MODELING STRATEGIC TECHNOLOGY MANAGEMENT WITH A HYBRID MODEL

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Abstract: In this study we will introduce a hybrid model to describe competition in a constantly developing market environment. A hybrid model referred here is a model that has both system dynamic and agent-based elements. Modeling effort begins from a literature review to strategic management and management of technology. From this background we build a model combining the theories from multiple theory tracks. The model is used to test the effects of more rapid strategy process to firm's profitability. To test the results we use statistical methods to analyze the data gathered from sensitivity runs. Our model founds support for the proposition that increasing agility increases also the competitive advantage of the firm. We also conclude that hybrid modeling is a strong research tool, but it comes with drawbacks of high hardware requirements and challenging more complex modeling tools.

Keywords: **Hybrid modeling, Agent-Based-modeling, System Dynamics,**

Strategic management, Management of technology

Introduction

Research on strategic management has been intensive for the last three decades. One critical aspect in today's strategy making is the role and management of technological change. Traditionally the tracks of technology management and strategy management have been treated somewhat separately, but in this study we build a model where these tracks are seen to be strongly complementary.

Due to the relatively abstract nature of strategy as a concept many different approaches have raised which address the problematic in strategic decision making with different logical justifications. The mainstream approaches are the market based view MBV (e.g. Porter, 1980) and the resource based view RBV (e.g. Barney, 1991; Peteraf, 1993 ;Teece et al., 1997). These views can be seen to be opposite theories, as the basic assumptions behind these theories are almost reversed. When considering the stand of these theories to technology this contrast becomes clear. In MBV firms are seen to be homogenous thus competitive advantage can not be built on technology; where as RBV is built on the assumption that firms are heterogeneous thus technology offers a base on which firm can build competitive advantage. Its no wonder that in such environment criticism is being raised against both theories (e.g. RBV criticism by Priem & Butler, 2001a, 2001b; Foss, 2005). The interesting notion for researchers in the modeling society is the fact that some of the critique in this research track has been aimed to the used research methodologies (Priem & Butler, 2001b). This highlights the need to approach the area strategic management with different research methodologies.

Harrison (2007) argued that modeling offers a strong tool for researchers to test how complex interrelated theories work as system and to test the overall logic of proposed theories. This combined with significant developments in both modeling methods and tools offers interesting possibilities to study strategic management through modeling. We continue on the path lay down by early modelers like Zott (2003) and Gary (2005), who used system dynamics to understand the consequences of strategic decision making. In our similar efforts Kortelainen (2008) we found that the structure of the model was strongly restricted by the system dynamics methods limitations. For this reason the new prospect of agent based modeling became apparent as it offers more flexible structure for the models.

In this paper we will introduce a model describing competition on constantly developing marketplace, which can be used to simulate strategic decision making concerning management of technology. Model can be seen to be a hybrid model as the structure combines elements from both system dynamic and agent based modeling. The selection of such implementation method was based on requirements set for the model. Our objective for the model was to create an environment where competing firms are able to build their own product portfolio based on different technological options to fulfill the specific customer requirements. Modeling such a dynamic environment with clear technology-product-customer requirement linkages would be almost impossible and certainly unpractical with methods building strictly on system dynamics.

The overall goal for the model under build is to create a model that can be used to test various different concept level hypotheses. To demonstrate the model we selected to use a setting from strategic discussion of fast strategy (Doz & Kosonen, 2008a), which suggest that firms can gain financial performance by being more agile, or being able to react to changes rapidly. The simulation effort will be executed in Anylogic modeling environment from XJ Technologies.

This paper is organized so that we will begin the work by introducing relevant literature required in building of the logic in the model. The third chapter describes the structure of the model and interactions between different agents. Fourth chapter describes the results in our testing environment and the sensitivity analysis made on the model. The last chapter contains the conclusions and findings made from the modeling results and insights gained from the actual modeling process.

Literature review

Management of technology

Technological change is undoubtedly a great force that constantly shapes businesses. Management of technology has proven to be a tricky task, as both success and disaster stories exist that all originate from technological change. Especially technology's ability to destroy big companies has intrigued researchers (Christensen, 1997). To better understand technological change, and thus to better manage it, researchers have turned the focus on the dynamics and nature of technological change. One commonly used way to describe technological progress is the s-curve introduced by Foster (1986) and later empirically adopted for example by Christensen (2004. The s-curve shape describes the pace of technological progress through incremental development with-in one technology generation (Figure 1). The framework suggests that the development pace of a technology starts to increase as knowledge progresses, but this pace again slows down as technology starts to near its limitations (Foster, 1986). To overcome this barrier, a discontinuous breakthrough is needed. The terminology describing discontinuous change is (see full discussion Garcia & Callantone, 2002), but in this study we will use the dichotomy of incremental and radical to describe different degrees of change. Radical innovation causes strong implications in the market place, because it destroys the competence base of existing products by significantly contributing to perceived customer value. For this reason radical innovation offers both great opportunities but also poses great threats for those not prepared for discontinuity.

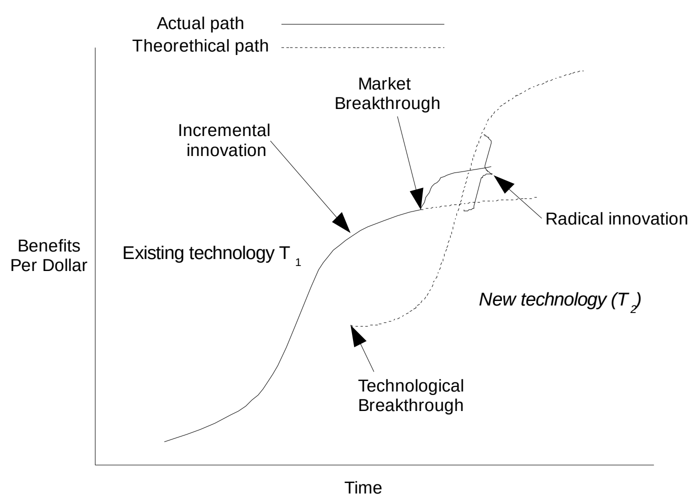

Figure 1 S-curve presented with radical and incremental innovation (Chandy & Tellis, 1998)

The ways firms have tackled the problem of technological change are internal processes that are aimed to manage and understand technological change. This literature can be seen to jumpstart based on the work done by Cooper (1993) on product development that covers work from a product concept to market introduction; named NPD in this study. As understanding on NPD progressed the role of pre-NPD activities started to attract researchers. The front end of innovation FEI (Koen et al., 2001) covers work phases from sensing technology and market trends to evaluation of product concept to firm's business strategy. Together with NPD, FEI can be seen to form firm's innovation process that is a holistic process for developing new product to marketplace that are in-line with firm's strategy.

