A SYSTEM DYNAMIC MODEL OF LEARNING AND INNOVATION PROCESS PROFITABILITY

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In this paper we will introduce a system dynamic model that aims to identify the mechanisms how learning in innovation process converts to profit. This model is built on a single firm level to from a strategic management approach. The model is built with modular structure that is in-line with different theoretical aspects that are covered with-in the simulation. In this research 3 main feedback loop groups are identified that offer different approaches in innovation process performance improvements for the manager. These options and their effects are evaluated with the help of the model and the initial data is presented in this paper.

Keywords: Innovation process, Learning, Dynamic capabilities, System dynamics

Introduction

Research on the effects of learning and its role as a builder of strategic capability has been studied little in the context of profitability of innovation process. Innovation process has unarguably a key role in building profitability as it provides new products to markets. The role of innovation process has increased as the markets have generally intensified leading to shorter product life-cycles and increased competition between products. The profitability from new products is determined by their number and quality, which can also be used to measure the performance of innovation process. The literature of technology management and especially knowledge management emphasize the effect of knowledge and learning in successful new product development, which has also been highlighted in strategic literature with the raise of Resource Based View (RBV). However, the practical linkages between the process of new product development (NPD), learning and dynamic capabilities and especially the financial processes of the firm are arbitrary at best. To address this gap, this paper conceptualized the effect of learning on NPD in a generic industrial firm to demonstrate the effects learning in innovation process. Harrison et al. (2007) call for a method to examine and demonstrate linkages between different theoretical constructs and propose modeling as one tool for the job. The system dynamic model presented in this paper aims to create a conceptual linkage between organizational learning and how it influences the profitability of firm’s business operations.

The topic of innovation process has been studied in the scientific community from various different angles and it has been subjected to modeling on multiple instances (Milling, 2002). These studies include models describing national innovation environment (Galanakis, 2006) and multiple studies on project-level simulation models (e.g. Lewlyn et al., 2006). However, the previous efforts leave a gap on modeling of the innovation process as a semi-open system in the single firm level, which was also noted by Warren (2005). This area was first approached by Zott (2002), who presented a model how capability accumulation leads to profits. This model continues the work on modeling innovation on firm level with a different approach to fulfill some of the gaps that the authors feel are exhibited by the existing models.

System dynamics have been used previously to model different situations in the innovation process. The system dynamics based research on innovation process has traditionally concentrated mostly to two main focus areas: 1) Understanding the flows in the innovation process on operational level modeled with high level of detail with the focus on project implementation and project management (Milling, 1996; Ford, 1998; Lewlyn et al., 2006) and 2) macro level, where the modeling focuses on the dynamic factors of innovation system (Maier, 1998; Warren, 2005) or on the perspective of national competence and national innovation systems (Galanakis, 2006). Roberts (1978) also outlined a third field 3) "interrelation between the R&D effort and the total corporation" [Roberts, 1978 p. 279], which has been studied to lesser extent. System dynamic research that sets between the two main focus areas, on the third field, can be seen to be the strategic level, where hypothesis how strategic decisions affect the dynamics of systems can be evaluated. During recent years the use of system dynamics in strategic issues has emerged (Repenning, 2002; Zott, 2003; Gary, 2005), but still Warren (2005) highlights the lack of system dynamic based research. Out of these previous contributions Zott (2003) is focused on the same problem area as the model presented in this paper, where the effects of strategic decision making are evaluated by simulating the long term profits from the innovation process.

The research problem for this paper is to identify the mechanisms between resource acquisition and profitability of the firm. The system model is based on existing theory and presents a conceptual model of how different processes in innovation and knowledge management interact. In other words the model tries to deepen the understanding over different elements concerning innovation process and its efficiency. This paper tries to illustrate the concepts, assumptions and the dynamic nature of the model. Fictional cases are used to demonstrate and test the assumptions made in the model.

The following chapter discusses the background theories and concepts that control the building of the model. The theoretical part is followed by the introduction of the model and its main components. The third part will present how the model can be customized to a given situation and it is followed by demonstration of model results. The final part of the paper will include the conclusions drawn at this stage and further research subjects that arise from this subject.

Background and Structure of the Model

Conceptual background

Strategic management has been studied from various aspects, which has resulted in a wide range of different frameworks and theories. The model presented here is presented on the resource based view (RBV). RBV suggests that firm's performance is determined by its internal capabilities and resources (Dierickx & Cool, 1989; Grant, 1996; Teece et al., 1997). The (dynamic) capabilities originally introduced by Teece et al. (1997) are defined as a capability to use and develop new competencies for sustained competitive advantage over rivaling firms, or in other terms a learned pattern of collective activity through which the firm generates and modifies its operational routines in pursuit of improved effectiveness (Wernerfeld, 1984; Teece et al., 1997; Eisenhardt & Martin, 2000). The key idea in RBV is that the firm and its capability are seen as and evolving over time, contrary to more traditional views where the industry or the environment is evolving and the firms competence is more or less static, even though the size may vary according to the situation.

Helfat (1997) emphasizes the importance of innovation in building firm's resource base, which increases the importance of innovation management. Innovation process can be seen as a process that leads to both accumulation of firm specific resources and release of new products to the markets in through resource deployment (Helfat & Lieberman, 2002). Learning is the mechanism which replenishes capabilities and is necessary to achieve and keep "privileged asset position" (Dierickx & Cool, 1989 p. 1506) over rivals, which was also suggested by Knott et al. (2003). Learning as a concept and as a process has been approached in strategic research, but research has been limited due to methodological problems such as inaccuracy in measuring knowledge stocks, capabilities, or the amount of learning and problems caused by long causality loops considering learning efforts and profits.

Regarding the process of innovation, many different process models have been proposed but stage-gate type process is the most common. In this paper innovation process is approached as a traditional sequential process, dividing the process in to two main stages (Figure 1): Front End of Innovation (FEI) and New Product development (NPD) (Herstatt & Verworn, 2001).

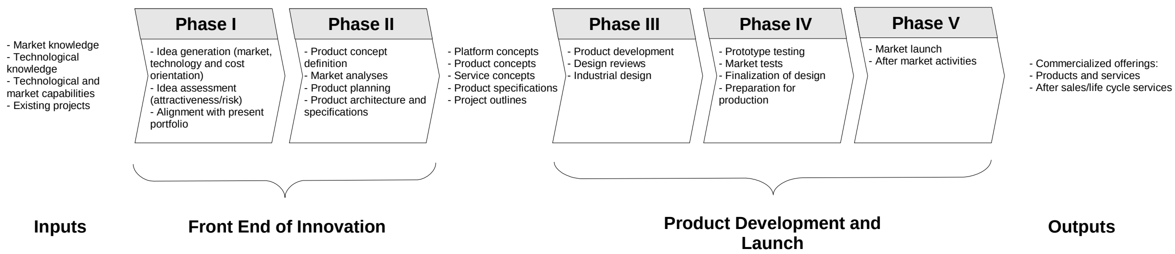

Figure 1 Innovation process divided to FEI and NPD stages (adapted from Herstatt & Verworn, 2001)

The role of FEI is to produce ideas to new product concepts for the actual development work and to select ideas which fit to firm's business strategy. The work done in FEI creates the groundwork for the whole innovation process and its importance to the performance of the whole innovation process has been highlighted by many researchers (Smith & Reinertsen, 1998; Kim & Wilemon, 2002). The role of NPD process it to develop the screened concept from FEI to a ready product launched to market. In many cases NPD is seen as a linear process where the understanding and functionality in the project increases as it progresses on the process and the process is managed though screening points or gates (Cooper, 1988; Tidd et al., 2002). The development is also generally the phase where substantial commitments in time and monetary terms are made, and the products are screened in the different stages of development.

