less new products next time around and the transition rates from the new products to the other aging products, go less each time except for mature products until time 24. They go down to zero (bottom right) due to high product development costs. This brings an unsuccessfulness in the product balance, which would affect both product quality and customer awareness in the same way after a time (bottom left). This does not affect them immediately because they get their budgets from the company, but after a time new product unsuccessfulness brings a disease to whole company. As a result of this, customers quit the company (top left) and the market share goes really high until time 50, but drops down later on (cf. Fig. 10).

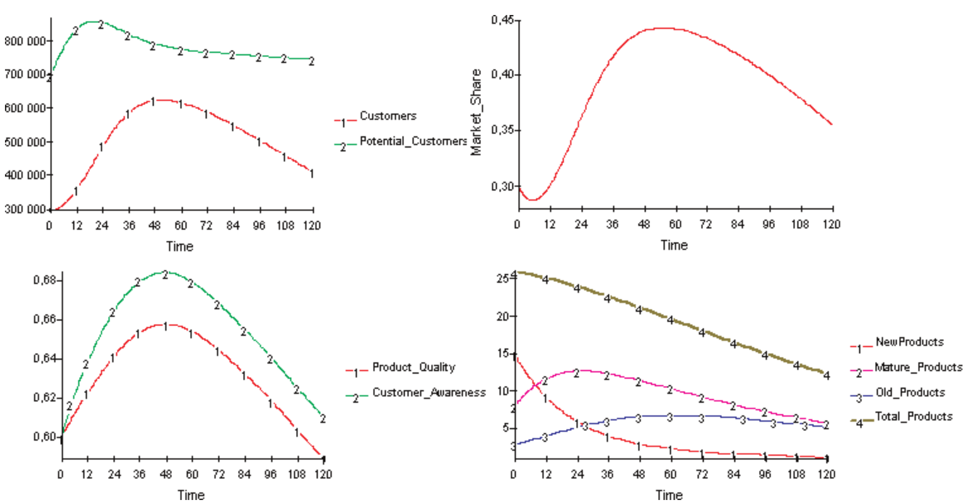


Fig. 10. Main stocks of the model after ANPV =100,000.

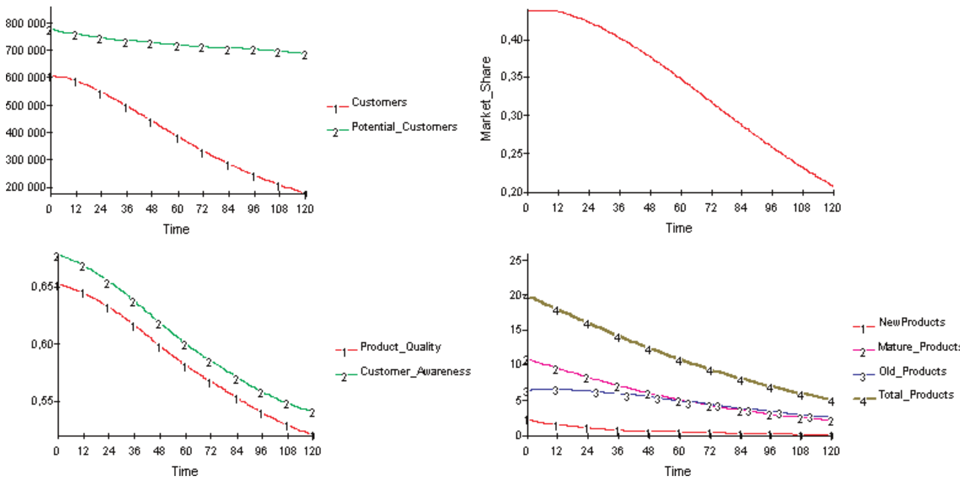


Fig. 11. Main stocks of the model after reference fractions = RRDF = RMBF = 0.001.

5.2.1.3. *Reference R&D fraction (RRDF) and reference MB fraction (RMBF)*

• They are both set to 0.001, which is a relatively low value. It is not zero in order to overcome the problem of divisibility by zero in the model. Simulation is started from −48 to 120 in order to eliminate this divisibility by zero effect. (Fig. 11 and Run6).

When budget fractions go to 0.001, which is a relatively low value, there can be made less (almost zero) and less budget next time around. As the budgets go lower, less new products are generated and the transition rates get low (bottom right). The budgets for the quality and awareness get decreasingly increasing values and this reflects to the awareness and quality (bottom left). As a result of this, customers quit the company (top left) and the market share goes to zero (top right).

• They are both set to:

$$\text{RRDF} = 0.5, \text{RMBF} = 0.5. \tag{3}$$

The reason why they were given 0.5 is that it was presumed that there were just two departments in the company for the extreme case (Fig. 12 and Run7).

When budget Fractions go to 0.5, which is the maximum meaningful value, there can be more budget next time around. As the budgets go higher, more new products are generated and the other product type stocks go higher (bottom right). The budgets for the quality and awareness get decreasingly increasing values and this reflects to the awareness and quality (bottom left). As a result of this, more customers adopt the products of the company decreasingly (top left). This can be seen in the market share figure. The net increase in the customers cannot keep pace with the potential customers (top right). As a result, marketing share starts dropping at the point where the net increase in customers is equal to the net increase in potential customers.

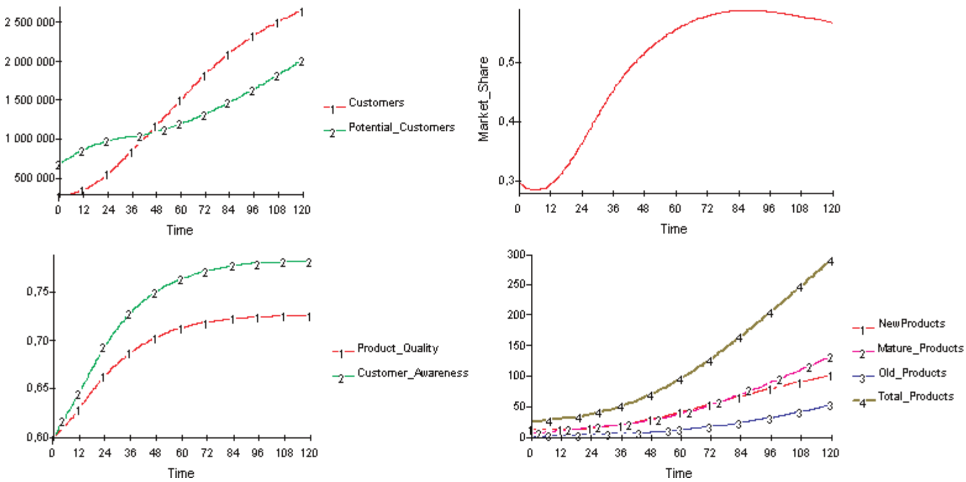


Fig. 12. Main stocks of the model after reference fractions RMBF = RRDF = 0.5.

5.2.2. *Sensitivity test*

This test consists of determining those parameters to which the model is highly sensitive, and asking if the real system would exhibit similar high sensitivity to the corresponding parameters [Barlas (1996)].