Convergence of management of technology and strategic management research

The roots of strategic research are in the studies on competitive models describing how competition evolves. A large variety of different competitive models have been created from which the most influential models for strategic management have been Chamberlain competition and Industrial competition (IO)(Barney, 1986). Chamberlain competition assumes that competitive advantage is built on heterogeneous resource base possessed by an individual firm; an assumption strongly conflicting with IO logic where firms are assumed to be internally homogeneous thus neglecting the possibility for competitive advantage based on firm's resources (Barney, 1986). A third influential early theorist is Schumpeter whose ideology of discontinuity has strongly influenced many researchers and contributed especially to research on strategic management of technology. In this study the ideologies by Schumpeter on change are seen as extensions to Chamberlain competition model.

In 1980s the dominant strategic approach was based on work done by Porter (1980), whose work was strongly based on IO competition model. Porter's (1980) argument was that the industry attractiveness determines the profitability possibility for the firm. This strategic school is referred as market based view (MBV). Porter suggested (1980) that industry attractiveness could be apprised with 5-forces, an analysis tool which incorporated the key elements introduced in IO competition model. According to IO logic, the main strategic decision in MBV was to select the most attractive industry and penetrate to markets. Post penetration the focus shifted to building market barriers to protect firm's market share thus maximizing firm's profit. Firm's resources were seen to be of secondary importance, as IO suggested that sustained competitive advantage could not be built resources.

A competing strategic school raised in mid 1980s when a literature track, since named the Resource Based View (RBV), was initiated. Early writers included Barney (1991) and Peteraf (1993) who laid the foundations by discussions on both the definition of term resources and also the connection between profitability and firm's resource base. The root of this discussion was strongly on the Chamberlain competition. Since the early start the number of major publications in the field soared leading to rapid development of theories produced by a wide body of researchers like Prahlad and Hamel (1990), or Teece et al (1997). The rapid development of RBV literature aroused also some criticism, where the focus of arguments was directed among others to research methodology and terminology definitions (Priem & Butler, 2001a,2001b). This confusing use of terms has lead to a lot of discussion and confusion in research society. In this paper we elected to use the term competence to describe firm's ability to create competitive advantage according to definition by Prahlad and Hamel (1990).

Parallel to discussion on resource term definition, Dierickx and Cool (1989) initiated an interesting discussion on the dynamic nature of resources. Their (1989) argument was that firm's resources form a pool, which needs to be constantly replenished in order to maintain firm's resource base against resource erosion. This approach was almost revolutionary as it opened a way for dynamic inspection compared to dominantly used static frameworks. This dynamic approach was brought to highlight by Teece et al. (1997), when they introduced a concept of dynamic capabilities, which turned the discussion from resource level to higher level of capability. A competence is created by bundling resources together (Teece et al, 1997). Firm's dynamic capability is concretely its ability to form and re-arrange these bundles according to current and future customer needs (Teece et al.). Eisenhardt and Martin (2000) argue that dynamic capabilities are procedures that facilitate change such as strategic decision making, product development process, or networking. These ideas behind Teece et al. (1997) and Eisenhardt and Martin (2000) are strongly overlapping, or can be seen to belong, to research track of knowledge management; known also as the knowledge based view KBV, but especially Teece et al. (1997) is also strongly linked to RBV literature. There has been much debate whether KBV should be seen as a part of RBV or as its own research track (Acedo et al., 2006). Our aim is not to contribute to this discussion, but we acknowledge that KBV –theories are in critical role in the processes that build firm's competence base and thus need also to be acknowledged in the actual modeling process.

The discussion on dynamic nature of resources was taken even further by Danneels (2008), who introduced an idea of second order competences. These competences were defined to be firm characteristics that describe how well a firm is able to implement resource building. In his empirical research Danneels (2008) found support that these factors were more correlated more significantly with profitability than for example firm size or firm's market dominance, that are commonly used in technology management research to explain the innovativeness of a firm. This initial finding supports also the hypothesis on the importance of dynamic capabilities in firm's performance. To sum it up, dynamic approach to firm's resource base has shifted the focus from particular resources to the processes that upkeep the firm's capability base.

Figure 2 describes how the theories presented above can be seen to form a single system. At the base of the system are resources (R_x) that are controlled by asset accumulation and erosion. A firm is able to build competences (C_x) by combining resources in different ways. Competences might have different value to the firm as some of them can be seen to be core competences that define most of firm's products. The management of these capabilities is done through dynamic capabilities, were both investment and disinvestment decisions are made according to current and predicted future customer needs. In some extremes firms might be able to manipulate future customer needs to better suit its competence base. Firm's products (P_x) are built by combining different competences in order to fulfill customer need (CuR_x) required by a particular market segment.

