Economic Dynamics of R&D:

Analysis of Technology and Development

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This paper analyses a theoretical model of a technology company as an input-delayed economic transformation process. Firstly, the research environment is introduced. Some literature related to technology management and learning is reviewed. Thirdly, a system dynamics model and its parameterization are introduced. Based on the analysis, we suggest some managerial implications related to price erosion, R&D productivity, time delays and interest rate sensitivity. Finally, the preliminary results related to product development are concluded and the practical applicability of the model is discussed for further research in the area.

Keywords: *R&D dynamics, price erosion, discounted cash flow*

1. Introduction

The economic performance of a contemporary company depends very much on its ability to introduce new products with regard to technological improvements. The relationship between the strategic product decision made in R&D and the phase of technology is a key question for many technology companies. In order to capture the dynamics of managing delayed New Product Introduction (NPI) process with time dependent prices, a theoretical model of a technology company is presented.

This paper presents a simple system dynamics model of a company developing and selling new products with insignificant production process. The main parameters of the model are: R&D investment, R&D productivity, Delay of development process and share of expenses spent on R&D. The strategies are analysed based on traditional net present value method. The analysed investment strategies are (1) base scenario (no changes made to the original parameters), (2) increasing R&D share, (3) increasing expenses, and (4) increasing both R&D share and expenses. The four main approaches of investments are tested with different price scenarios: (1) increasing price, (2) stable price development, and (3) price erosion. Sensitivity of the model is tested by varying interest rates. In the remainder of the paper the managerial implications results of the testing the model are discussed. Finally, further implications for research are outlined.

2. Literature on Technology Progress

The competition between new rival technologies and old technologies is changing businesses in many industries (e.g. Utterback 1996); the changes will occur in production or product technology. Emerging technologies are replacing existing techniques in a quick pace. Day, Shoemaker and Gunther (2000) have described the features of such technologies. Typical for emerging technologies are (1) unknown applications of technology, (2) highly speculative markets, (3) new players in the industry and (4) emergent infrastructures. For instance, the companies on computer business are different of those decades ago – mostly because of business process based improvements. The key changes have been from mainframes to minicomputers, from minicomputers to personal computers. Other similar effects have been reported in the hard disk industry, mechanical excavators, tractors, electronics products etc (Sahal 1981, Christenssen 2000, Iansiti 1997).

An essential performance measure with the emerging technologies is the technology trajectory. This concept was introduced by Dosi (1982) and developed by several authors, for instance Christenssen (2000) and Sahal (1981). Technology trajectory analysis is about plotting performance of competing technologies on a time series chart. The market changeover from old technology to the new one is related to the break-even point where performance curves meet each other. Economic analysis is connected to performance measures and compared with the market requirements. Figure 1 illustrates an example of technology trajectory analysis. The logarithmic scale chart shows the data transmission speed of several mobile phone technologies during the last ten years. Development of curves highlights advances on technology. The drastic changes occur on performance gaps between technologies.