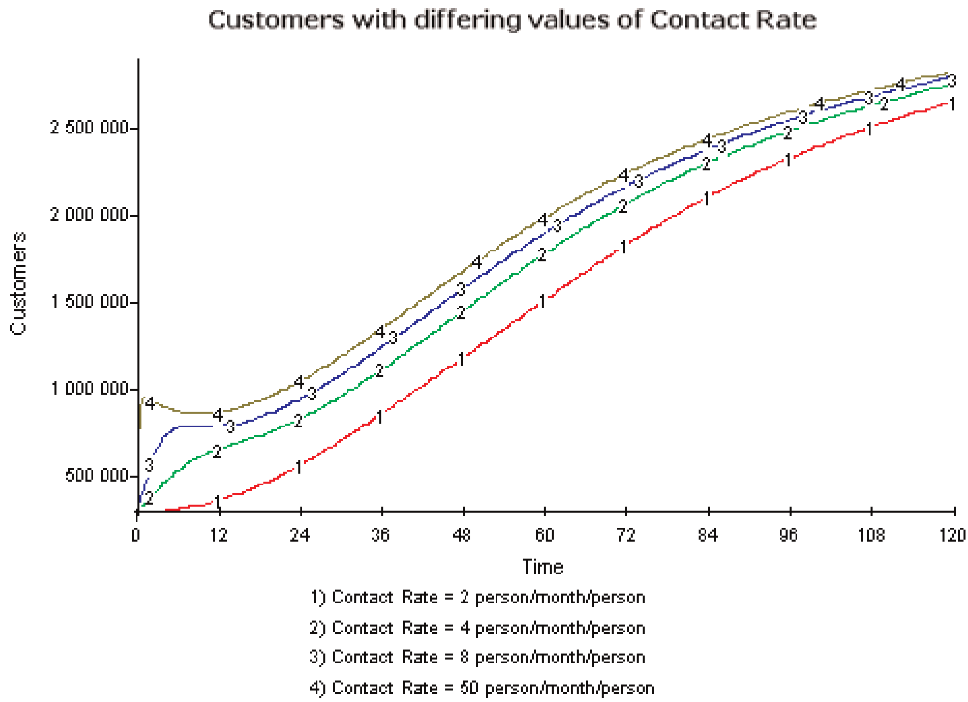
5.2.2.1. *Contact rate*

It is common sense that no company can estimate contact rate exactly because we are human beings and we have desires and changing goals each time. This makes us different from animals and plants. We behave in a random way most of the time. While wandering through the city, we coincide with friends or there are many phone calls between each side. It is really impossible to say that I have made five contacts this month, because it is even arguable what a contact is and what its effect is on the phone or face to face. There is a huge uncertainty in this rate, so one must pay special attention to these kinds of variables in a model that bring uncertainty with itself. This was the departure point for selecting this variable as a sensitivity variable. One can see the result of the analysis in Fig. 13 and base run and run 9,10, and 11.

As the contact rate is increased, one can realize that in the initial six months or so, the behavior in the customer stock shows a different trend than the base case where the rate was two persons/months/persons.

It is obvious that if the contact rate is increased, there would be more space for potential growth in the customers via WoM the next time around. However, the trend that marketing share and customer follow is different each time.

The company should assume high contact rates if they had done advertising or distributed free products previously in the market, so that there occurs more customers interested in making WoM effects to others. The reverse case is that if the company is a start up without previous efforts, then a low contact rate should be chosen. The middle values can be chosen as an insight for the model for the other types of mature companies.



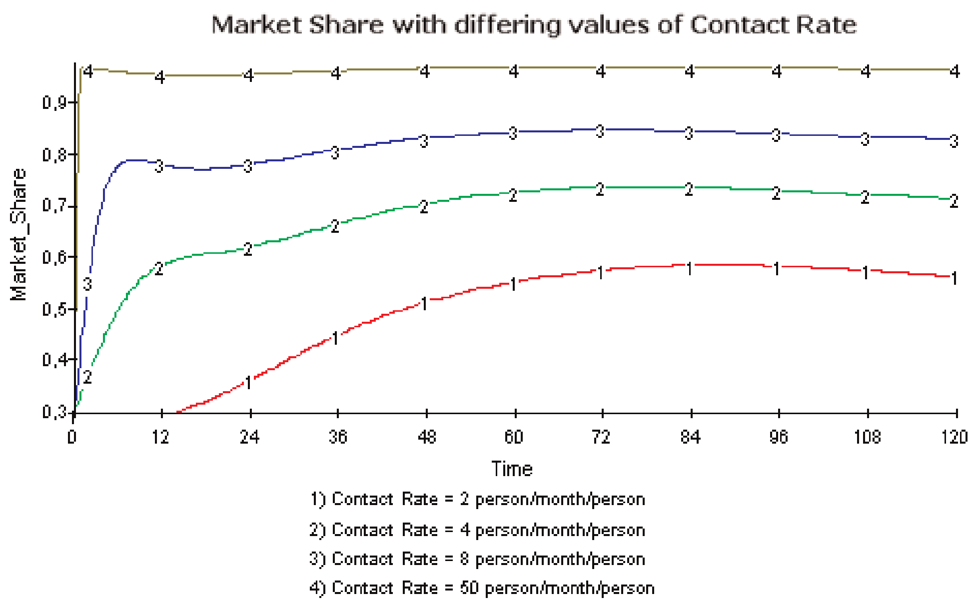


Fig. 13. Market share and customers with differing values of contact rate.

6. Simulations and Behavior Discussions

In this section, it is aimed to express why the model generates what it generates. The discussion would be made with the base run. The stocks would be explained with the underlying Net Flow to the stock. Net flows are calculated instantly such as:

$$\text{Net flow}_\text{S} = \left(\sum \text{Inflow}_\text{S}\right) - \left(\sum \text{Outflow}_\text{S}\right), \text{where S is the index of the stock.} \quad (4)$$

6.1. *Base run*

In this run, the GDP growth and WoM probability are designed in the following way:

$$\text{WoM}_{\text{-Prob}} = \text{NORMAL}(0.1, 0.005, 2) * 0 + 0.1/12 * 1 \quad (5)$$

$$\text{GDP}_{\text{-GROWTH}} = (\text{SINWAVE}(\text{RANDOM}(0.01, 0.05, 6), 48) * 100/12) * 0 + (0.1 * 1/12) * 1. \quad (6)$$

6.1.1. *Potential customers*

One can see the net flow formula for the potential customers below (fig. 14):

$$\text{Net flow}_{\text{Potential customers}} = (\text{Potential growth rate} + \text{Quitting rate}) - (\text{Adoption rate}). \quad (7)$$

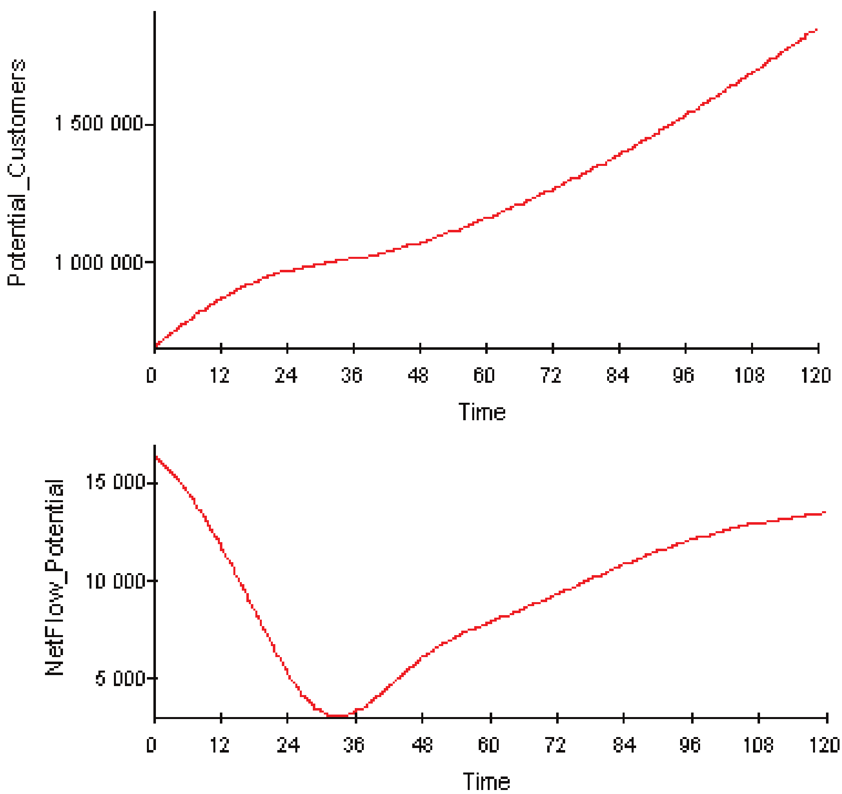


Fig. 14. Potential customers and its net flow.