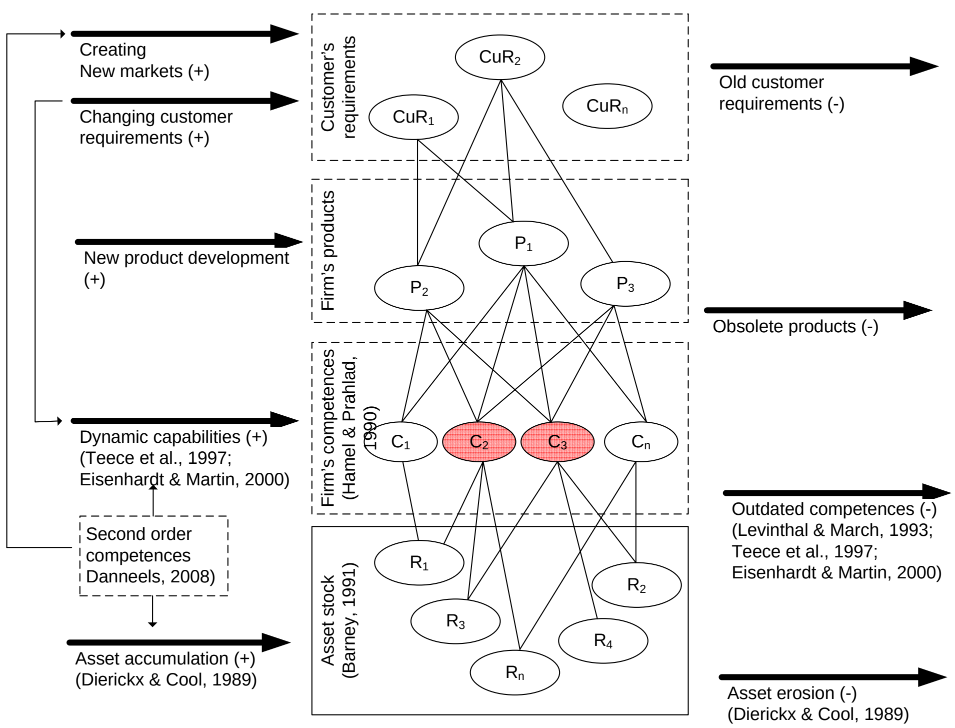

Figure 2 Model of strategic literature dynamics

Fast strategy

Traditionally strategic management has been based on long and thorough processes, where the objective was to find long term strategic commitments for the firm. Such a approach lead to a inelastic strategy process. This inelasticity has been a central point for criticism by a bunch of researchers (e.g. Mintzberg, 1994; Doz & Kosonen, 2008a) who argue that such an approach is illogical in today's rapidly changing business environments. To compensate with the high speed of change, strategy process needed to become more lean and reactive to market changes; thus a concept of strategic agility was born. Doz and Kosonen (2008b) define that strategic agility is built on three dimensions: (1) strategic sensitivity, (2) resource fluidity, and (3) leadership unity. Doz and Kosonen (2008b) argue that if strategic agility helps firm's to cope against stagnation and overlong investments that lead to decline.

From System dynamic modeling to Agent-based modeling to Hybrid modeling

System dynamics began in the late 1950s by studying the dynamics of a supply chain (Forrester 1958). As such the whole methodology is over 50 years old and the amount of research in the field has been vast and diverse. Agent-based modeling started to gain popularity in the 1990s as the computational power of computers has increased to a high enough level. According to a recent literature review (Hilletofth et al. 2009), the maturity of agent-based models is still very low.

The first hybrid models integrating these two methodologies began to appear in the late 1990s and early 2000s (Kim & Juhn 1997; Akkermans 2001; Schieritz & Grössler 2003). All of the papers studied supply chains and all of them used a system dynamics approach and incorporated agent-based principles in the models. However, these models were still under the main principles of system dynamics and had a fixed structure. This same approach has been used in other areas as well (such as fishery management) (BenDor et al 2008).

One reason for the scarceness of hybrid models might have been the lack of proper toolsets. Osgood (2007) studied how well different toolsets could be used to study both system dynamics and agent-based modeling. Some toolsets (such as Anylogic) are well suited in simulating both of the methodologies. Thus, it would be assumed that the amount of hybrid simulation models should increase in the near future.

Background and Structure of the Model

Structure of the model

Figure 2 offers the rough guideline for the model, but a more detail approach was needed for the actual modeling. Increase in detail increases also the complexity in actual modeling process. When inspecting the plausible structure for the model suggested by FIG2, we noted that modeling the resource level offered little interesting information towards our goals. For this reason and to limit the complexity of the whole model, the resource level was restricted from the model. It is also likely that if resources would have been included and modeled with agent based modeling as required by our modeling objectives, computing restrictions with conventional hardware would have become a problem, as the agent network managed by the modeling software would have increased exponentially.

The actual modeling started from the decision to make a hybrid model, that would incorporate both system dynamic and agent based elements. The four main agents in the model are presented and described in Table 1. Each agent contains a system dynamic model that describes the development of an individual agent. Communication between agents is done through events that causes communication to be discrete not continuous. Terms market and customer need are used interchangeably to describe the customer need agent in this paper.

Table 1 The agents in the model

Agent	Description
Customer need	Describes how customer need develops. The size of market is assumed to be dynamic and it evolves during simulation. Agent also keeps track of different products and their quality competing in the marketplace. Market can be destroyed by the following customer need.
Technology	Agents are created by new customer needs. These agents represent the plausible technologies that may be used to fulfill the customer need. Agent is responsible of tracking the overall development of technology and firm specific knowledge accumulation within the technology. Technology agents are destroyed when the customer need it fulfills is destroyed, and accumulated firm specific knowledge may pass on to the following technological solutions.
Product	Product agents are created when a firm decides to invest in product development. Products are based on one technology and they fulfill a single customer requirement. The overall quality of product is dynamic, which is controlled by the technological knowledge and NPD efforts. Products are destroyed when the customer need it fulfills is destroyed.
Firm	Is the central agent in the model. Contains firm specific decision making logic and firm level parameters. Contains model describing firm's cash processes.

Figure 3 describes how the network created by agents is organized. This picture identifies some of the simplifications made in agent network structure. The number of technological options per customer need is limited to three. All these technologies are able are able to independently fulfill the need, which is contradicting to view by Teece et al. (1997) of capability bundles. This restriction was done to simplify the logic structure of network. A firm can invest in product development which creates a product that is based on a single technology and fulfills a single customer need. A firm can have multiple products, but only one product for each customer need. Competitors can also have products with similar networks fulfilling the same customer requirement leading to competition. Thus customer requirements work as a connector that ties different firms' networks together. Communication between agents is implemented through cyclic events or with functions. In cases where it was possible cyclic events were replaced by dynamic events to make modeling lighter for modeling software.

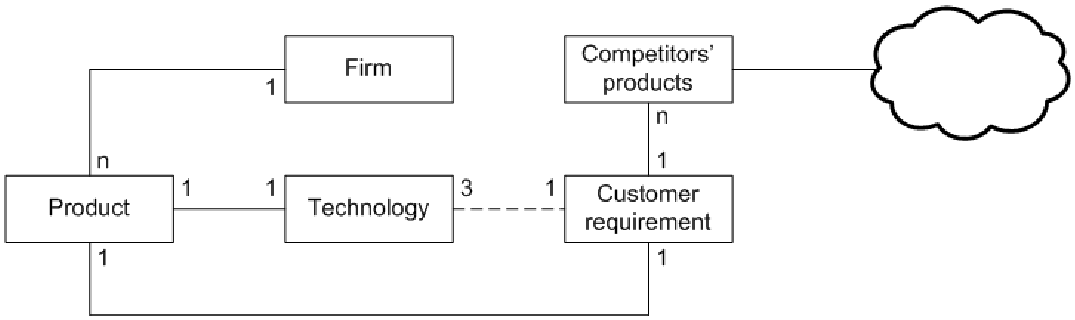

Figure 3 Connections between agents in the model

Agents

To provide insight how the logic inside a single agent is built each agent will be presented here as a causal map. Figure 4 presents the firm agent, which is the central agent that controls the central analysis object. When assessing the profitability of a firm cash flows are in crucial role. These flows are implemented with the use of system dynamics, where sales revenue from focal firm's active products add to the cash stock and total investment costs reduce this stock. Sales revenue is assumed to be a stream of capital that represents profit from sales after manufacturing and fixed costs are deducted. Total investment costs are calculated from all the investment activities that the firm currently engages.