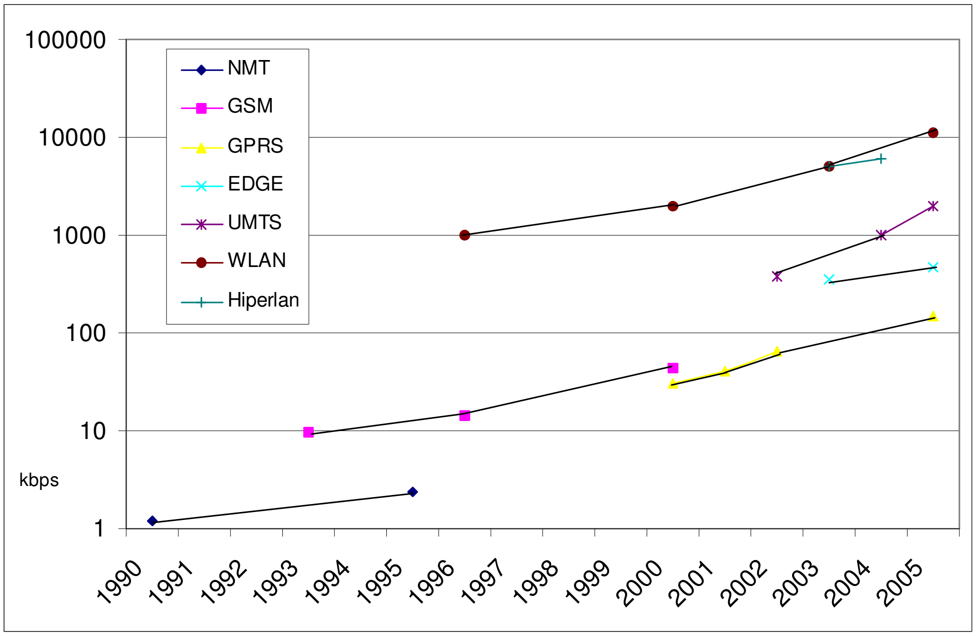

Figure 1. Technology trajectories of seven mobile telecommunication technologies 1990 – 2005.

The progress of technology is a driver for productivity (e.g. Pratten 1980), and also economic cycles (e.g. Kondratieff 1935). There is a connection between learning of new technology and the price behavior of a product. The experience gained during the time allows technology companies to compete with price as well. The business effects of experience curve are well know and researched phenomenon (see for example Abernathy & Wayne 1974; BCG 1972; Zgodavova 2001). Fierce competition on the markets drive technology products, such as memory chips, to lower price levels that are more easily achievable for greater number of customers and applications. This decreasing price effect is referred as price erosion and is well known in electronics industries. In practice, the price erosion means that the sales price of a product may decrease 5 to 15 percent monthly from the introduction. Timing the product introduction may be then very essential for improved profitability. One good example from the understanding of product development and pricing interface has been Intel; they have been able to create certain price shields for currently offered products with superior product development performance. As Wilson and Warren-Boulton (1995) have shown that they successfully priced their similarly performing 486 processors much higher than the most significant rival, AMD. According to Wilson et al. (1995) customers just needed to pay this premium from their processors, because they needed to be involved within the group, which received better service for next generation deliveries.

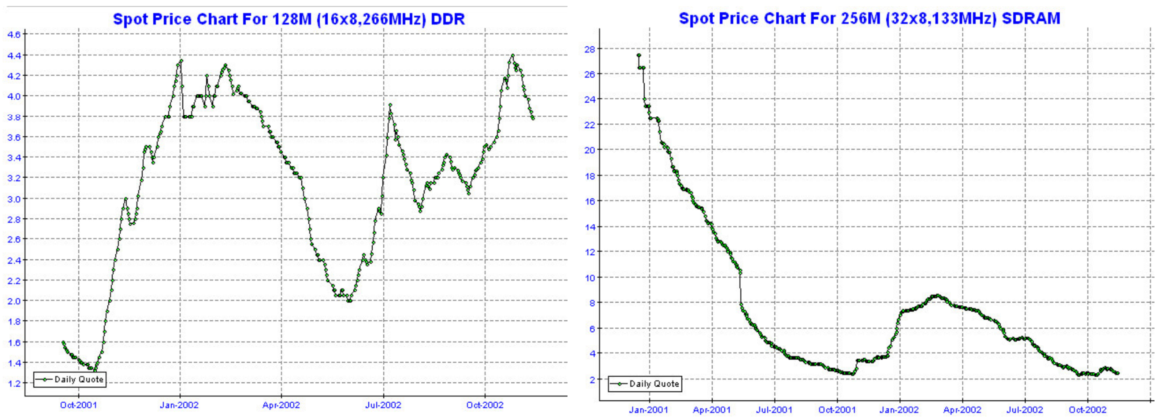

Figure 2. Examples of increasing prices and decresing prices in the semiconductor industry (Source: http://www.semiconx.com).