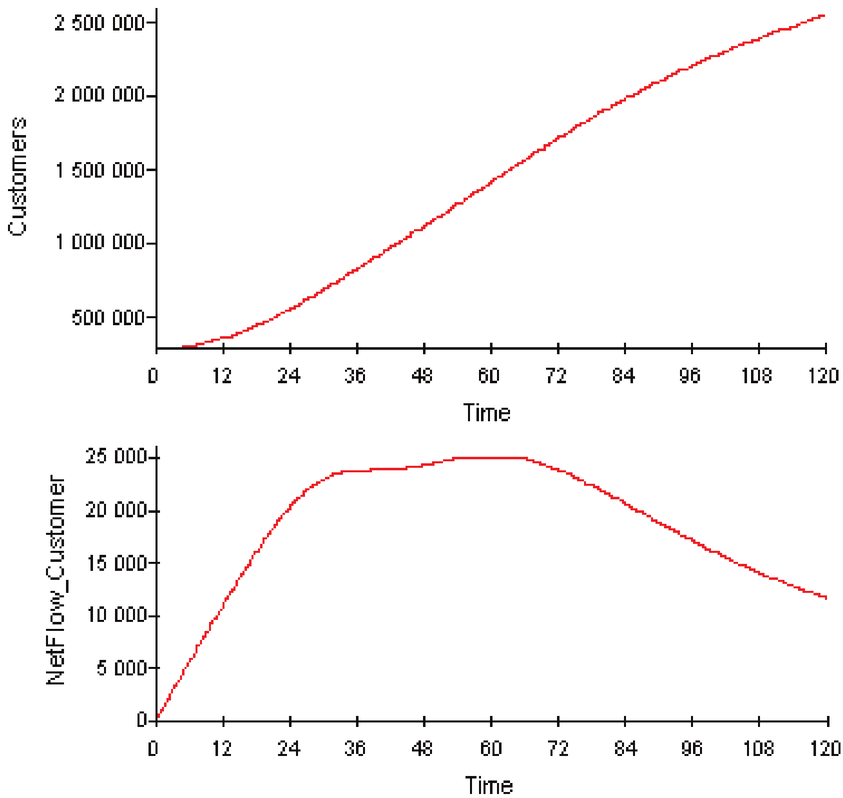


Fig. 15. Customer and its net flow.

As one can see in the base run, potential customers increase throughout the simulation. Around time 33, the growth is the minimum, which can easily be seen from the net flow graph. Until that time net flow decreases to a certain amount around 3,000, but this does not mean that stock would do the same because a stock is the result of the integration of its net flow with time plus whatever it had previously. In other words, the area under the net flow graph plotted against time gives us the additional stock value. During this period potential customers follow a goal seeking behavior with growth. After time 33, net flow starts increasing like a goal-seeking behavior, but not a pure one. The stock, however, follows a transition in the growth trend from linear to some form of growth and then gets closer to linear growth again.

6.1.2. *Customers*

One can see the net flow formula for the customers below:

$$\text{Net flow}_{\text{Customers}} = (\text{Adoption rate}) - (\text{Quitting rate} + \text{Attrition rate}). \qquad (8)$$

Customers show an increasing trend with different characters throughout the simulation. It first increases like an exponential growth due to its net flow's almost linear increase till time 24. Then, the net flow decelerates and comes to a smooth valley during which customers increase very close to a linear way. After time 66, net flow starts to drop down, which would bring a decreasing increase to the customers.

6.1.3. *Product quality*

Product quality shows rather a distinct type of behavior. Until time 12, there is a growth close to exponential growth in the net flow and this reflects to the stock behavior certainly. Stock almost behaves in the same manner, but suddenly at time 12, net flow starts decreasing till around 18 and after that there is a drastic decrease. Between time 12 and 18, we cannot see a specific changing behavior in the stock due to the impact's effect is valid for a short time and net flow's being small. The area under that time range is really small to change the stock, so that we can see a differing path. (We could have seen the behavior if we just make the graph bigger in scale, which is not feasible here.) After time 18, product quality follows a path to reach its goal, but stabilizes below that value in the long term (Fig. 16).

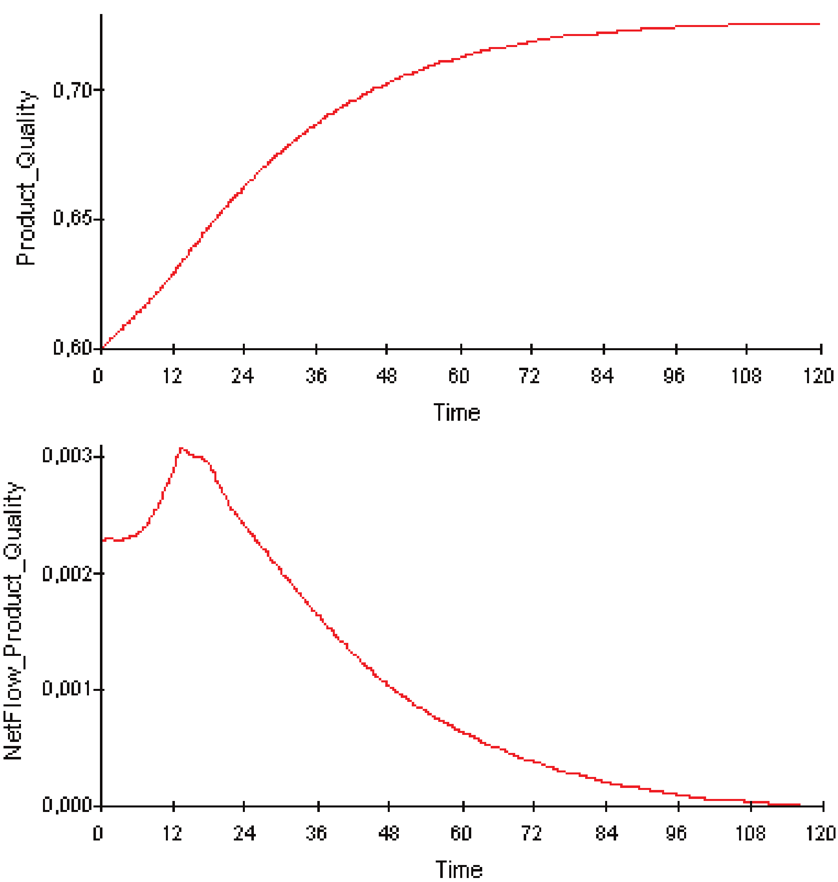


Fig. 16. Product quality and its net flow.

One can see the 3D phase plots of the product quality (z-axis) and its two flows, namely quality inflow (x-axis) and quality outflow (y-axis). Hot colors such as red and its neighboring colors reflect higher values.

6.1.4. *Customer awareness*

Customer awareness also shows a similar behavior with the product quality stock. However, the behavior of the net flow is not the same with the product quality. Until time 7, net flow decreases decreasingly down to a level and gets a local minimum there. During this time, customer awareness increases, but never gets a flat behavior because the net flow is still a positive value, not zero. Then, from time 7 to 12, net flow starts increasing, which affects the stock the same way. The exact behavior related to those net flow changes cannot be seen due to the already-mentioned reasons of scaling. Then, from time 12−18, the rate of increase in the net flow just slows down and expectedly stock has still its growth over time. After time 18, net flow starts going down, which would affect the stock with the goal-seeking type of behavior due to the net flow's decreasing to zero, which means there is no growth at all.

One can see the 3D phase plots of the customer awareness (z-axis) and its two flows, namely making aware rate (x-axis) and forgetting rate (y-axis). Hot colors such as red and its neighboring colors reflect higher values.

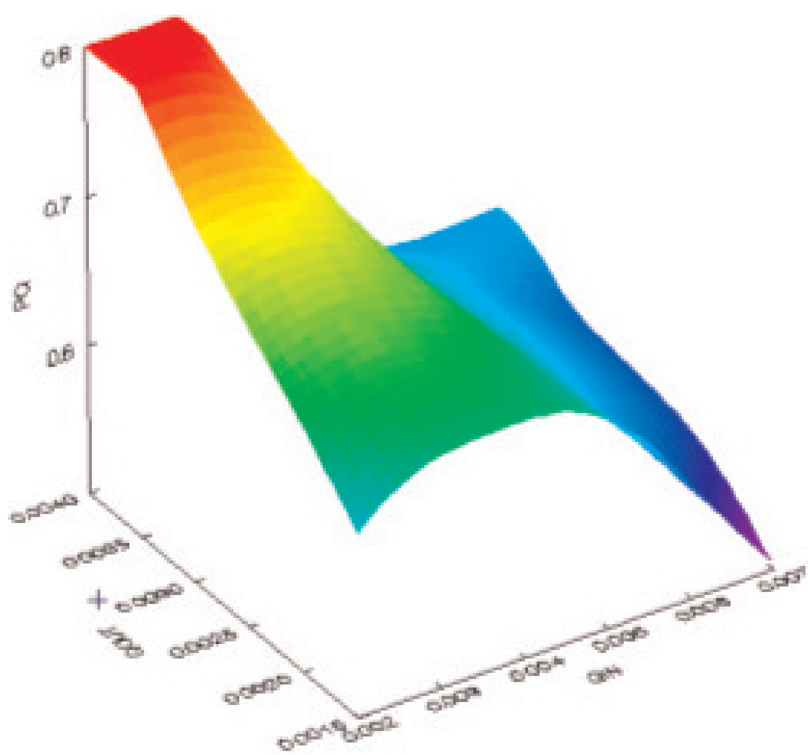


Fig. 17. Product quality and its flows.