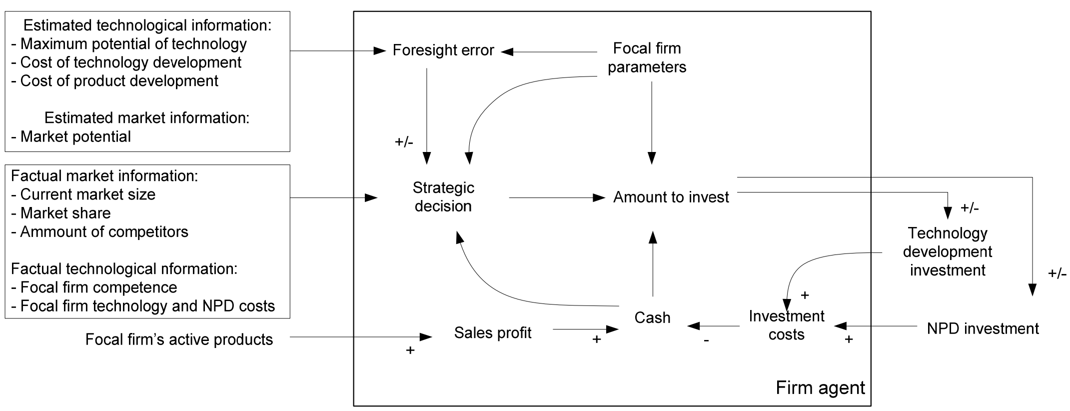

Figure 4 Firm agent

The main source of logic, and also the source of loopback in the model, is the strategic decision made by the firm. The strategy making process is divided to three stages: (1) analysis, (2) decision making, and (3) implementation. Time firm spends on each step is constant on firm level. This attribute is the central variable in our testing of fast strategy in this paper. Strategic decision making combines information from multiple sources. Some of this information is seen as factual, or error free, that the firm can apprise correctly. However some information is seen to require estimation, where stochastic error element is added to decision making variables. The size of this error is dependent on firm's ability to forecast technology or markets correctly. In our model the firm has five different strategic choices: (1) invest in technology, (2) invest in NPD based on technology it has invested, (3) disinvest in particular NPD project, (4) disinvest in particular technology development, and (5) do nothing. The strategic cycle goes from analysis to decision and finally implementation, and the cycling speed is dependent on firm's parameters.

After the decision is made the amount for dis-/investment is decided. Disinvestment is assumed to be total, so disinvestment will terminate development on a single technology or a NPD project. In investment case the invested amount is dependent on cash available for the firm and the aggressiveness of the firm, defined in firm's parameters. This aggressiveness factor causes more aggressive firms to invest relatively more on a single technology or product than more passive firms. When investment decision and investment amount is decided strategy is implemented and information is passed to relevant technology or product agent.

The structure of customer need agent is presented in Figure 5. The role of the agent is to keep record of both products competing at the market place and model the market development. Market size describes the volume of market place per one simulation round. The size of market is enlarged by market growth. Market growth speed is controlled by current market size, market maximum potential, and the quality of products at market place, which describes how ready the technology and products based on it are. Using both market maximum potential and current market size data to control growth an s-curve shaped market size growth can be achieved. When market size is known the profit gain by a single product is calculated by comparing the qualities of the products competing in the same market place. The profits are divided according to relative quality of a product and this information is collected by the firm agent.

A following customer need that replaces previous customer need is initiated, when particular market reaches maturity or after a counter reaches pre determined value. Counter can be used to control the speed of customer need progress. Market decline starts, when a first product satisfying the following customer need is introduced. The decline speed is dependent on market growth in the following markets. When market size has fallen to a predetermined level market is determinate causing also to the deletion to technologies and products aimed to fulfill this market requirement. In certain market conditions it is possible that the following market is not strong enough to terminate its predeceasing markets, but it is terminated by its following market share the interconnection is corrected between the newest market share and previous still alive market. Such a case is seen to represent a situation where a radically new product has failed to replace existing products.

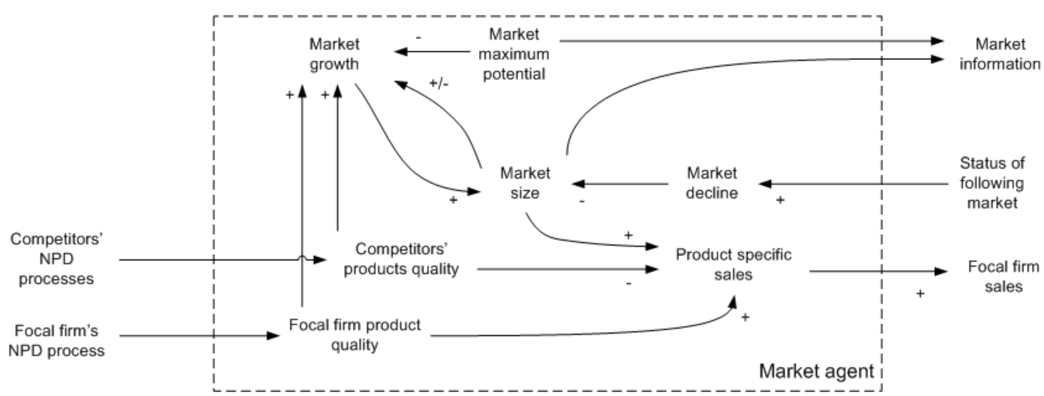

Figure 5 Customer need agent

Figure 6 presents both technology and product agents. These agents were decided to be presented together as they are strongly interrelated. A technology agent is initiated when a new market in created and a link between technology and where it can be used is created. At this time technology is also given parameters describing the maximum potential of technology and the cost of technological and NPD activities. In addition the plausible continuity from previous technology is controlled with a stochastic element.