Assumptions in the model

The model has been developed according to the following basic assumption to simplify the modeling process, which has of course come with the cost of some inherent limitations. The model presents a generic industrial firm with an internal, not networked, NPD organization. The model describes a self standing firm, which forms a semi-open system; the product ideas flow to the process from whatever channels and the products are launched to steady consumer markets, from where they exit after a predetermined lifecycle period. The markets cannot be saturated by the NPD effort and outside factors or the firm’s actions do not affect prices or demand. Each simulation round is run independently so other different settings that are compared are not dependent on each other. Firm is also seen to work on consumer markets where it is able to choose its product selection without any regulatory or other limitations. Next we will present the assumptions made behind the model that are summarized in Table 1.

Table 1. Assumptions in the model

ASSUMPTIONS	DESCRIPTION	WHY
Categorizing good and bad projects according to their “true value”	Concepts and projects are divided based on their value to the firm, which means that it a good project or concept has a good strategic, technological, market fit.	Division enables the identification of process error, where a bad concept or product is accepted for further development.
An element chance exists in innovation work	Chance of a wrong decision is added to all decision making. Firm with higher level of capability is more likely to make correct decision but it cannot always make right decisions.	Innovation process research have shown that even the best make mistakes at both concept acceptance and product launches.
Modeling of learning is tied to the decision making	Learning is released as a decision is made weather a concept or project should continue further. Decision making works as trigger for learning to release.	Modeling aspect, as triggers are needed. The nature of decision (correct/wrong) influences on the amount of learning occurred. No additional delay is added to learning.

First assumption in the model is that the concepts and projects in the innovation process are divided to good and bad ideas on the basis of their true value. An idea in itself is not seen as good or bad but it is assessed on its true fit to firm’s strategy, technological capability and markets. So good means in this context: a correct option for this particular firm. This decision is based on making the model more simple and small additional value gained from treating these categories independently. The ideas entering FEI are all presumed to be feasible product ideas. As the idea is developed further, they develop to good or bad concepts, which in their turn proceed to the actual new product development. The concepts are treated similarly in decision making, but firm with higher capabilities is ‘more capable’, and thus more likely to pick out the good ideas over bad ones. The true value of the idea has effects to its possibility of becoming a high earning product. Good ideas can lead to any of the product categories where, but bad ideas can lead only to mediocre or bad product. The actual selection in which groups the idea ends is again defined by probability. With the basic parameter of the model, a good idea has the highest likelihood to become mediocre product and the lowest probability to become bad product. With bad ideas the highest probability is to end up as bad product. These probabilities are evolving in the model due to changes in capability levels caused by learning and erosion of capabilities.

Second assumption is that there is always an element chance present in NPD. This is brought to the model through adding a probability of wrong decision to each decision making situation. The underlying idea is that the firm with better capability is more likely to make right decisions than competitors thus leading to better profits in long run. However, even the best firm might still make process errors. Process error is defined here to mean a situation where firm makes a decision that is not optimal. In real life identification of process error might be hard or even impossible to realize, but with categorizing the ideas to good and bad ones, this can be done in simulation settings.

Third assumption is that learning is tied to decision making. Each decision in the NPD process forms an increment of learning, as the decision makers act upon their knowledge and learn the consequences of the decisions. The firm, or the people within, learn by executing their tasks and observing the results, which results in knowledge accumulation and building of asset stock. The firm's ability to deploy resources is dependent on decision making and the effectiveness is dependent on the human condition of the individual responsible for decision making. Cohen and Levinthal (1990) named the ability to recognize opportunity and proper action, as 'absorptive capacity', which dictates the ability to receive and assimilate information and to identify relevant and valuable pieces of knowledge. In this paper, the definition of learning is knowledge accumulation through action. The model assumes that the capabilities are deployed through decisions, where the decision maker makes distinctions, classifications and acts upon those (Piirainen et al., 2008).

Structure of the model

Table 2. Major theoretical concepts behind the model

THEORETICAL ENTITIES	USE IN THE MODEL	MAIN REFERENCES USED
The basic structure of the innovation process	Used to divide innovation process to two main stages: Front End of Innovation (FEI) and New Product Development (NPD)	Cooper 1988; Herstatt & Verworn 2001
Flow of projects in the innovation process	Used to approximate flows in the innovation process and estimate the likelihood of success.	Stevens & Burlet, 2003
Dynamic nature of capabilities	The underlying theoretical background for development and erosion of capabilities.	Dierickx & Cool 1989; Teece et al. 1997; Eisenhardt & Martin, 2000; Helfat & Lieberman 2002; Knott et al 2003
System dynamics methodology	Methods for understanding and organizing the problem area	Harrison et al 2007; Sterman, 2000

The model builds on four major modules as presented in Figure 2: Innovation process, products at market, financial module, and capabilities. The division to these modules is done based on both theory and functionality. Each of these modules is an entity that has certain internal dynamics and can be integrated to other modules through somewhat standardized interface. The modules are discussed one by one in more detail. The underlying theoretical concepts behind the model are summarized in Table 1.