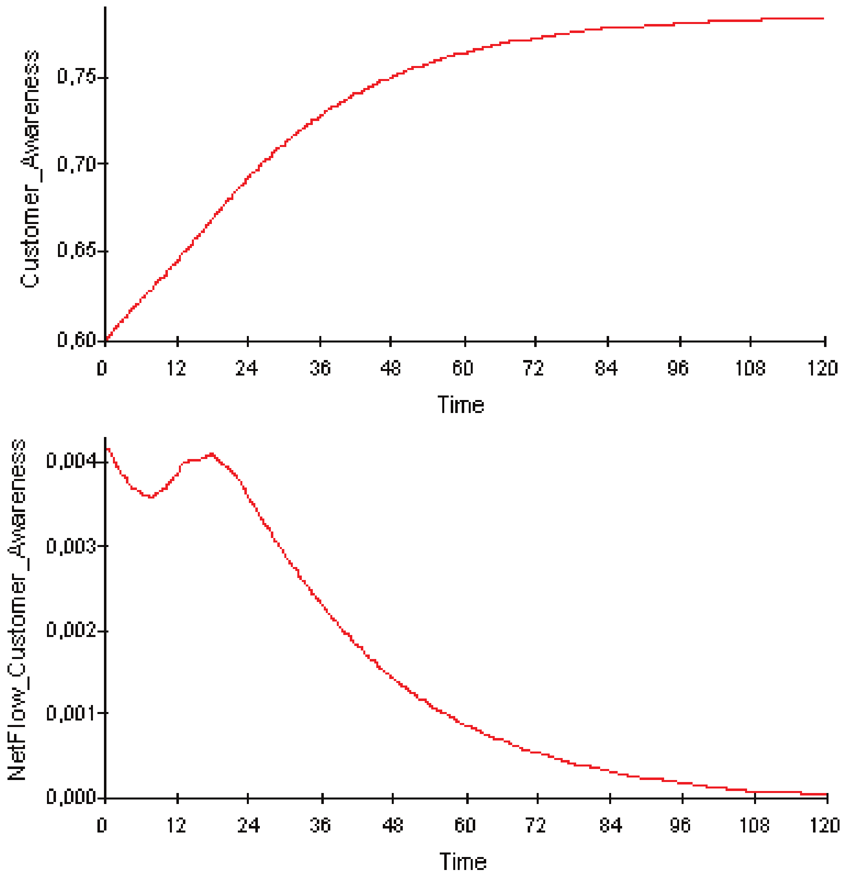


Fig. 18. Customer awareness and its net flow.

6.1.5. *New products*

This stock is the first in a series of aging products. Although net flow increases until time 24 like an exponential function, one should pay special attention to the values it takes, because until time 12 it takes negative values, which increase (get closer to zero) through the mentioned time range. New products initially decrease very little due to this reason. In the time range between 12 and 24, the increase in the net flow still goes on and the behavior in the stock is exponential growth. However, there is an inflection point for the net flow, which is very close to time 24. Net flows start to increase decreasingly, which would affect the new products get closer to the linear growth from exponential growth. After time 78, net flows start to go down, which would affect the stock get closer to a goal value.

6.1.6. *Mature products*

Net flow for the mature products follows a negative goal-seeking behavior until time 18, but still has a positive value. This would affect the stock, mature products, gets

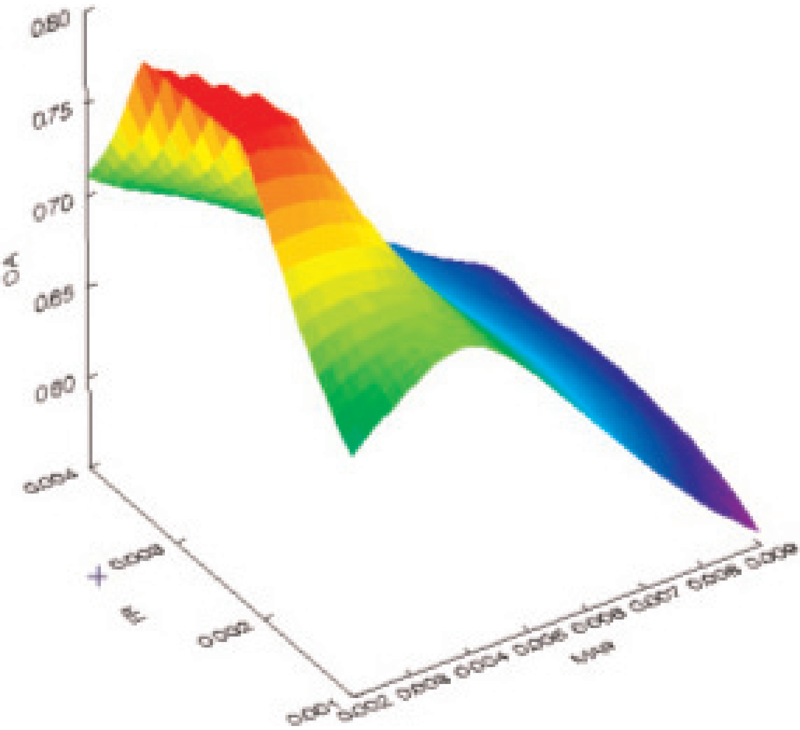


Fig. 19. Customer awareness and its flows.

very close to a flat (but not) region around the same time 18. After time 18, net flow starts to increase and experiences an inflection in the growth at about 55. During this time period (18−55), stock follows an exponential growth. After that time, the stock behavior gets closer to a linear growth due the fact that net flow starts to stabilize at around a value of 1.5.

6.1.7. *Old products*

This is the third stock in the series of product stream (in the new product sector). The net flow of the old products is a similar version to that of the mature products except there is decrease in the net flow of the mature products initially. This is because of the fact that, in the higher orders of the aging chain, the last stocks just follow the previous ones and the previous ones follow the first stock. Considering all time constants and delays, the last stock just does not respond the same way to the system as the first stock does. We can see this in the net flow behavior of the old products and mature products. What matters is the ratios of the adjustment times in this aging chain. This defines the behavior of the product chain members. As the net flow, here, increases continuously which would affect the stock the same way. Net flow gets a stable value much after the simulation, then the stock would increase linearly or exponentially depending on the options for the net flow.

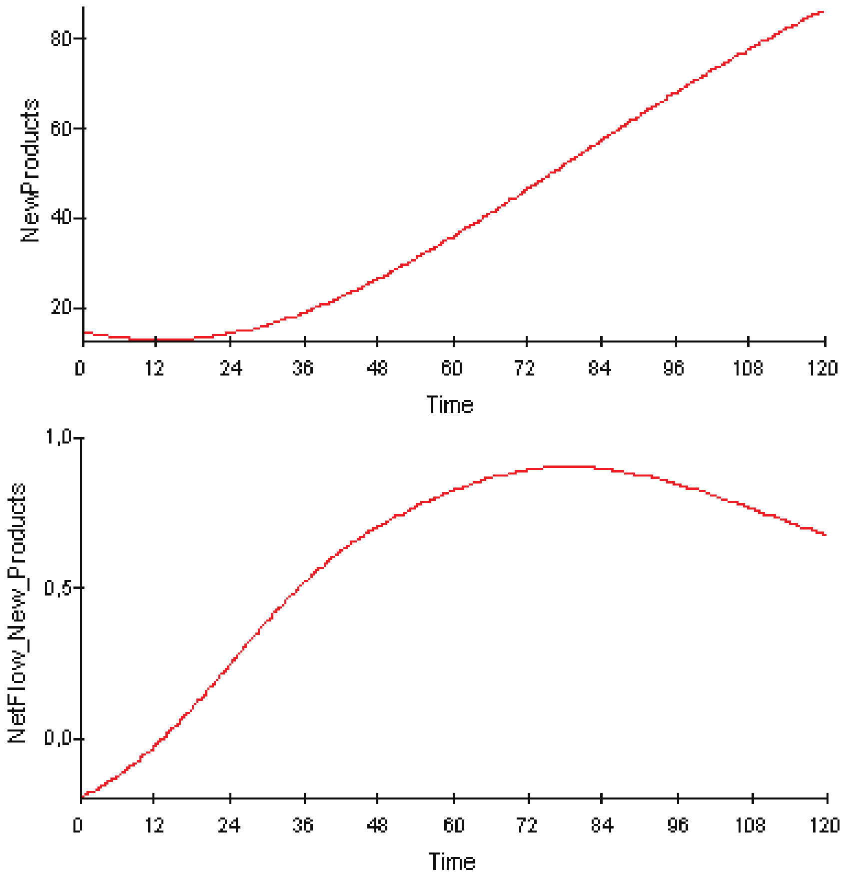


Fig. 20. New products and its net flow.