The central variable in technology agent is the firm specific technological capability. Firm specific technological capability and development rate is modeled with system dynamics by using array variables to keep track of each individual stock with a simple structure. The technological development speed is controlled by both firm's own technological knowledge and the overall level of technological development. No firm can gain more technological knowledge that is the current overall level of technological capability. Overall technological capability is developed through the combined effort of all firms and also by a constant basic development rate, which can be seen as the efforts of universities and other non-profit institutions. The basic shape of this development is s-curve as suggested by a large number of researchers (Foster, 1986; Christensen, 2004). The speed on which s-curve reaches its maximum is dependent on technological characteristics and also the overall amount of invests made by the competing firms. There is a delay between overall level and firm specific technological capability that is dependent of the amount the firm invests in the technology. The difference between overall capability and firm specific technological capabilities starts to reduce as the technology matures and overall development speed slows down. The inter-relationship between different generations of technologies is also carried in technology agent. If the firm possesses knowledge on the previous technology some of this knowledge can transfer to the progressive technology. Information on the likelihood of this continuity is embedded to a single technology, which can be used in firm's strategy process.

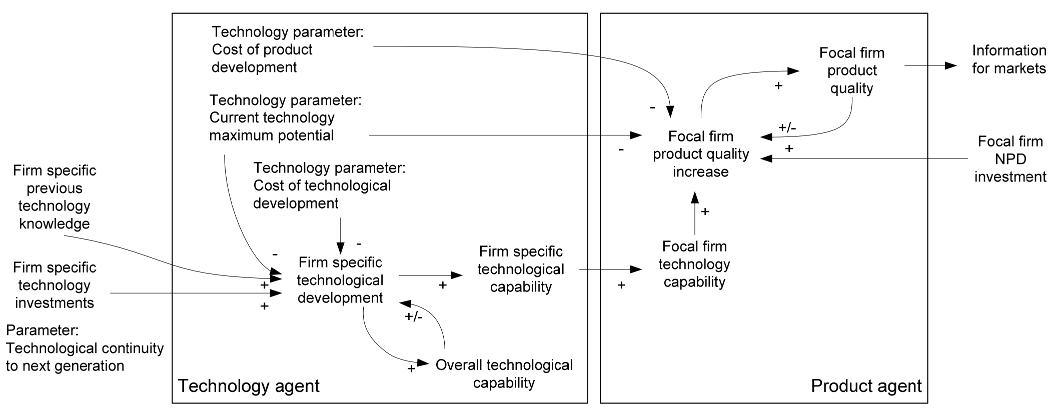

Figure 6 Technology and product agents

Product agent is initiated by a strategic decision made by a firm to invest to particular NPD project. The created agent is tied to a particular firm and technology and its role is to follow how the quality of a single product develops. The shape of the product quality curve roughly fits to a s-curve, but it might deviate from this form due to development rate changes in relevant technology agent. The development of quality is controlled by multiple elements. An investment in the project leads to the possibility that product quality is increased. Product quality development is restricted by the technological knowledge possessed by the firm; and ultimately controlled by the technology maximum potential. The structure used between these two agents creates a delay to the transformation of technological know-how to product quality.

Restrictions of the model

Restrictions and limitations are used in modeling to simplify the modeling task. The use of agent based modeling offers a way to reduce the need for limitations. For example a common limitation on strategic level system dynamic modeling is the limitation of the amount of firms, markets or products modeled to a small sample size caused by problems in the structure of the model. In agent modeling this restriction is not as strict and a large amount of agents can be simulated in the model. Despite the flexibility of modeling method, the number of agents has to be limited due to limitation in computing speed. Hardware limitations are not a real in a single simulation run or a run or in a simple Monte Carlo simulation, but in complex sensitivity runs the restrictions come apparent. As the sensitivity tests are crucial for our purposes we elected to restrict the number of companies to 10, market places to 10, and restrict that only 3 different technologies can be used to satisfy one customer need.

In the literature view we identified four different levels: (1) markets, (2) products, (3) capabilities, and (4) resources. In the modeling effort we decided to restrict resource level inspection from the model as it would have significantly increased the complexity and likely lead to little contribution to the overall goals for the model. When considering the technology management literature and especially the concept of dynamic capabilities the biggest restriction in the model is that the structure between technology and products is linear, not a network as suggested by theory.

The market share of a single product is determined by its relative attractiveness compared to competing products. The attractiveness is a function of firm’s NPD efforts and technological knowledge. However, in real world the relation between product quality and market share is not as straightforward, as for example marketing efforts and firm’s brand have an effect on products’ market shares. Thus these marketing aspects are currently excluded from the model. Also the manufacturing costs are assumed to be fixed, which is contradicting to the phenomena of learning curve.

Setting up the Simulation

Three main variables used to model individual companies are: (1) firm estimation error, (2) firm aggressiveness, and (3) strategic cycle speed. Firm estimation error and aggressiveness can both have values of [1,3,5], thus creating 9 different combinations, which are used to initiate 9 competitors used to simulate the market place. Strategic cycle speed is assumed to be constant with every firm. In addition to these companies a single company is added to system that works as the central object of analysis in our experiment. This focal company is given a strategic cycle speed 50% or 80% of the original cycle speed of competitors and then run in 9 different case scenarios derived from all variable combinations. As stated in model structure, our model has in-built stochastic elements so Monte Carlo simulation was needed to get more reliable results from the model. Our Monte Carlo runs are based on averages from 100 simulation replications.

The simulation model will have one base scenario (Table 2). The main results will come from the base scenario but in order to understand better the dynamics of the model, sensitivity analyses will be conducted with other variables as well. The base scenario will include 18 different combinations for the focal company (9 different scenarios with two different cycle time speeds) but in the sensitivity analyses there will be overall 1944 different scenarios (18 * 3 * 2 * 3 * 3 * 2). As each scenario will be run 100 times, the overall amount of runs will be nearly 200 000.

Table 2: Parameters for the base scenario

Parameters	Value in base scenario	Values in other scenarios
Cost of technology development (COTD)	2	4,6
Initial amount of cash	4000000	1000000
Initial size of market	2	1,3
Initial technological maximum maturity	5000	2500,7500
Time on market (TAA)	90 days	60

As the amount of simulation will be 200 000, the sensitivity analysis will require a long time. In order to get the results more quickly, the sensitivity analysis simulations were divided to two different computers. The first ran the scenarios with a cycle time of 5 for the focal company while the other one ran the simulation with focal firm cycle time of 8. The simulations took overall about four and a half days using computers with a 2,33 Ghz dual-processors. It should be noted, that Anylogic only uses one processor at a time so the only one of the processors was used in the actual simulations. The results for the simulations were studied with the help of Minitab 15.The network picture presented in Appendix A is constructed with Pajek.