The other example of price effect is the case of increasing prices. This effect is also known in numerous technology products. The increasing prices are typically connected to increasing demand and limited supply capability. Sometimes the demand peak is artificially generated by hedging policies by the companies on the supply chain. Figure 2 illustrates examples of both price scenarios in the semiconductor industry. The system dynamics model presented in the following chapter uses these price scenarios in addition to stable price situation.

3. The System Dynamics Simulation Model Used

The simulation model presented (see Figure 3) and analyzed in this paper is positioned to the strategic and tactical decision making situations. In some occasions, important daily and weekly operational decisions are ignored. As could be noticed, the model generally could be divided to two different parts. The upper part contains all the financial aspects of a startup company: productivity factor, revenues and expenses. The lower part presents the value-adding product development process. Among delayed development process lower part contains such elements as total share from expenses to efficient and effective development work as well as the development lead-time. The aim of this paper is to draw better understanding, when three different parameters are changing, named as: R&D productivity, R&D share and budgetary expenses. One important parameter, product development lead-time does not change between different simulation runs, and its value is 12 months (refer to Hilmola, Helo & Ojala 2003 for justification). Whole simulation period is 100 months long (around 8 years), and observation frequency is one month.

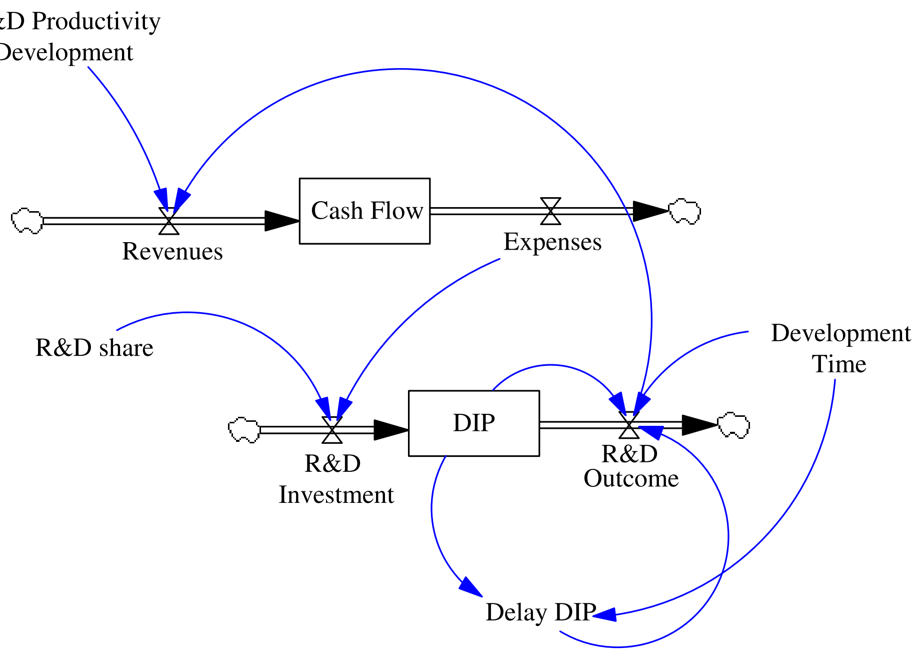

Figure 3. The system dynamics model used to simulate the changes of R&D productivity, R&D share and expenses.

All the equations and parameter values used in this model are presented in Appendix A. As could be noticed from Appendix, presented situation with these equations is the scenario, where R&D productivity is declining (Equation 10), and both R&D share (Equation 11) and budgetary expenses are increasing (Equation 5). All of these changes are going to happen with step-wise manner, every 20-month time will R&D productivity loose one point, R&D share increase one percentage point and budgetary expenses increase with $10,000.

In the model it is assumed that a very small company starts from clean slate: It does not have any revenues from the current business operations. As could be noted from Figure 4, in all of the different scenarios cash position will be more or less negative for the first 30 months. Most often entrepreneurs themselves and/or investors will provide this desperately needed amount of money. This funding might hinder some delays (and also varying number of rounds), but these are not taken into account in this model. In the very beginning budgetary expenses start from $10,000, and R&D share from these expenses is 20 percent and R&D productivity is 10.