6.2. *Alternative run*

In this run, just the GDP and WoM probability are changed in the following way:

$$\text{GDP}_{\text{-GROWTH}} = (\text{SINWAVE}(\text{RANDOM}(0.01, 0.05, 6), 60)/12). \tag{9}$$

GDP is given with a sinus wave whose amplitude is a random function between 0.01 and 0.05 with a period of 60 months (five years). It is assumed that GDP of the country oscillates (due to historical data) between certain values. These values are divided by 12 just for the input function and monthly adjustment.

$$\text{WoM Probability} = \text{NORMAL}(0.1, 0.005, 2). \tag{10}$$

A distribution is given to the probability for the WoM effect. The probability is reduced by 100 assuming that it is not so probable for a contact to end up with an actual customer.

One can see the summarized results of the alternative simulation below (alternative run):

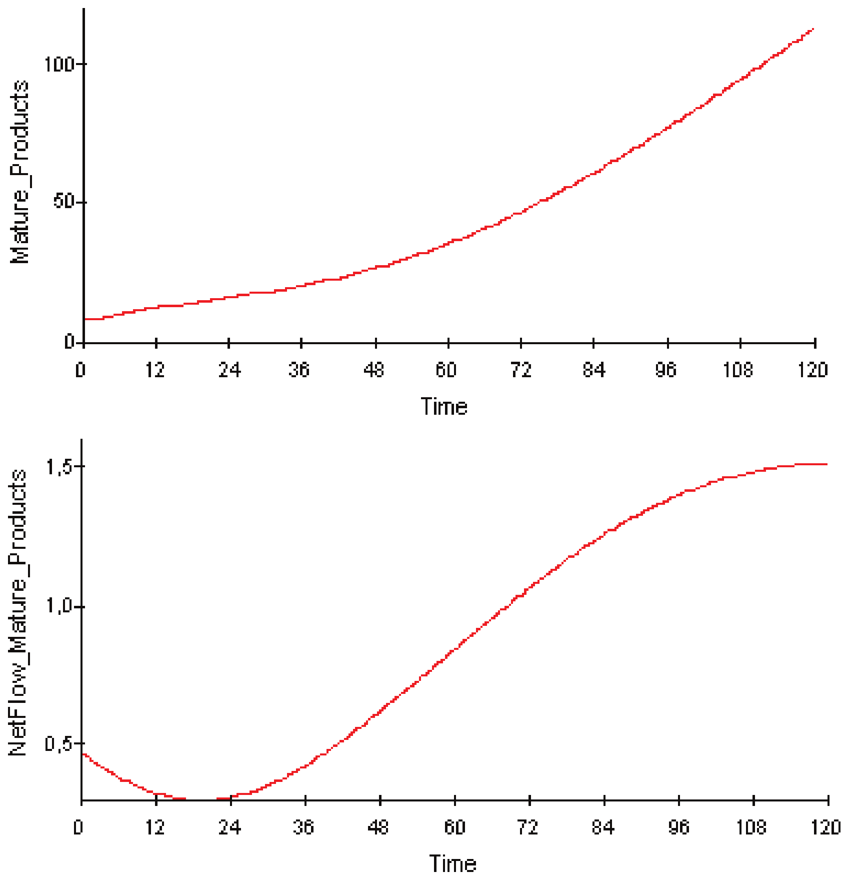


Fig. 21. Mature products and its net flow.

The oscillating level of GDP growth (top right) is averaged for R&D and marketing (middle right). In other words "White Noise" has been utilized for random input to GDP growth. However, as in reality, these ups and downs are in a way smoothed via "Pink Noise," which addresses the fact that our perception of a real issue comes with a smoothing effect. We have utilized the heuristic called "anchor-and-adjustment." We anchor to an initial value and adjust it through a perception process.

GDP growth in turn affects the budget amounts much (top left). Marketing budget and R&D budget are oscillating with an increasing trend. Both product quality and customer awareness get oscillating values (middle left). In addition, mature products also get higher values throughout simulation (bottom left). The fractions according to these trends in the products are seen on the bottom right. New fraction and mature fraction dominate the spectrum and there is an oscillating trend in the last 80 months and old fraction is always around 0.1 level.

Market share skyrockets drastically (top right) in the beginning and after a time it stabilizes with very minor oscillations around a certain value. This can be interpreted as the market is cannibalized as a consequence of the allocation

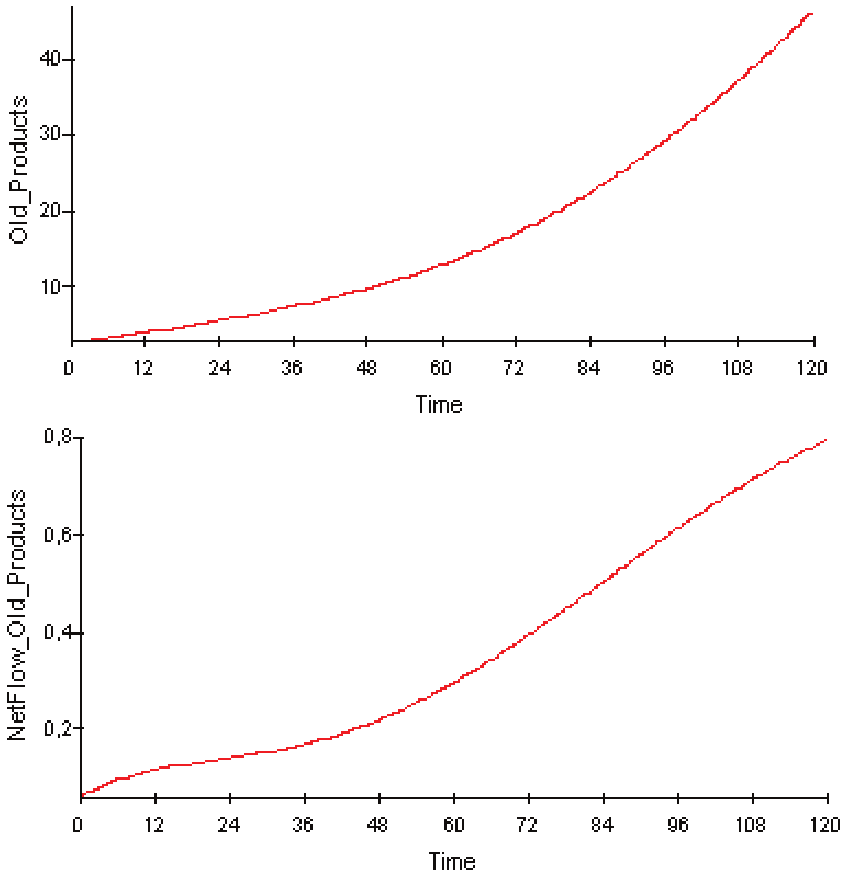


Fig. 22. Old products and its net flow.

strategy. This is due to the timing of R&D and marketing activities. On the other hand, being a crucial component of the revenue, price is kept low during the upturns and high during the downturns. It is oscillating (bottom right) mostly due to the GDP effect on price. The economic developments and price trends might seem contradictory during the downturns especially, but this effect is also compensated during the upturns when the incomes of population are relatively higher. Beyond compensating, the benefits during the upturns are much bigger than that of the downturns, because the market share is kept at a high level. One other factor is obtaining the market share, which is an indicator also for future profits in a way.

The objective of this alternative run was to show the effect of budget allocation between marketing and R&D activities by taking into consideration the GDP growth of the economic environment. The main hypothesis beyond this run is that companies should invest in R&D activities when the economic trend is upturn, since there is enough source to fund them. However, when the economic situation is downturn, companies should try to focus on their marketing activities to boost their sales capacity.