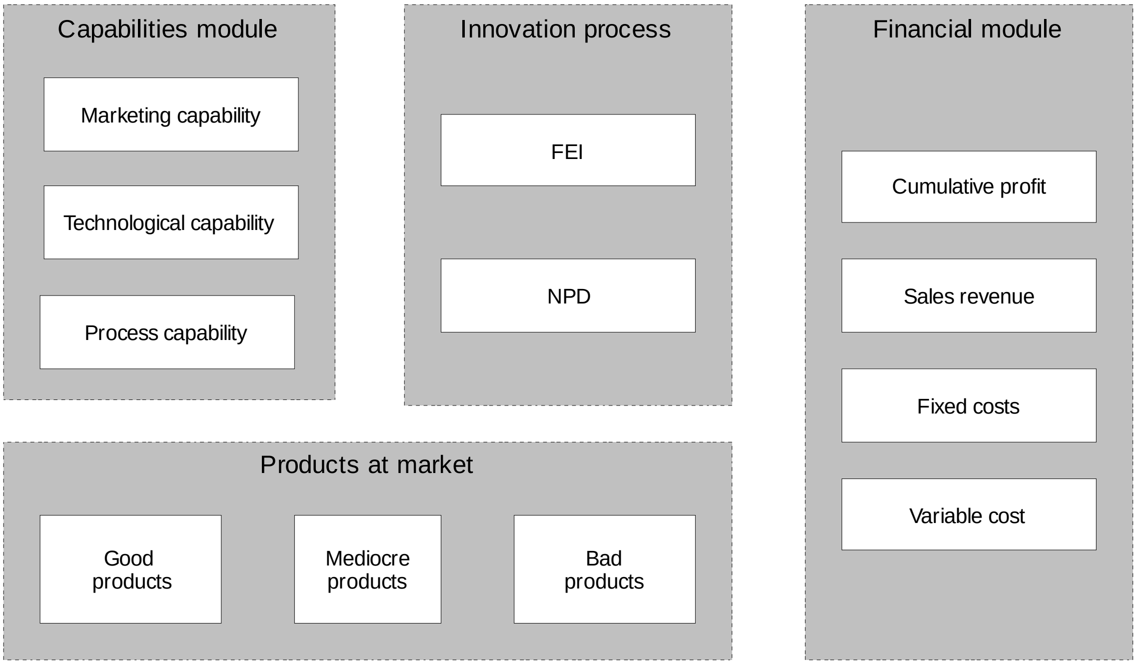

Figure 2 The basic modules in the model

Innovation module

The role of the innovation process module is to develop new products to the markets and it is the module piece on the whole model. For a general NPD organization, as Stevens and Burley (2003) found on their UK-based innovation survey, out of each 3000 "raw" ideas 125 ideas are developed to product concepts in the FEI phase, nine of which become development projects and on average a little fewer than two enter the markets. The FEI in the model starts after preliminary idea screening and comprises the concept development and screening. At the final concept screening the idea can be dropped to the idea bank or can be forwarded to development. This is also the point where the good and bad concepts are distinguished from each other. The concepts that are killed go to concept bank and those accepted progress to the product development phase. A well performing FEI will produce higher portion of good ideas compared to bad ideas that will have effects on the probabilities of success during next phase of the process.

The process of NPD as presented in Figure 1 above starts from the idea generation, where the initial product possibility is identified. The development phase normally comprises several stages from the product design to testing the product and launch planning. During the development stage, the product design and manufacturing is planned. The next stage is testing and trials, where developed product is tested and validated. The plans are implemented and first batches are produced, from which prototypes are taken to field testing and validation. The model does not intentionally distinguish the stages but simulates the generic process where some projects are killed during the process, which end up in the project banks. As the projects proceed in the process they are screened between each stage and in an ideal situation only bad projects are terminated and good projects get launched to markets.

The decision making of managers is tied to the number of ongoing projects at NPD compared to the resources available for the phase. Ongoing projects in innovation process lead to cost where projects in NPD stage cost is significantly higher than of those projects in FEI stage. If the number of projects increases over the optimal level of projects the performance of the process starts to decline, which leads to problems in getting products ready to markets, a phenomenon also known as resource saturation. Resource saturation will hinder the progress of all projects until the number of projects will be lowered. The ability to keep the amount of projects in control is dependent on firm's process capability.

As the final stage in the development the validated product undergoes a launch to the markets. The process output is on average a little under two products in a year, one of which will be successful in the markets, in other words a star product. Due to inefficient development or errors of judgment during the NPD, change of customer preferences and different other factors, roughly half of the launched product end up as mediocre or downright failure in the market.

The "products at market" module controls the flows of each product group. The product module is divided to three categories: bad products, mediocre products, and star products. The modules responsibility is to control to which category either good or bad product ends up. This flow is controlled through probability that is derived from firm's capability and controlled by project source (the NPD process). Once in market the product life cycle is controlled again by the industry dependent average product life-cycle time. On the case of bad products managerial kill decision is also added that helps firm to get rid of unwanted products at market.

Financial module

The main variable in the financial module is the *"cumulative profit"*, which counts the cumulative cash flow in the model. The money flows are controlled by sales revenue, fixed costs, and variable costs. Sales revenue is created from products at market, with good products creating the greatest revenue and bad products creating negative result. This revenue is assumed to be the total profit that the products generate after other business costs, such as manufacturing or infrastructure costs, are deducted. Fixed costs are generated from the basic resources available in NPD stage. Variable costs are generated from ongoing development projects in both FEI and NPD stages. Profit on a single simulation round can be found by deducting sales revenue from fixed and variable costs. However the prime indicator for profit used in this model is the cumulative profit, which includes the same information over time.

Capabilities module

The capabilities module has three main variables: Market, Technological and Process capabilities. Capabilities reflect the relative capability level compared to industry average and they affect how well firm can do innovation work. This division can be seen to relate with Cooper's division of product development process activities to marketing and technological (Cooper, 1988; 1993). The level of competencies is determined by the difference between capability erosion and capability creation. Capabilities grow from either deployment through learning-by-doing achieved in innovation process, or by basic research. The erosion of relative advantage in capabilities is caused by learning by competitors. These variables are determinant on how firm can perform these activities. Loss of competence is faster when firm gains higher relative capability due imitation occurred in markets. This assumption can be based on e.g. work done by Dierickx and Cool (1989) who characterize (intangible) assets, such as capabilities or R&D, as stocks, which are replenished and drained with different flows. The most important repercussion of this notion is that, as per the law of diminishing returns, asset stocks can not be bought in the sense that the flows can be adjusted but the stocks have to accumulate. Considering R&D or NPD, the knowledge and capability to execute operations deteriorate as the knowledge needed for action is drained through obsolescence, competitive imitation, and the relative advantage over rivals deteriorate and the ability to execute deployment of capabilities deteriorates over time as the routines which constitute the act of development (Helfat & Lieberman, 2002) deteriorate unless they are exercised.

The logic in the model is that the capabilities affect the ability of the firm to develop good products. Learning in turn affects the capabilities. The learning function employs the logic of diminishing return so that the incremental learning from each decision is larger when the quantity of screening decisions is smaller. The capabilities, or the level of the knowledge stocks, affect the success rate of NPD and product launch. Adhering to the theory of absorptive capacity (Cohen & Levithal, 1990), when the firm has above average technical capability, it produces better product ideas as the decision makers are able to recognize technological opportunities better and develop novel solutions to fill customer need.

Market capability grows from the stock of market knowledge and affects the ability to recognize the market need, in the model this translates to idea quality/feasibility, and it also dictates the ability to execute market launch. The process capability is basically the ability to exercise the market and technical capabilities of the firm. It affects what Cooper (Cooper, 1993) would call quality of execution in the process, that is, the concepts/projects are executed efficiently, bad projects are killed at the screens and so on. The actual knowledge is created in the process stages and release of knowledge is triggered by flow control between stages. Knowledge accumulation is greatest when correct decisions are made in the process and process error lead to smaller or even negative learning. The overall capability creation is controlled by a relative learning efficiency factor that can be used to simulate different levels of learning. The amount of learning is thus dependent on learning efficiency and number of stage shifts in the innovation process. If the firm is unable to finish innovation projects in form of project kills or ready products it will start to lose capability through inadequate learning. This ties innovation process performance to capability building.