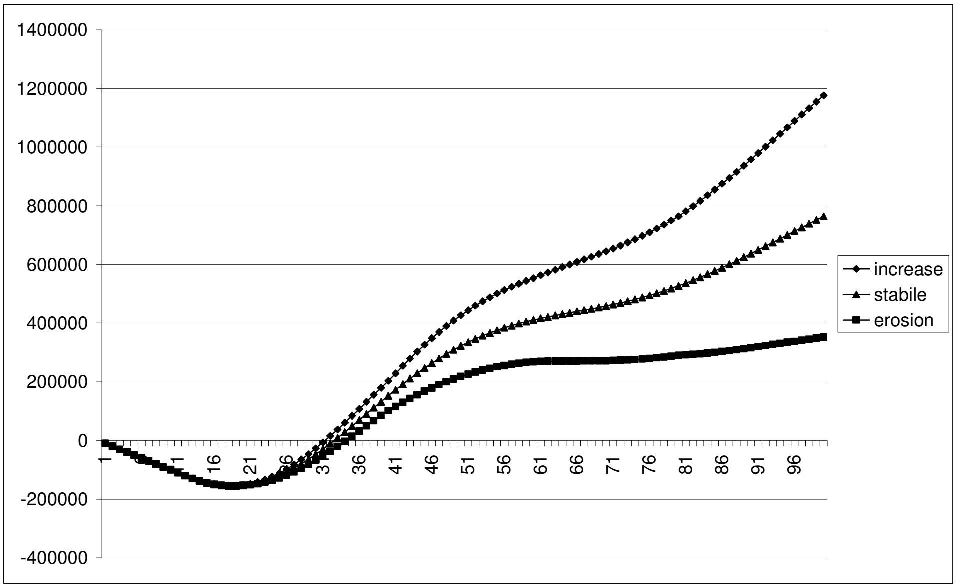

Figure 4. Development of cash flow[1] in the model, when only R&D productivity changes.

Expenses and R&D share are linked to the product development process directly. For example, in the starting point 2,000 dollars (20 % out of $10,000) are invested into the time delayed product development process. All the R&D investments will remain in the Design in Process (DIP) for the time it takes to develop the product (model aims to provide a rough view concerning the phenomenon and therefore development delay time is assumed to be fixed). In the model some restrictions for the R&D outcome exist, when the DIP is not on a sufficient level. It should be noted that in the starting point of this simulation, DIP is empty. R&D outcome and R&D productivity development will tie the two stages of the simulation together. Revenue in a particular month is simply the R&D outcome multiplied by R&D productivity development. This latter parameter is assumed to decline from a value of ten to a value of six (see von Braun 1990; Boer 1999: 127-137), because markets will value earlier innovations more.

4. Analyzing the Results of the Simulation

Net percent value is being used in the following as a primary evaluation criteria between different models. It could be noted that this measure is one of the most accurate and one of the most well known investment appraisal methods available (e.g. Drury 1996: 383-409;

[1] Please note that this element is type of inventory, not exactly flow. However, financial literature and practice uses this term.

Brealey, Myers & Marcus 1999: 147-233). Figure 5 shows the results from three different R&D productivity scenarios, and four different software company business configurations. As could be noted that excellent results are provided by the following strategies: (1) aggressive increasing of budgetary expenses or (2) increasing both, budgetary expenses and R&D share. However, the outstanding success of these are limited to the situations, where R&D productivity stays within the same level all the time, or it will increase.