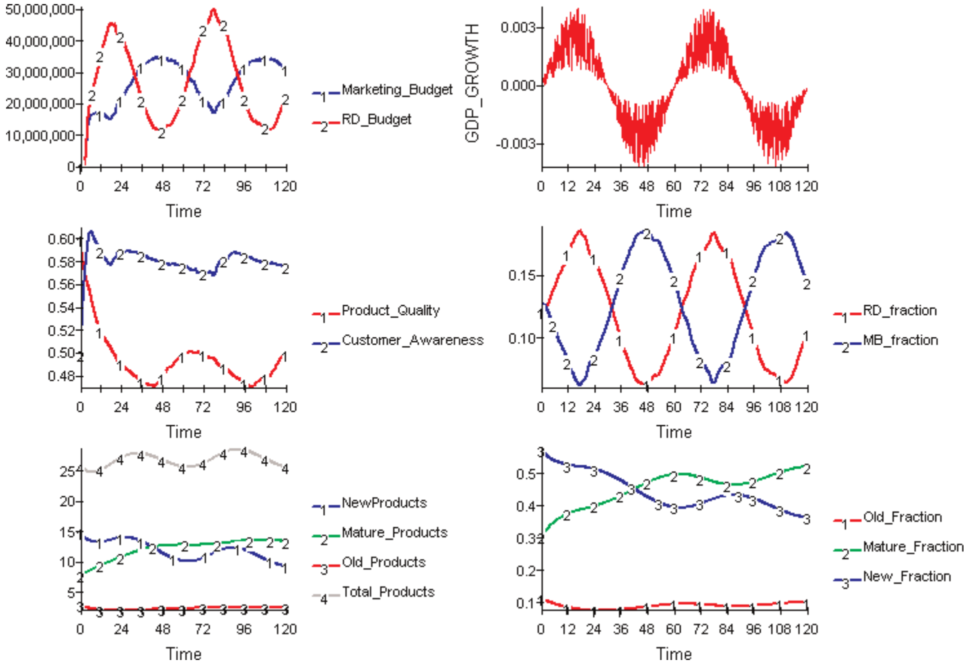


Fig. 23. Some variable results for alternative run.

7. Policy Design and Evaluation

In this section, we aim to design some policy tests for the base run, which has the simple assumptions. The departure point for the design of the policies was the decision for the marketing spending and R&D spending. It was assumed that the share to the total of R&D and marketing departments is a fixed percentage of the revenue which is 25%.

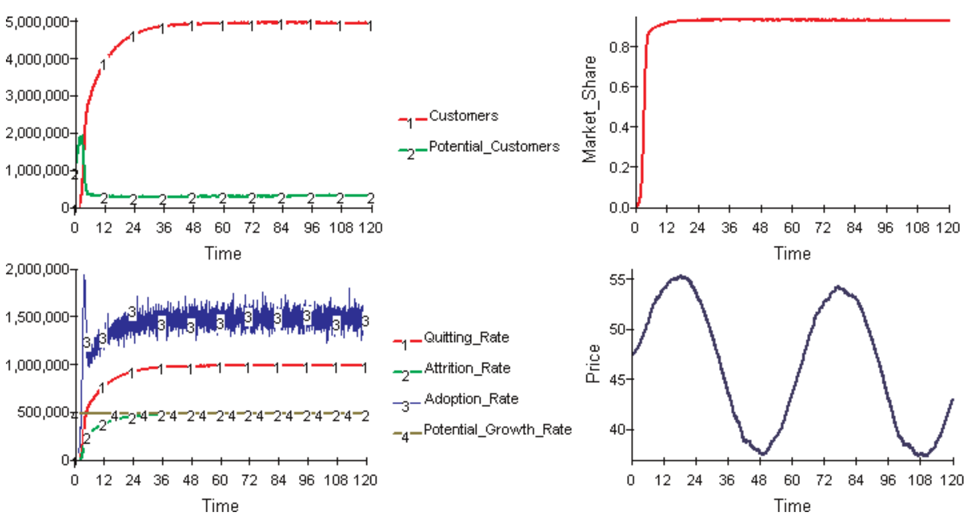


Fig. 24. Customer and market share figures.

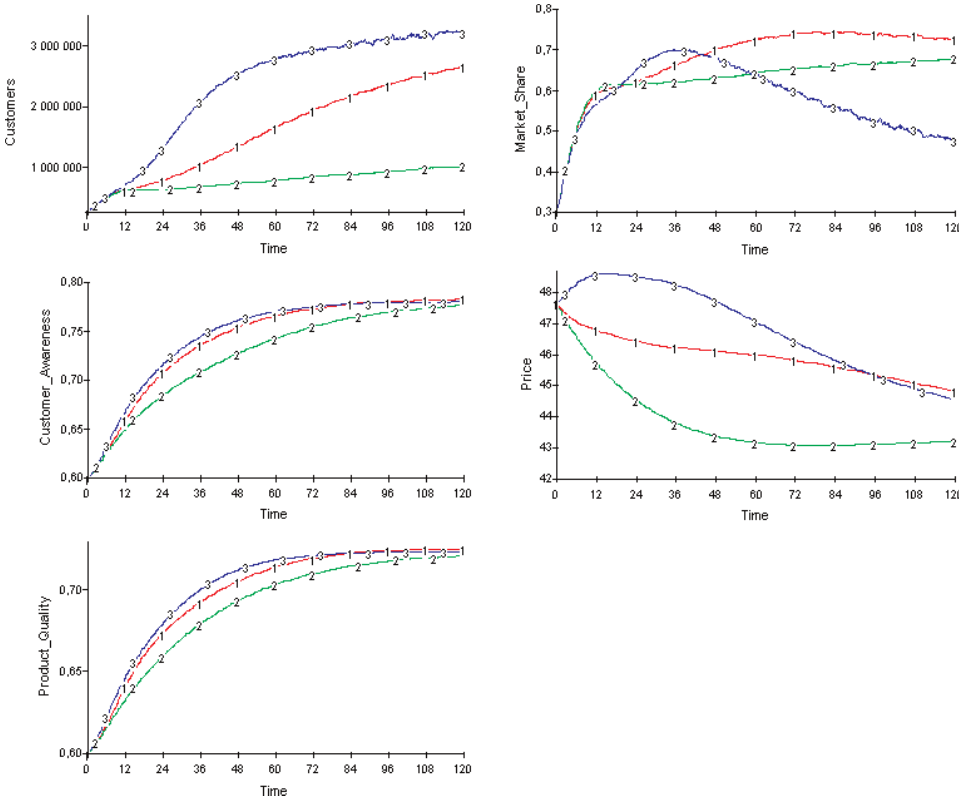


Fig. 25. Results of important indicators for policy evaluation.

Before going on with the policies, it would be beneficial to discuss survey results for allocation of the budgets between marketing and R&D for high-, medium-, and low-tech companies. The survey was carried out online on a Yahoo! Groups poll site, which is devoted to a strategy development group in Turkey. The results seem to confirm Trott [2002]'s classification.

High-tech case results: About 68% of the participants gave more weight to R&D than marketing. This shows a tendency in this sector to promote innovations more than marketing activities. However, the participants were indifferent between 10% and 15% (M-R&D) allocation and 5% and 20% allocation. This gives flexibility to the policy design for these types of companies.

Medium-tech case results: About 80% of the participants gave more weight to marketing than R&D. This shows a tendency in this sector to promote marketing activities more than innovations. The participants were clear about the allocation since more than half of them decided on 15%−10% allocation. Extreme R&D allocation is very low.

Low-Tech Case Results: About 83% of the participants gave more weight to marketing than R&D. The participants were clear about the allocation since half of them decided on 20%−5% allocation. There are no extreme R&D allocations (i.e., 20% R&D or 24% R&D).