Causalities in the model

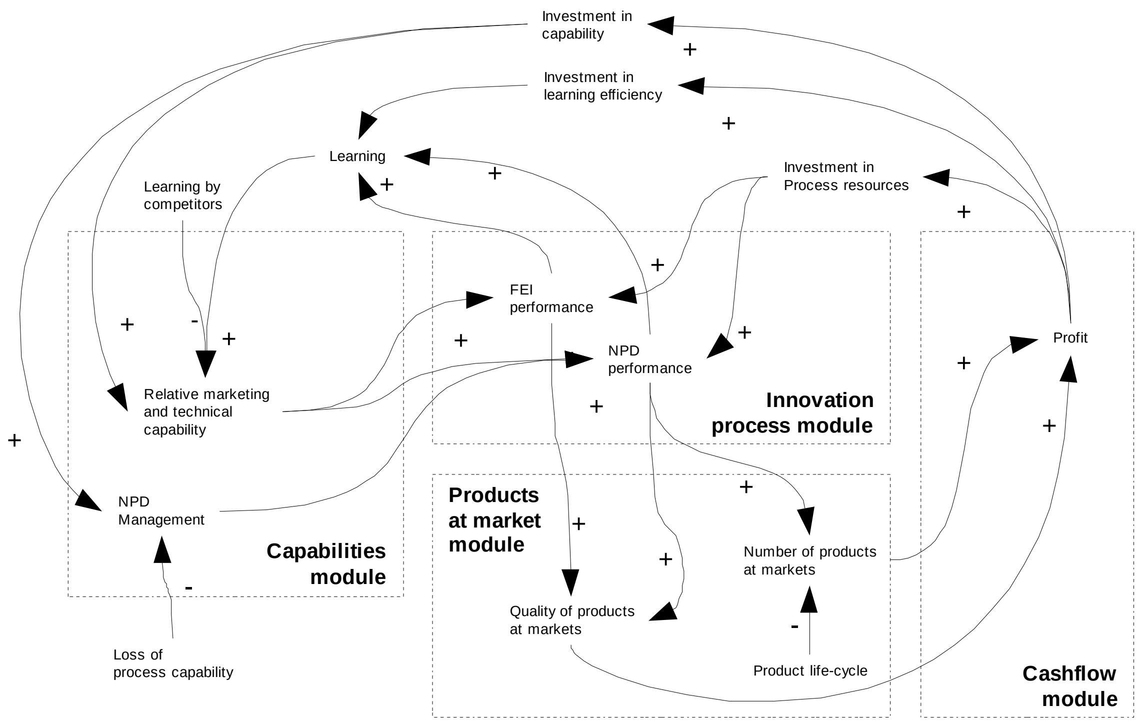

Figure 3 Causal loop diagram illustrating the NPD system

The causal impact chain between learning and profitability is presented in Figure 3. This figure contains the key dynamic elements in the model. The components have been grouped in modular groups and interfaces between different modules are presented by an intersection of module barrier and causal relationship line. Overall, the system is quite simple: the performance of FEI and NPD dictate the number and quality of products in the market. The number of products and the quality affect the profit, and accumulated profit enable investment to expand the capabilities. The capabilities are eroded by competitive imitation and lack of deployment and replenished by learning. Learning in turn is a function of operations in FEI and NPD. The relative capability then affect the performance of NPD and FEI, and the cycle starts over. The figure contains many different feedbacks, which can be divided to three distinctive cycles: Group 1 includes loops that are tied to investment in capabilities; Group 2 includes loops that are tied to learning. These loops will be presented separately in this chapter; and Group 3 includes loops which occur when firm invests in innovation process resources.

The capabilities interact with the process of innovation through different decision points in the process, and the higher the relative capability the more the firm makes “right” decisions and the higher the amount of successful products. High capability level will increase the likelihood of good ideas and reduces the chance of process errors. High relative capability increases also the probability of creating a higher quality product that increases firm’s profits. The opposite is true when firm loses capability, which ultimately leads to lower profits in the innovation process. The system is controlled by two main constraining forces: product life cycle → controls the number of products on market, and learning done by competitors on market → capability erosion. These restricting forces are strong enough to control the system so that capabilities or profit on simulation round level will not grow indefinitely.

When the firm wants to develop the capabilities, the three main options are: invest directly to new capabilities available for innovation process, resource scaling or investment to capabilities. Direct investment in capability is seen to cover many different forms of capability or knowledge acquirement such as hiring competent staff or technology acquisition. The second option is the "organic growth" option where capabilities are built through increased action in innovation process. The number of ongoing concept and project development is controlled by the available resources. Managers have the ability to increase this capability by investing to staff and facilities. This option allows managers to increase the amount of work done in innovation process, which have effects to the learning through increased amount of possible learning in the process. The third option is to develop capabilities through investment in learning, education and research, which raises the capabilities but does not directly affect the amount of projects.

When comparing these different mechanisms a significant difference between these options can be found. Investment in capability will lead to better decision making that increases profitability through better use of firm's scarce resources. In other words this increases the probability of success on single project level. Investing on resource availability offers firm to try more times that leads to both increased learning and increased product output, without changing the relative probability of making a good product. Investment on technical and marketing capability can be seen to increase the accuracy of the innovation process, as investment process resources is more *"learn by doing"* type of approach in making innovation process more productive.

A related aspect of the model is the effectiveness of learning. On the practical level, the accumulation of capabilities in deployment is moderated by learning efficiency, which mirrors the firm's capability to learn by doing. The learning efficiency affects the capability accumulation from each decision directly.

In a more detailed inspection, Group 1 loop can be found from the outer edge of the causal map presented at Figure 4. The common factor for these loops is the idea that they are derived from increased profits from new products, which enables investment to new capability base. The effects of these investments lead to increased FEI and NPD performance, which has positive effects on both quality and number of products at market. This feedback is positive if firm is capable and does decide to invest in its capabilities, but will lead to negative feedback if investments are not made.

This kind of situation occurs if a firm decides to either educate staff or to acquire capabilities through some other methods like (out-)sourcing, licensing, or networking. Although this loop is simple it has still many challenges for manager. Buying competence is not necessary the most efficient method in the long run, because, depending on the implementation method, it does not give a real incentive for building the capability sustainably through deployment. Investment will most likely lead to a boost in performance, effect of which is lost when firm in not able to sustain high level of relative competitive advantage. Another major problem is how to implement such a resource investment. It is likely that the procedure of "transferring" competence in to the firm is not going to work as efficiently as possible leading to loss of the actual competence level of resource of entity that is bought. This effect of implementation deficiencies in the firm is not however included to this model.