Results

Dynamics of the model

In the result chapter we will introduce the sensitivity runs from the model and statistical testing done to the strategic agility concepts. In addition we will present descriptive single simulation round results from the model to describe the dynamics of the whole model.

The single simulation presentations are based on the base scenario and focal firm is given aggression factor of 3, error of 1 and cycle rate of 5. Figure 7 describes how different firms accumulate cash on these settings. From this figure we can see that the model needs around 100 rounds to set-up after which the dynamics start to show. The figure also illustrates how the dynamics evolve and change in cash is incremental and continuous.

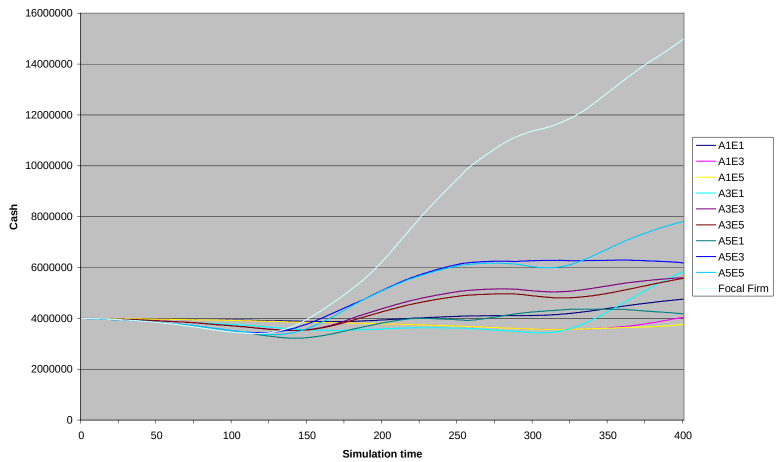

Figure 7 Firm spesific cash deposit

Figure 8 describes market dynamics. On the left is shown the overall fluctuation in the model. The fluctuation is caused by first market growth, but after from market decline and replacing market needs. Sudden end of a market graph is a result from a radical innovation, where demand suddenly ends causing a stop in demand. On the right is presented the dynamics with-in a single market. Market enters to active state when the first product or products are introduced to market. Market shares are divided between the competing firm according to their product quality, which is deriver from their technological and NPD investments. The figure incorporates also the overall size of the market. Single firm's profit is calculated from the relative market share and overall size. This information is used to control firm specific cash flows.

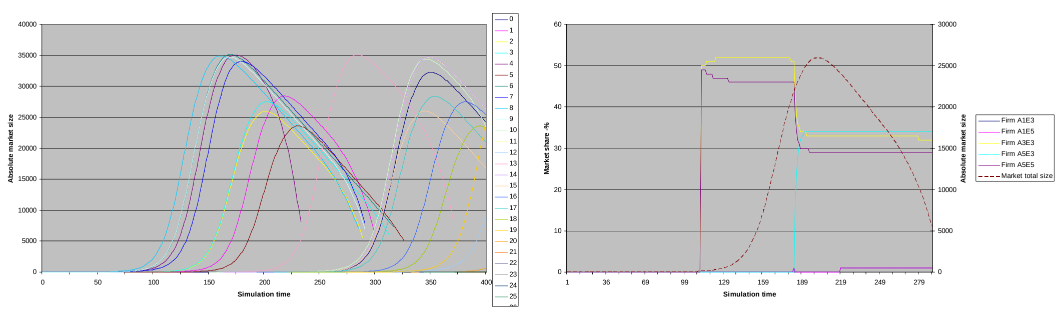

Figure 8 Dynamics in overall market development (left) and with-in (right) one market in the model

As stated in the structure chapter, one of the main benefits from agent based compared to system dynamic modeling is the more flexible structure it allows. Figure 8 describes how this dynamicity actually goes, but the whole relationship network developed during a single simulation round is presented in Appendix A.

Results from the testing

As it was postulated in the previous chapter, it should be beneficial to make decision faster than the competitors. We will test this by studying the difference between the average cash for the focal company compared to the nearest competitor. Here, the nearest competitor is the company which has the same aggressiveness and forecasting error than the focal company has. The histograms for cashes are presented in Figure 9.

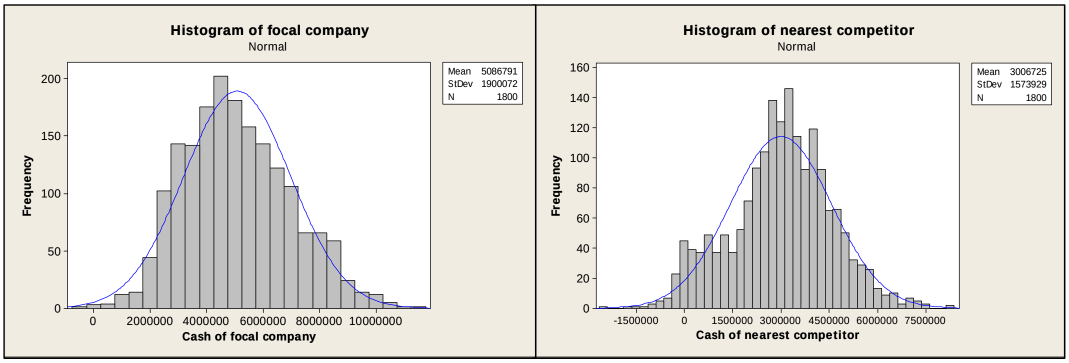

Figure 9: Cash of the focal company and the nearest competitor after the simulation run

As it is possible to notice from the histograms, the focal company generates a lot more profit compared to the nearest competitor. This can also be seen from the box-plot (Figure 10) of these two companies. As the values are not normally distributed, they will be tested using Mann-Whitney's test. The results for this test are presented in Table 3.

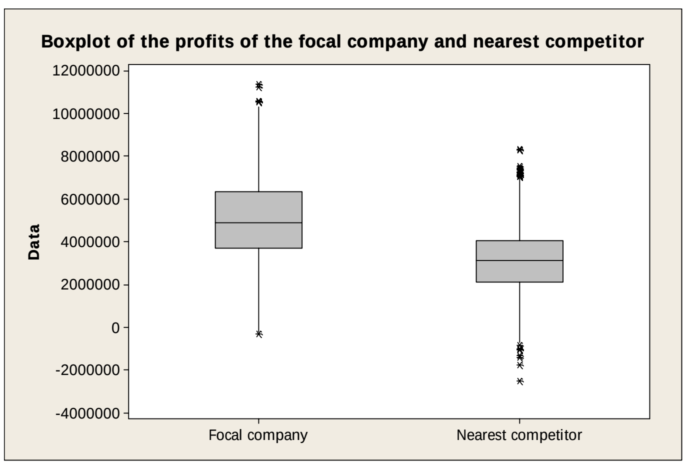

Figure 10: Box-plot for both of the focal company and the nearest competitor

Table 3: Mann-Whitney test for the difference between the cash of the focal company and the nearest competitor

Variable	Value
U –statistic	4199836,5
Sample sizes	1800
Significance	P < 0.0000

According to the Mann-Whitney test, the difference between the distributions is statistically significant. This implies that the speed of decision-making impacts the profitability of a company. A faster decision cycle will also increase the results even further. Figure 11 shows the box plot for the profitability of the focal company and its nearest competitor.