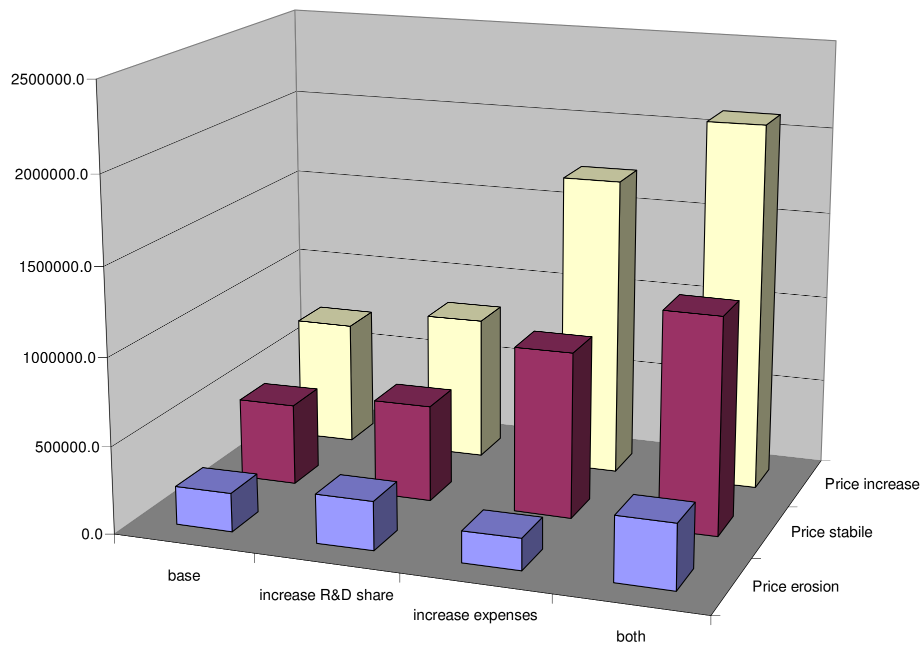

Figure 5. Net Percent Value (NPV; r = 10 per annum) of different scenarios with respect of used strategies.

As was pointed out in the literature research earlier, most often price erosion (R&D productivity will decline among the time) will be present in the technology markets. According to the results of the simulation, in these situations increasing expenses would not produce sufficient results. As could be noticed that this strategy will produce lowest amount of discounted cash flow. However, in contrary it is interesting to see that enhancement of R&D share will produce much better results in this situation. This could reveal that technology companies should concentrate more and more to their "core competence", and be very cost efficient with all of the administrative expenses. In practical settings this might mean that outsourcing should be favored within really extensive manner.