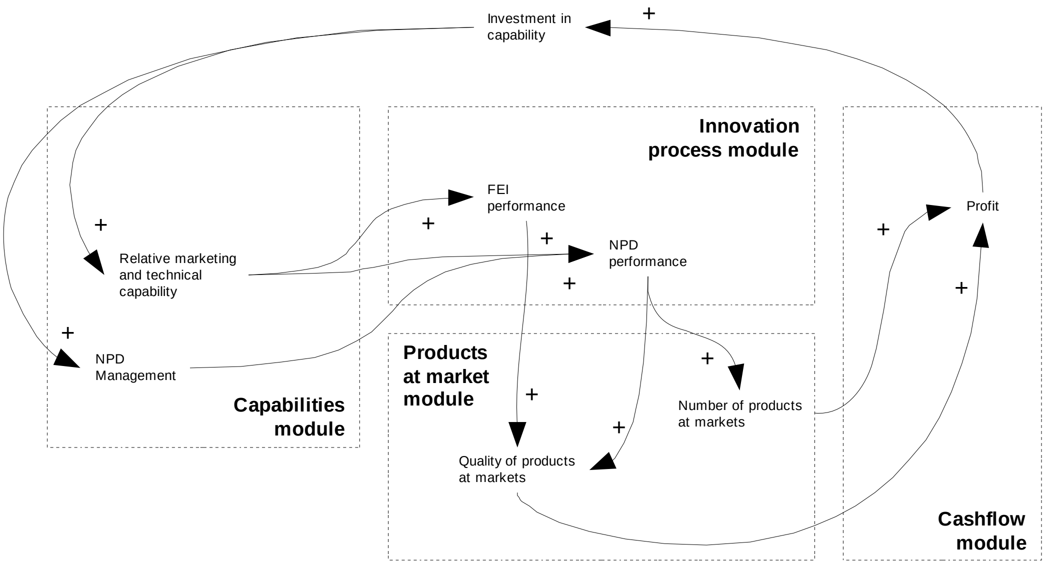

Figure 4 Group 1 feedback loops: Direct investment in capabilities

Group 2 loops tie the innovation process performance to accumulation of firm's resources. These loops can be found in the middle of the causal map and the form between innovation process stages firm's capabilities through the process of learning (Figure 5). This loop is also influenced by the decision to invest in its learning capability. The loops form the basis for sustaining firm's competitive resource position. A steady stream of ongoing projects and finished products will lead to constant level of learning that can be used to compensate the erosion of relative capability caused by advantages achieved by competitors and lack of deployment of own capabilities. By increasing firm's ability to learn from the process, the effects from this feedback will increase that will lead to new equilibrium state for firm's capabilities.

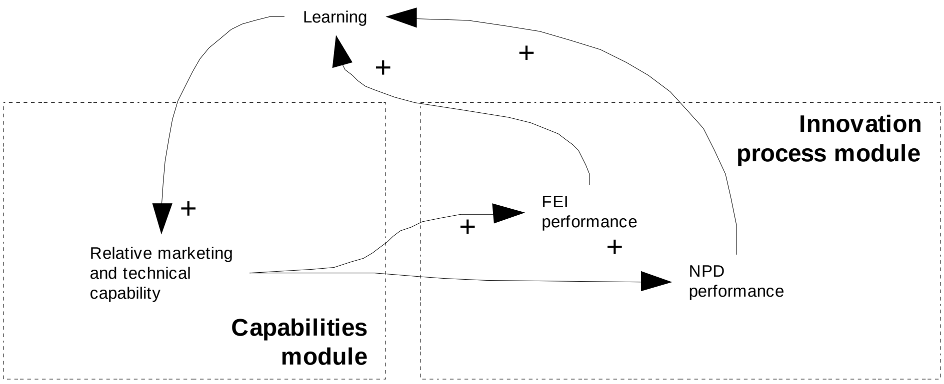

Figure 5 Group 2 feedback loops: Learning-by-doing

Group 3 loops are presented in Figure 6 below. This figure composes of two distinct stages. The first stage (located on the right side) is created by increased number of products at market caused by the increase in process resources. This phase can create a positive cycle that increases profits with a brute force approach as discussed above. The second stage of this loop group is caused by the increased amount of learning opportunities that occur when the pace of innovation process work is increased. This increase in learning opportunities will lead to accumulation of marketing and technical capability that will lead to better odds in success over a long time period. As a practical implication; the effect of this loop actually depends on resource cost, as profit generally depends on revenue and cost, so the profit increases only if resource cost is low enough to permit increase in revenue.

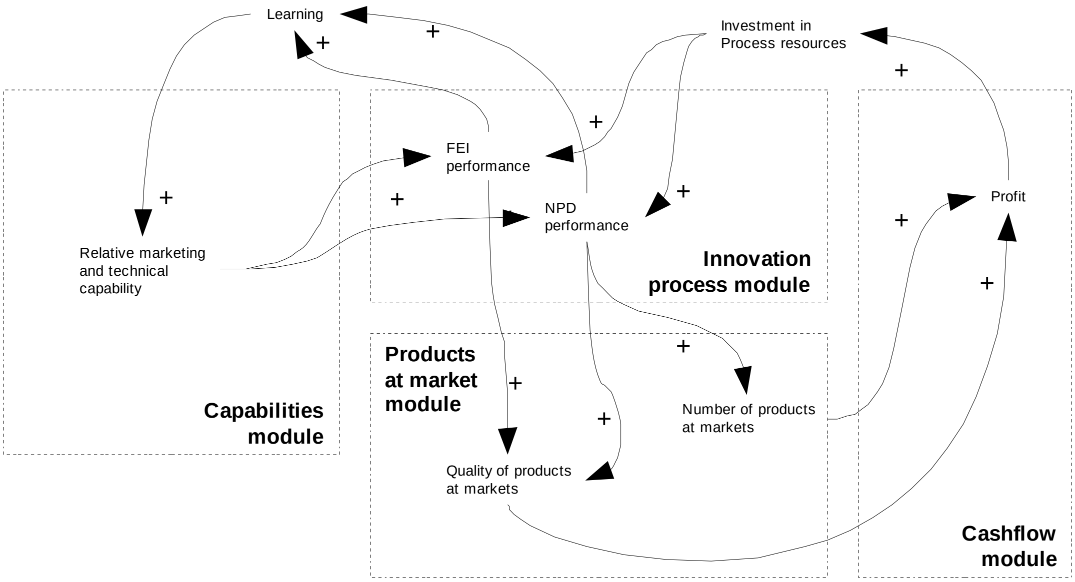

Figure 6 Group 3 feedback loops: Growth of the R&D operations

When comparing these different loops groups, certain differences can be found. Group 1 offers the quickest opportunity to add to firm's competence base. The upside of group 1 is that the firm's performance can be boosted rapidly if the need be. However groups 2 and 3 offer an opportunity in longer time periods, where learning-by-doing offers firm to expand its competence base more organically. The risk with group 1 is that if firm seeks certain performance level it may be jammed to a vicious cycle, constantly pumping cash to capability investment. The, sort of, spirit of RBV is more in favor of developing and deploying the unique resources of the company to gain competitive advantage, not to 'buy' revenue and stock price through mergers, acquisitions and licensing for example. However, capability investment allows a company to hit the ground running, so to speak, and to gain a base for unique capabilities through wise investment and continue to build the unique competence base through learning.