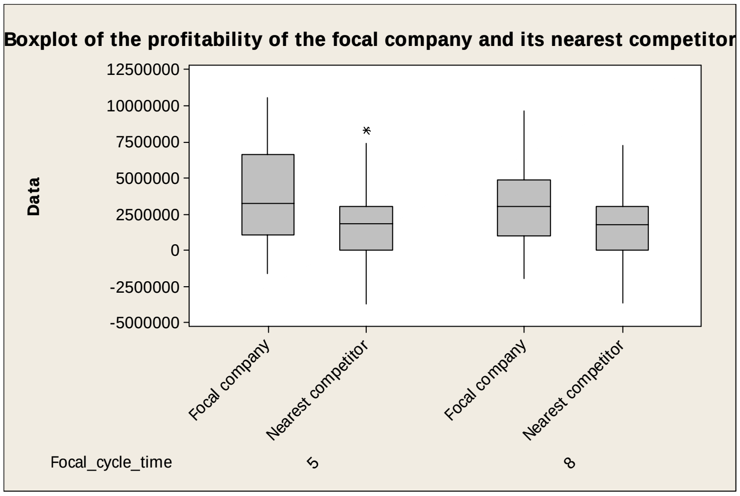

Figure 11: Box-plot for the focal company and its nearest competitor in with different cycle times

From the base scenario it can be clearly seen that faster decision cycle time is a better one. The rest of the variables (forecasting error and aggressiveness) can also be studied. Figure 12 shows the bar chart of all of the companies. The focal company has the highest profits, but passive companies have the second highest results. The forecasting capability has a small impact on the results but aggressiveness plays an important part.

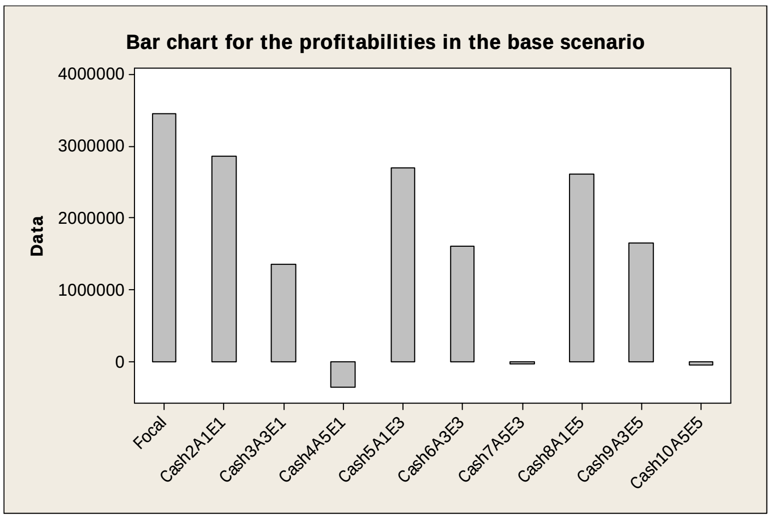

Figure 12: Bar chart for the profitability of all of the companies in the base scenario

Overall the results from the base scenario seem to be logical ones. The focal company is clearly better than its competitors. However, the base scenario has a lot of different parameters which might impact the results. That is why a sensitivity analysis is needed and it will be presented in the next chapter.

Sensitivity analysis

As it was shown in the "Setting up the simulation" Section, there are 8 variables which are assumed to impact the results from the model. The sensitivity analysis is conducted by using a GLM-model where the second level interactions (for instance using A, B and the interaction between AB as independent variables) have been accounted for. In the sensitivity analysis we have studied how the independent variables impact the relative performance of the focal company. The relative performance has been calculated by standardizing the performance of the focal company in each one of the simulation runs. The main effect plots have been presented in Figure 13.

From the main effects plot it is possible to see that two of the parameters, aggressiveness of the focal company and the maximum maturity of technology, impact the results much more than the other variables. As the aggressiveness of the firm increases, it is able to make better profits. Also, when the technology is easier to develop (maximum maturity), the focal company is able to make more profits. On the other hand, the forecasting error of the focal company and the initial size of cash have a very mild impact on the results. The rest of the variables have small impacts on the results. All together all of the variables have a statistically significant impact on the results and the tests are presented in Appendix B.