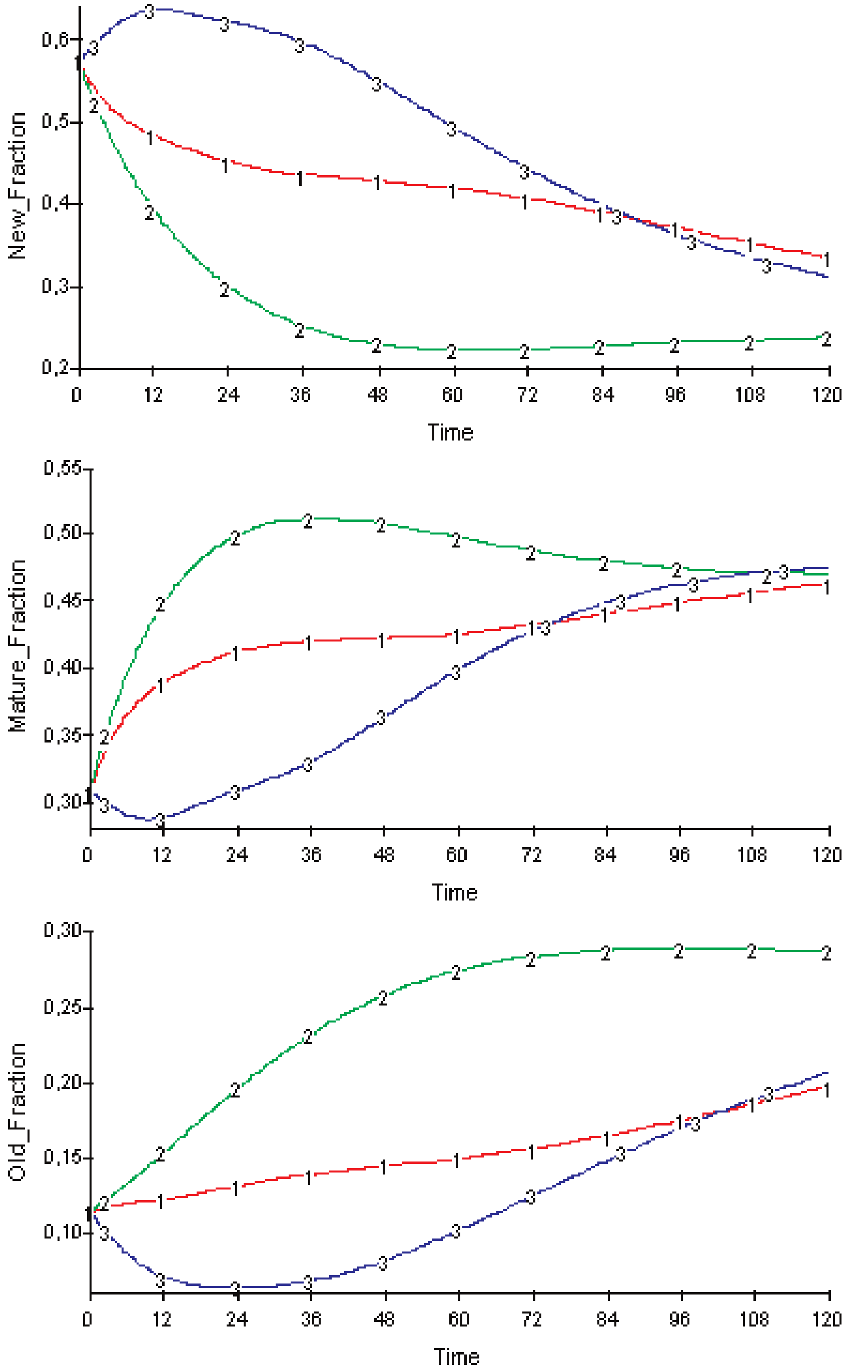


Fig. 26. Results of product fractions for policy evaluation.

7.1. *Policies*

7.1.1. *Policy* 1: *Base policy*

Policy 1 is thought to be the base case for an average electronics company who invest in both R&D and marketing. The percentages are as follows: Please see Run P1.

$$\text{Marketing percentage} = 20\% \tag{11}$$

$$\text{R\&D percentage} = 5\%. \tag{12}$$

7.1.2. *Policy* 2: *Marketing emphasis*

Policy 2 is thought to be the base case for an average electronics company who invest less in R&D and more on marketing. The percentages are as follows: Please see Run P2.

$$\text{Marketing percentage} = 24\% \tag{13}$$

$$\text{R\&D percentage} = 1\%. \tag{14}$$

7.1.3. *Policy* 3: *R&D emphasis*

Policy 3 is thought to be the base case for an average electronics company who invest more in R&D and less on marketing. The percentages are as follows: Please see Run P3.

$$\text{Marketing percentage} = 5\% \tag{15}$$

$$\text{R\&D percentage} = 20\%. \tag{16}$$

7.2. *Policy evaluation*

Policies designed above are evaluated in this section. First of all, a manager must face the reality that he or she has to choose among some policies to implement and by doing so he or she has to do some trade-offs. They are clearly and intuitively realized in the results of the runs for the policy parameters below. The representations of the policies have the same number indices in the graphs: Curve 1 & Policy 1, Curve 2 & Policy 2, and Curve 3 & Policy 3.

In terms of customers, Policy 3 seems to be the best policy, because heavy investment of R&D in quality and new products has a dominating effect on all of the departments of the company. Policy 2 is the worst, which can give an insight to the manager that even though the marketing spending is very high, the return is not so as it was expected to behave accordingly. Low R&D investments can affect the marketing in a decreasing way. Policy 1 is the mediocre among these policies.

In terms of quality and awareness, Policy 3 seems to work best among the other policies, because the company can reach a higher value earlier than the other policies. Policy 2 is again the worst policy to adopt under these circumstances. The achievement of the same level according to the other policies is much later. Policy 1 is still the second choice.

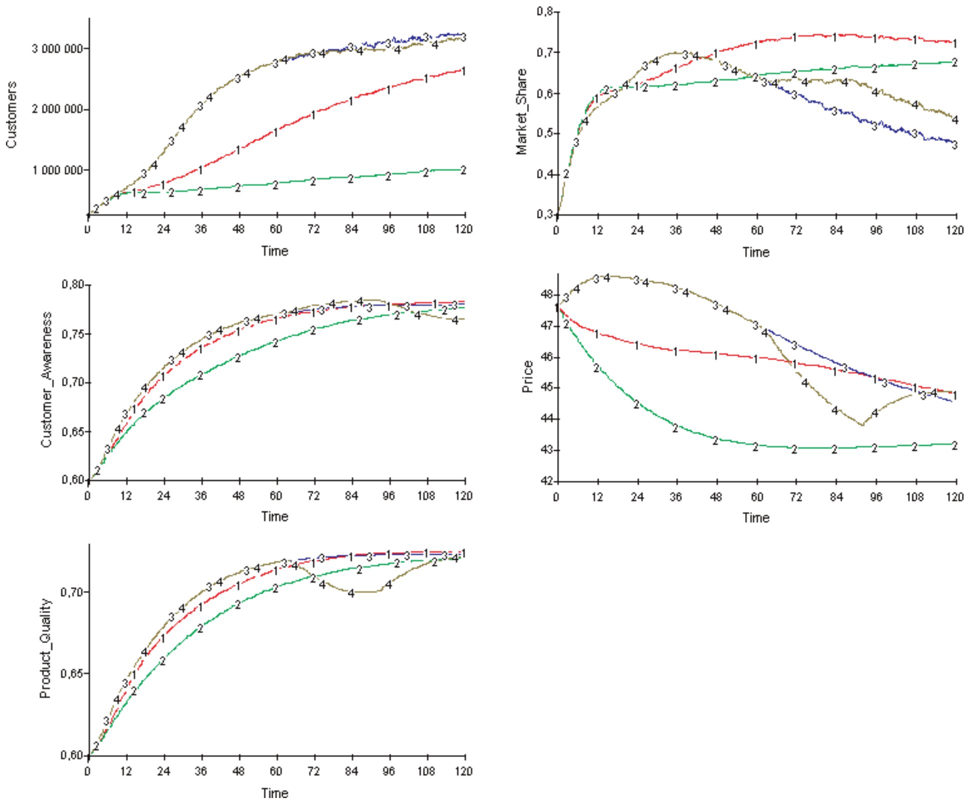


Fig. 27. Results of important indicators for policy improvement.

In terms of price, Policy 3 is still the best. It is much over the other two policies till time around 90. This is good because the revenue is made up of customers and price mainly. During this high price season for the Policy 3, the number of customers is the highest too among the others. This means it is the highest revenue case.

In terms of market share, Policy 3 is still good until around time 44 at which Policy 1 passes by. However, one should not forget the potential market is enlarged by the effect of the company's good products and quality and awareness of the customers. If you make your customers aware of the industry, this would affect the entire industry so it grows too. As it grows, your marketing share decreases by a certain amount. Therefore, it seems that though the marketing share is on the fall, one should pay attention that capacity constraints are beyond the scope of this project. In fact, this is a good sign that model works well. It gives one clue about the future improvements and research about the project. If the company increased the capacity, then there may be increasing or constant level of market share.