Setting up the Simulation

Using the causal loop diagram as a starting point, the model is set up for simulation in Ventana Systems VenSim modeling environment. Despite the dynamic nature of system models in general, the model has some constants, which reflect the assumptions documented above, to provide the basis for the model (Table 3). Using constants eases the modeling, but they also create an error source of their own. Assumptions behind constants attributes should be made logically so that the model stays intact. The model presented here concentrates on the firm's internal dynamics, which lead to decision that constants should be used as little as possible in internal factors of the firm. The constants presented at Table 3 (Below) realize that as they mostly market and industry related assumptions, even to that extent that these factors contain all the determinants of firm's business environment build in the model. This enables that the model can be customized relatively easily to new market settings by altering these constants. The numbers used in this simulation are based on rough estimates got from our experience from business cases, and aim to replicate a sort of general industrial firm. Thus the results are also reported mainly for the purpose of highlighting the dynamics of the model more than anything else.

The simulation of markets is controlled via profits and product life cycle. The profits are described by profit gained from the product per one simulation round. The profit is tied to the product class, where good product makes the highest profit and bad product leads to negative result. The product life cycle is controlled through an average product life cycle that leads to somewhat uncertain lifespan for the product. The average life for bad product is assumed to be lower due to proper management in post innovation process activities.

In capabilities module the biggest assumption concerns the erosion speed of capabilities, which is strongly tied to industrial settings. The erosion speeds for each capability can be set individually, but here the same erosion rate is assumed for both technological and marketing capabilities. A project management capability is assumed not to erode continuously like other capabilities, but discreetly as the capability is tied to individual personnel.

Both the market situation and capability erosion speeds are assumed to be constant. This assumption strikes some controversy with the evolution paths of industries and concepts like product diffusion or dominant design. It is likely that all these attributes are going to change as the industries evolves and goes through cycles. Simulating this attribute as a dynamic factor would considerably increase the complexity in the model that was not desirable according to our modeling objectives. To compensate this problem the numbers used to model market behavior should be selected carefully. One way to tackle the problem with non-dynamic market parameters is to use estimates of average value for each attribute along the whole industry development cycle. This kind of approach gives the most accurate picture in long run, but it makes the environment less turbulent or ‘ideal’ for the firm.

Table 3 Fixed variables in the model

CLASS	NAME	DESCRIPTION	VALUE
Markets	Profit from good product Profit from mediocre product Profit from bad product	The profit that firm receives from each product at market for each simulation round.	500 90 -20
	Average product life-cycle for good or mediocre product Average product life-cycle for bad product	The product life cycle is simulated through setting an average lifespan for product at the markets. The lifespan for bad products is assumed to be shorter due to managerial capability.	200 rounds 50 rounds
Capabilities	Erosion speed of capabilities	Capabilities erode over time that is relevant to selected markets	1/200 of current capability.
Process costs	Fixed resource cost	The cost that is generated for each project resource available at NPD stage	-25
	Variable resource cost FEI Variable resource cost NPD	The cost of each ongoing project at selected phase.	-1 -6
Investment costs	Investment in available amount of resources	Firm can invest to the amount of ongoing projects by investing to resources.	-4000 (-100 for 40 simulation rounds)
	Investment in capabilities	Firm can add directly to its capability by investment.	Simulated discreetly

The core of the model is created by dynamic variables that change as the simulation time progresses. These variables are presented in Table 4 below. Each variable is given an initial value that in this case is based on intuition. These initial values describe the current state of the firm before any simulation is done. In other words these values can be customized to fit a single firm and thus offer the chance to code in a particular company. These variables will be presented here in more detail.

Table 4 Main variables in the model

CLASS	NAME	DESCRIPTION	INITIAL VALUE
Financial	Cumulative profit	Describes the cumulative cash flow from innovation work.	2000
Innovation process	FEI concepts	These are ideas that are being developed to product concepts.	15
	NPD projects	These are product concepts that are in product development phase to become products. This stage is divided to good and bad ideas that are dependent on FEI phase's performance.	3 Good projects 6 Bad projects
Markets	Good products Mediocre products Bad products	Number of each product group at markets.	0 2 0
Capabilities	Relative technical capability Relative marketing capability	Variable that describes firm's relative capability compared to average firm at the given market.	1 1
	Relative process management capability	Figure describes firm's capability to manage new product development.	1

The final number that all the other values lead in this model is the cumulative profit. The variable or stock is a naïve indicator of cumulative earnings, financial position and investments capability all rolled into one. Cumulative profit is dependent on sales revenue and both fixed and variable cost caused by innovation work. The cumulative profit also reflects the amount of financial resources available for further investments by innovation manager and is the main decision variable in managerial decision logic in the model.

The number of innovation projects can change as the simulation progresses. The number of ongoing processes is limited by the number of process resources available at NPD stage. The dynamic flows between the stages are based on research done by Stevens and Burley (2003). This data was used to determinate what the odds are for a single project to go through to the next phase or to be killed to idea/project bank. The size and number of projects is scaled according to the changes made to resource base. The production from innovation process increases the amount of products at markets. When a project leaves innovation process it is categorized to one of three categories. The likelihood for a product to be categorized to a given category is dependent on both capabilities possessed by the firm and the quality of the project itself. The productivity of innovation process fights the erosion speed of products at market caused by product life cycles.

The capabilities module provides the model a method to link dynamic firm specific capabilities to profitability. This is done by simulating how the firm's relative capability evolves as simulation goes on. These capabilities are changed via learning in the process and by direct investments to capabilities and eroded by development occurring outside the company. The erosion speed is tied to the level of relevant capability so that if firm possesses high relative advantage its capability is eroded faster due imitation that in situation where the advantage is lower. This leads to controlled behavior of the capabilities in long run where the system seeks for balance.

In this chapter the parameters for the model were discussed. Each of these parameters can be changed to customize the model to given circumstances. By adding constant factors to the model, the model was made more understandable and simple with the cost of losing accuracy in the model results. The decision how fixed and dynamic variables were selected is based on the research objectives set for this model to deepen the understanding of linkage between capability building and profitability with a strategic perspective.