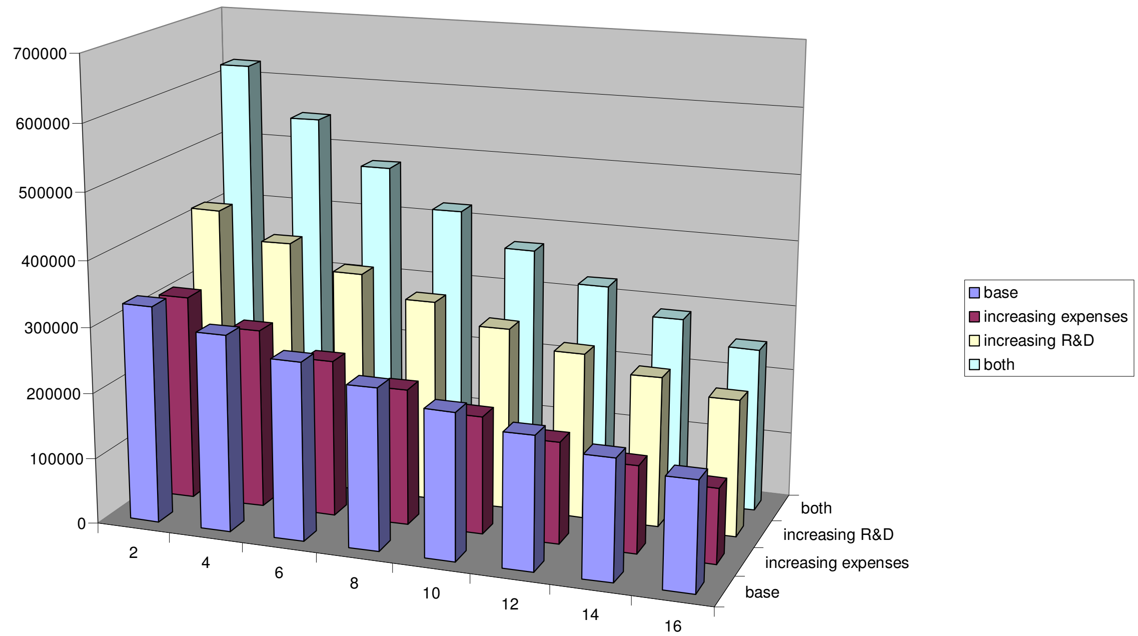

Figure 6. NPV with varying interest rates, while markets face price erosion.

As the outcomes of price erosion scenario seemed to be interesting, were different interest rates used to evaluate if shown results are somehow connected to the smaller real value of more distant sales. However, as Figure 6 reveals, this possible effect of interest rates is quite marginal. It is of course true that the strategy of increasing expenses will perform much better while interest rates are declining, but in reality the order of importance between different strategies won't change. As could be noted that with very low interest rates (2 percent), the financial results of base strategy and increasing expenses are near to parity.

As interest rates decline, the differences will widen between strategies of increasing R&D and doing both, increasing R&D as well as expenses. It seems to be that latter strategy will be very effective then. Thus, its performance contains very volatile elements. If interest rates are about to increase, its outstanding performance will diminish remarkably. In contrary, increasing of R&D share will have very sustainable and unchanging position – whatever the interest rate really is, its results are predictable and considerably high. However, it should be noted that very high interest rates will flatten the differences between alternative strategy scenarios. It seems to be that changing nothing (base strategy) will produce quite sufficient results then.

Conclusions

The hypothetical system dynamics model of a technology company, presented in this paper, suggest comparing the investment policies with regard to expected price scenario. In practice, this may be difficult since product life cycles may be very short and the scenarios may change from increasing to decreasing in a short period of time. The main results, however, suggests that during a period of low interest rates a basic, cautious strategy is a relatively safe choice. On the contrary, during a period of high interest rates increasing investments in R&D and especially other budgetary expenses seems to be a promising strategy.

As for the managerial implications, the preliminary result suggests taking the interest rates into account, since the sensitivity of the model may vary due to this parameter. The issue of timing technology introduction and investment is one promising avenue further research. Also, as typical with simple models, there are in real-life situations many intermediate variables that may affect the results gained by managers in real companies, even if some earlier studies support our findings. It may in any case be worthwhile to try and develop the model so that it takes more of these variables into account.

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Appendix A. Used equations of software startup model.

(01) Cash Flow= INTEG (+Revenues-Expenses,0)
Units: dollars

(02) Delay DIP= DELAY FIXED(DIP, Development Time, 0)
Units: **undefined**

(03) Development Time= 12
Units: Month

(04) DIP= INTEG (-"R&D Outcome"+"R&D Investment",0)
Units: dollars

(05) Expenses=10000+step(10000,20)+step(10000,40)+step(10000,60)+step(10000,80)
Units: dollars/Month

(06) FINAL TIME = 100
Units: Month
The final time for the simulation.

(07) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(08) "R&D Investment"=Expenses*"R&D share"
Units: dollars/Month

(09) "R&D Outcome"=IF THEN ELSE ((DIP-(Delay DIP/Development Time)<0), 0, Delay DIP/Development Time)
Units: dollars/Month

(10) "R&D Productivity Development"=10+step(-1,20)+step(-1,40)+step(-1,60)+step(-1,80)
Units: **undefined**

(11) "R&D share"=0.2+step(0.01,20)+step(0.01,40)+step(0.01,60)+step(0.01,80)
Units: dollars/Month

(12) Revenues="R&D Outcome"*"R&D Productivity Development"
Units: dollars/Month

(13) SAVEPER = TIME STEP
Units: Month
The frequency with which output is stored.

(14) TIME STEP = 1
Units: Month
The time step for the simulation.

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