In terms of product ages, one can see that, with Policy 3, new fraction is almost always the highest. Policy 1 passes it by just in the end of the simulation. Policy 2 that was low R&D case shows that new fraction is the lowest among all. Old fraction is the lowest with Policy 3 almost always, which is a good feature

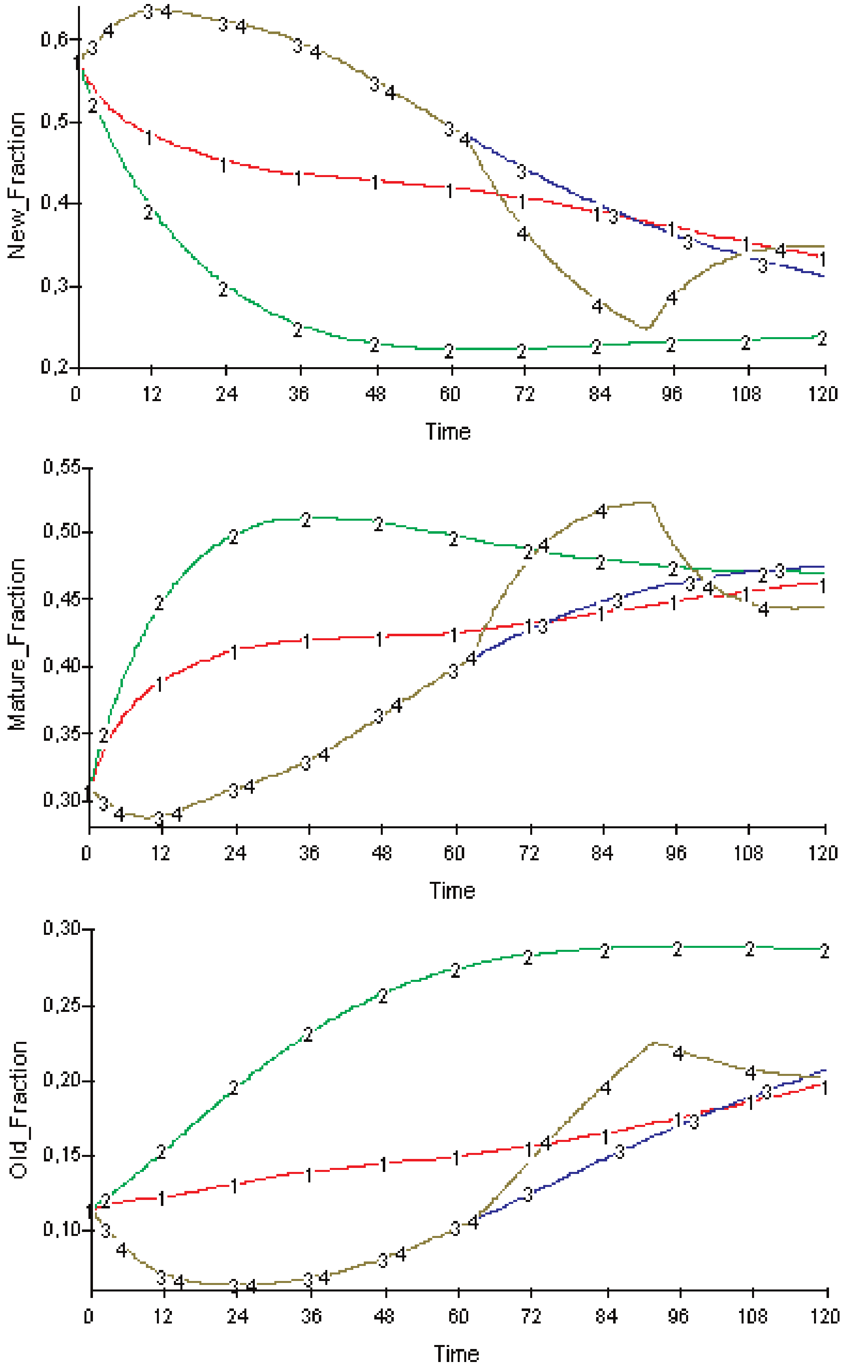


Fig. 28. Results of product fractions for policy improvement.

for a company, especially for an electronics company. Policy 1 becomes better in the end.

From all these points made, Policy 3 seems to be the best policy to be chosen among the alternative ones. Although there are some trade-offs, the manager can easily evaluate that Policy 3 is the preferred policy for the sake of the company. However, let us not forget that Policy 3 is a bit more expensive policy than the others. This can also be another future analysis for the project.

7.3. *Policy improvement: policy 4* (*Hybrid Policy*)

Policy 3 is chosen to be implemented but a few improvement actions can be taken. Policy 4 is created for this reason with better and more feasible figures. Here is how Policy 4 is formed:

Policy 4: (1) Follow Policy 3 between time 0 and 60. (2) Shift to Policy 1 at time 60 and stay with it until time 90. (3) Shift back to Policy 3 at time 90 stay with it until the end.

The results can be seen from fig. 27. Curve 4 is Policy 4.

As one can see, Policy 4 is the replication of Policy 3 till time 60. The difference comes just after time 60. Between the time range 60 and 90, the market share is pretty much kept constant because of the shift to Policy 1, which has more marketing expenditure. For this period, quality drops to a level but awareness does not. The reason is that awareness is fed with the marketing budget during which it is more than Policy 3. Price also drops significantly. The customer base does not change much. It is almost the same. After time 90, market share starts to drop again because marketing budget is now limited to some degree. This time quality starts to get up again due to high R&D budget. Awareness starts to drop due to low marketing again. Price on the other hand starts to increase.

At this point, it would be beneficial to make a comment about the effects of R&D and marketing to the industry demand. From the analysis until now, one can say that R&D affects the industry demand more than the marketing does.

Policy 4 until time 60 is the same with Policy 3, which was mentioned before. When the shift occurs, the new fraction starts to drop, but after the second shift to Policy 3 again, the new fraction reaches a level that is higher than Policy 3 would do itself. Besides, the old fraction starts to decrease after the second shift.

Policy 4 seems to be a good hybrid of Policy 3 and Policy 1, which is also much cheaper than Policy 3 itself. The manager can choose Policy 4 for a less costly policy and if he or she wants to have a longer period of stable company. What can be done more is that he or she can play with these policies more by shifting from Policy 3 to Policy 1 from time to time.

8. Conclusion

8.1. *Key findings*

After the analysis of the policies, one sees that Policy 4 is a good policy for a company. Satisfying both the sales and the revenues with the marketing share and customer base would be possible.

The reason why Policy 4 is the best among the studied alternatives is that many managers are evaluated based on their performance on market share. Even though they have good sales, there is always a question such as why the market share is dropping. The current model enables the manager to control this issue, too. It is recommended for the manager to increase the R&D fraction and decrease marketing fraction. By doing so, he or she can assure his or her position in the company and provide sales to the company. The policy may seem obvious, even intuitive, but it has a reason behind it. Most of the managers may have already been doing this, but are they really on purpose or is it just the market drive?

In alternative run (altrun), the model is run under the oscillating level of GDP growth instead of a constant growth. It is recommended this time to increase the marketing when GDP is a downturn situation and increase the R&D share when GDP is on the rise due to the fact that when GDP growth goes up, it is assumed that people get more purchasing power and they can afford more new products. If GDP is down, then the company should make marketing on the existing products more.

By investing in R&D and marketing companies can enhance market growth by increasing the awareness among the customers, so that they decide to buy the company's products, which may result in increased market share.

8.2. *Limitations and suggestions for future research*

The general framework of the model includes decisions such as marketing and R&D (for both the average quality of the products and aging new product launches). Production, inventory, backlog, and issues such as delivery delay, competitors' reactions, and licensing are not considered.

This model may be enlarged by adding some variables such as production, inventory, backlog, capacity, licensing, and some sectors such as finance and Employees. By this way, it would be a more thorough and complete analysis. The analysis may be carried forward especially in terms of cost and profit sides, so that the decisions can be made in a more reliable and complementary way.

Rivalry is another issue that may be analyzed in future studies. The company can identify certain types of rivals and group them into classifications, so that the analysis gets easier as Warren [2002] and Scherer [1967] state. The company can have a group of rivals sectors added in the model.

8.3. *Managerial implications*

Before attempting to solve resource allocation problems, it would be very helpful to understand the underlying structure of the problem at hand. SD is a useful tool dealing with causalities and nonlinearities, which are neglected, ignored, or even feared by the most of static analysts.

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