Preliminary Results

In this chapter we will present initial data from the model. These numbers are based on averages from multiple simulation rounds based on same initial data. The simulation horizon for the graphs presented in this chapter is 30 years and one simulation round corresponds to one week. The time period is very long due to the relatively small size of the firm presented here, which is assumed to produce only 1.7 products per year at initial settings. The time horizon needed to demonstrate how the system seeks toward balance would shorten if the overall output of the whole process would be increased. These graphs provide initial data from the model and their purpose is to demonstrate how the model reacts in different situations. This chapter is structured so that first the overall dynamics of the model are illustrated, that are followed by inspection on loop level dynamics.

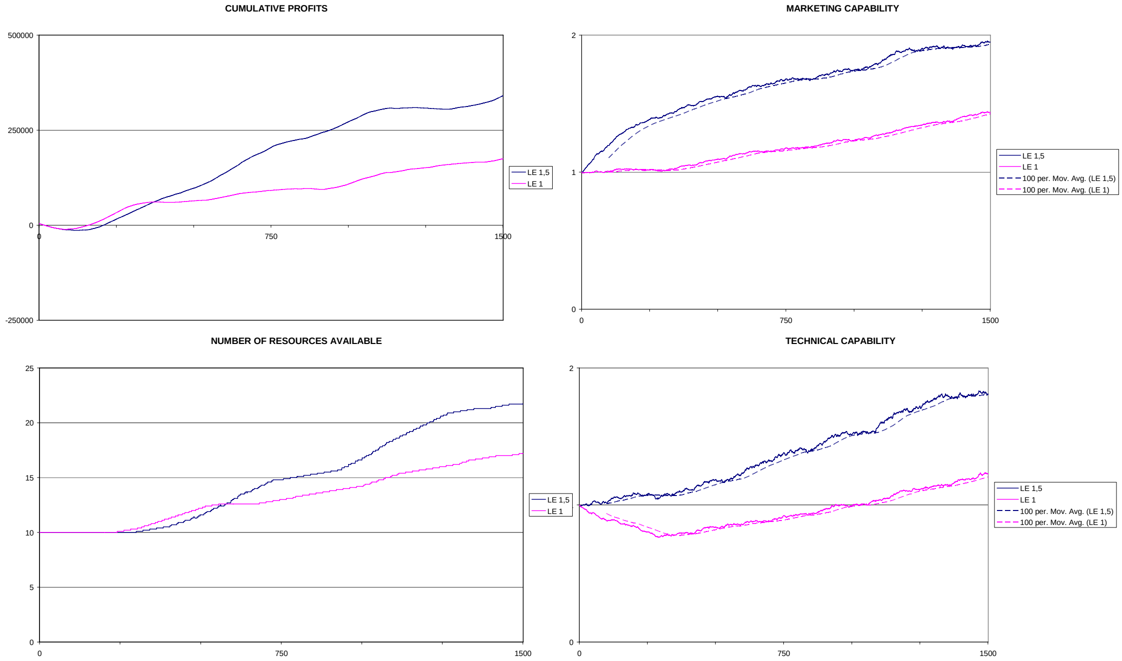

Figure 7. Overall dynamics of the model

Figure 7 illustrates how different key elements interact. In these graphs, the performance of two firms with different capability to learn (learning efficiency LE) is compared on profit, process resources available, marketing capability, and technical capability. These meters show that according to the model created firm with higher capability to learn is able to outperform inferior learner. This is further illustrated in Figure 8 where the correlation between differences is learning efficiency and profitability is shown. This correlation between growing efficiency to learn and growing profitability shows to follow logarithmic function, which implies that in investments to learning efficiency exists diminishing marginal benefits. The reason for differences in profitability can see from the right side graph in Figure 8 where the number of products developed by the firm is illustrated according to their category. This graph shows that the more capable learner is able to reduce mistakes (bad products) and increase the amount of good products. The financially well performing firm is able to increase its resource base that allows it to produce more products to market, which further increases both profitability and capability accumulation.

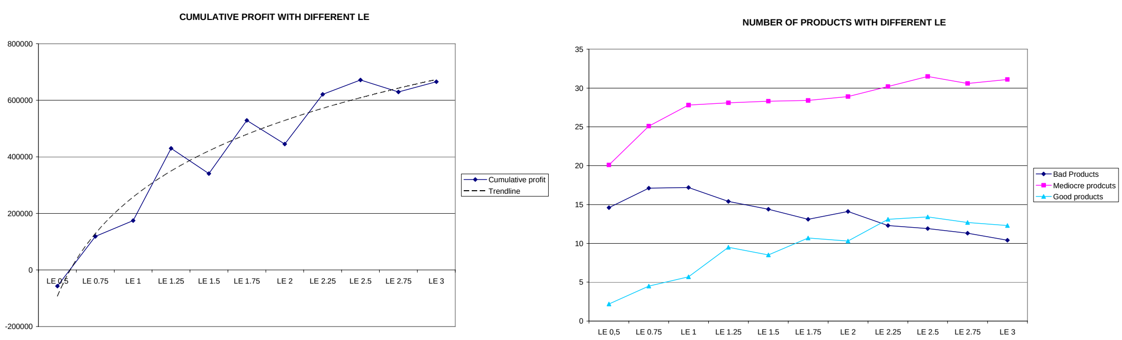

Figure 8. Effect of learning variance in learning efficiency

In Figure 8 is shown what effects direct investment to capability (Group 1 feedback loops) actually has to the profitability of the firm. In this simulation a relatively large direct investment is injected to the system on the simulation round number 500. This injection causes a sharp increase in the capabilities that materializes within 100 rounds by improving firm's odds of creating successful products. After the injection, the capability of the firm decreases rapidly, because the firm is not capable to sustain higher relative capability level. However, the capability remains on higher level than the original system due to growth as the firm is able to grow faster with the increased performance of its innovation process. The true profitability cannot be identified here because capability injection was not priced.

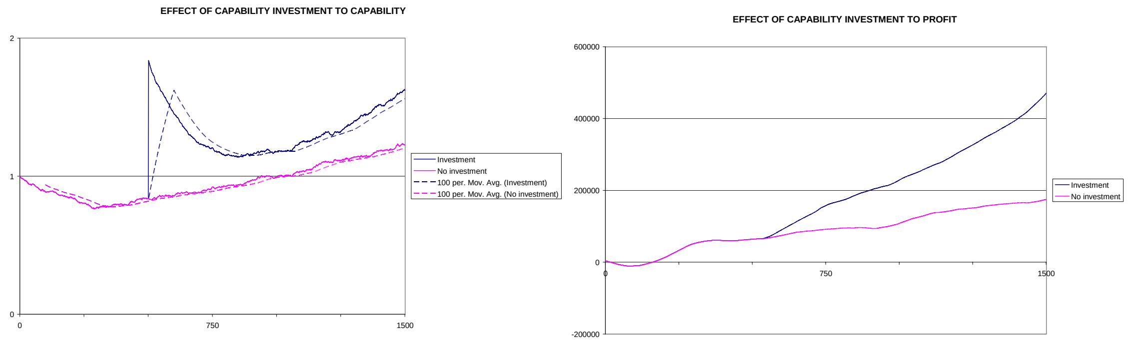

Figure 9. Effects of direct investment in capability to profitability

In Figure 10 is presented how investment in learning efficiency (Group 2 feedback loops) influences the profitability. Contrary to Group 1 effects Figure 10 illustrates a composed growth that causes sustaining increase in capability levels. The investment in learning is assumed to inflict no cost that makes comparison of profitability hard. When comparing the profitability improvement accomplished by direct investment in capabilities, distinctive differences can be seen. In Figure 9 the response to investment is quick in both capabilities and profitability as in Figure 10 the change happens calmly. However, at the end of simulation period the capability level was higher and growing faster in investment to learning, which suggests that this methods a path to more sustainable raise in firm's performance.

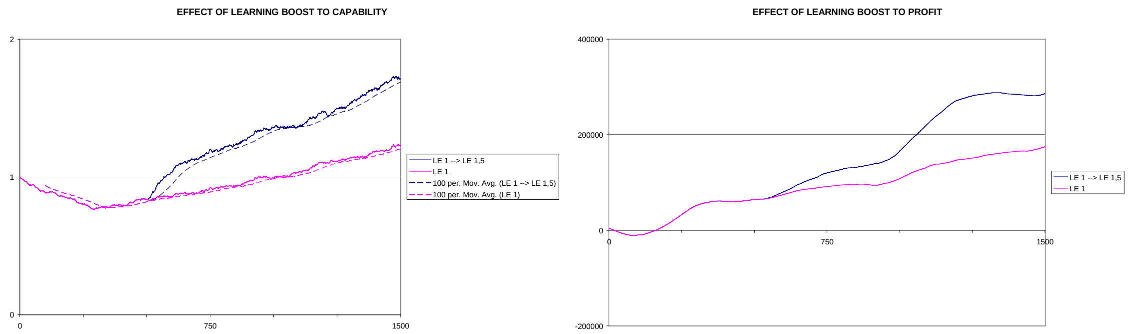

Figure 10. Effects of investment in learning to profitability

The last feedback group was caused by growth in firm's innovation process, for witch the results are presented in Figure 11. The growth in number of innovation activities increases also the amount of learning occurred in the process. This leads to increase in firm's capabilities as is illustrated below. However in overall profitability the difference is not similar with-in the simulation time. This is due to costs inflicted by the growth that restrain financial results. The increased capability level would lead to significantly higher profitability if the simulation time would be extended. The effects caused by growth in innovation process are interesting. In Figure 11 is presented direct implications from growth, but it plays a key role also in effects caused in other feedback loop groups. This fact implies that growth in the process should not be overlooked in terms of profitability or in strategic implications.

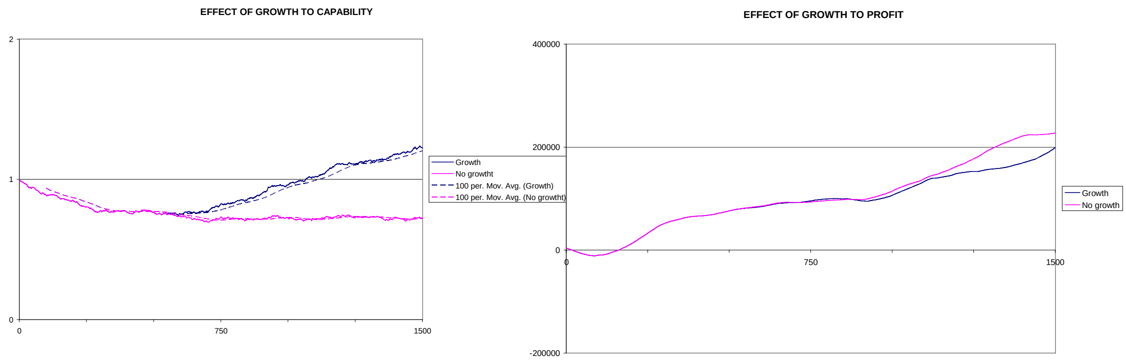

Figure 11. Effects of growth

Conclusion and discussion

The contribution of this paper can be divided to theoretical results and modeling results. The model that describes relationships between learning, innovation process and profitability is as such a contribution to the scientific discussion on the subject innovation process, as it is not clearly based on any existing innovation model and it presents existing theory linked in a novel way (Harrison et al. 2007). The validation of process requires theoretical study to backup assumptions made in the model. The outcome data from the model offers also an interesting opportunity to analyze the behavior of the model. The data can be used to asses the importance of learning, and to identify the mechanisms that lead to financial profit. Identification of these mechanisms and their relative importance gives valuable insights to the dynamics of the innovation process. When using modeling in this kind of research it is good to recognize that the modeling approach also has certain error sources; the first pitfall is deciding what are in fact the relevant parameters that need to be included in the model, the second is the choice and forming of the decision model and the third is of course interpretation. Still, as George Box put it, "*all models are wrong but some are useful*"

The paper presents a theoretical contribution to the field of innovation management through forming a system of the process of innovation in an industrial firm, and demonstrates how the process is linked to the capabilities and learning as well as how the learning affects the competitive advantage of the firm through new product development. Based on the considerations presented above, learning through action in NPD has important implications to competitiveness especially after immediate future.

As for other results, Table 5 below gathers the most obvious practical implications from the causal loop diagrams. Even prior to simulation results, the model offers some clear managerial insight to innovation management and capability development. The possible decision scenarios are discussed independently, but in reality it is likely that these decisions would be used in combinations. The decisions have distinct strategic and tactical, as well as immediate and long-term results.

Table 5 Managerial implications of the model

DECISION	**INVEST DIRECTLY TO CAPABILITY**	**INVEST TO LEARNING EFFICIENCY**	**INVEST TO PROCESS SCALE**
Primary effect	Increase in marketing and technical capabilities will increase the odds of successful product launches.	Firm is capable to better digest and utilize the learning opportunity created in the innovation process leading to	Productivity in the innovation process increases as more resources become available.
Secondary effect			Productivity increase in innovation process leads to increase in relative capability due increased learning by doing
Short term strategic implications	The frim's performance is boosted by increase in quality of its products	Little effects can be seen on short run as accumulation of capability is slow	The productivity of innovation process increases.
Long term strategic implications	Relative capability is lost if investment to capability is not continued.	Firm gains relative capability that increases the quality of its products.	The capability of innovation process increases steadily.

The main reason for the development of this model is to use it to support further research. The model presented here is on a preliminary stage and is being actively developed to reach more accurate modeling of real life environment. One of the main activities ahead is development of more accurate parameter for the model. For this a case research is likely required. Another research track ahead concerns the theoretical side of the research. Once the parameters are acceptable the model can be used to simulate different phenomena in innovation research such as strategic implications of radical innovations.

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