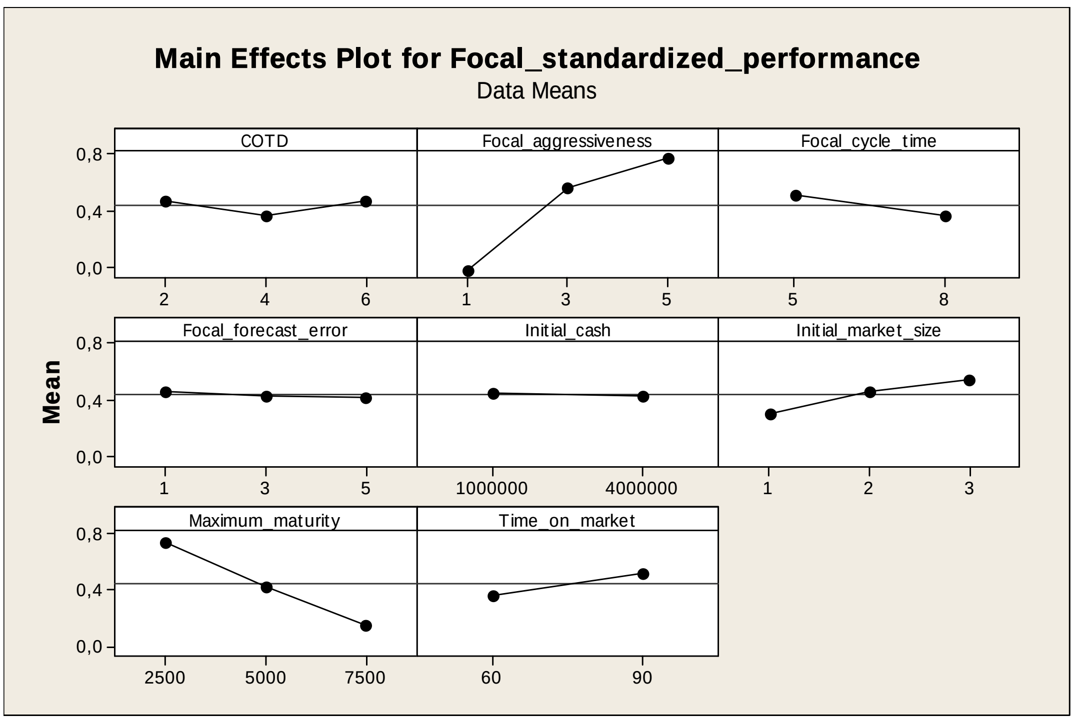

Figure 13 Main effects plot for the performance of focal company

The main effects plot only studies the impact of one variable at a time but it is possible to get more insights by studying the interaction plots between the variables. These are presented in Figure 14. All of the interactions are statistically significant (presented in Appendix B) but most of the interactions do not have any practical implications. For instance, the forecasting error seems to have only very small changes when interacting with different variables. The most drastic interactions between other variables exists with cost of technology development. If the cost of technology is low, then a higher amount of initial cash will clearly increase the performance of the focal company. However, when technology is more expensive, a higher amount of initial cash will *decrease* the performance. There might be different reasons for this. As the results are standardized results, it is possible that the competitors are able to keep up with the focal company and the average results for them are higher. It is also possible that the focal company tends to over-invest as it has more investable assets so its performance will diminish. On the hand, when the company is highly aggressive the increase in the price of technology improves the performance of the focal company. It is not possible to make simple conclusions regarding this behavior and it should be further studied.

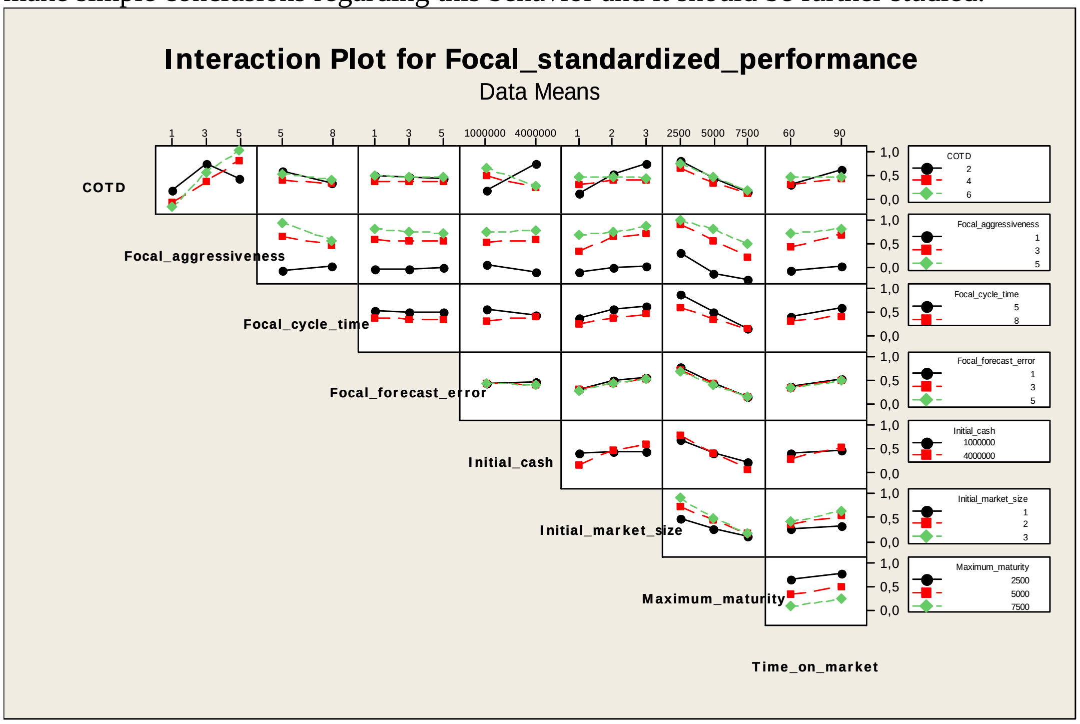

Figure 14 Interaction plot for the performance of the focal company

Vast majority of the differences in the results can be explained with the main effects of the independent variables. As it was mentioned before, the largest interactions are between the cost of technology development and other variables (aggressiveness, initial size of cash reserves, initial market sizes and time on market). Some other interesting interactions exist with the maximum maturity of technology and the initial size of markets. If the maximum maturity of technology is high, the initial size of market does not impact the results. Also, if the amount of initial cash reserves is low, the size of the markets will not impact the results.

Overall the sensitivity analyses give additional information regarding the dynamics of the system. It would be very difficult to find most of the interactions as they might be counter-intuitive. It is possible to conduct sensitivity analyses even with models constructed with the principles of agent-based modeling even though it is very difficult due to computational requirements (Rahmandad & Sterman 2008). In further research the sensitivity analysis could be expanded by conducting a GLM model with higher level interactions.

Conclusion and discussion

The objectives set for this paper was first to build a modeling environment for modeling of competition in evolving market settings. The secondary objective was to demonstrate the functionality of the model by testing the effects of fastening the strategy process to profitability. We will begin the conclusions from the testing demonstration and end conclusions to notes on hybrid modeling.

Our results support the basic hypothesis of fast strategy that being able to increase agility correlates positively with profitability. Reason for this is that a firm with rapid strategy process is able to make correct decisions earlier than slow competitors, but also firm's ability to disinvest from wrong decisions in time than decreases unnecessary monetary loss. The results from sensitivity analysis show how an aggressive company benefits a lot from a quick decision-making cycle. Also, if the technology is easy to develop, the agile companies are able to find the best niches and occupy them. These two variables explain most of the benefits gained from a fast decision-making cycle. The sensitivity analysis also show that with a fast decision making cycle it is possible to make poorer judgments (seen as forecasting errors) and still be able to win the competition.

Using agent based modeling in conjunction with system dynamics offers many opportunities for researchers. The clearest addition to opportunities compared to basic system dynamic approach is the more flexible model structure. Agent based modeling allows the build of dynamic networks to describe a interconnected system. Building such a complex system with system dynamics is plausible, although really work intensive, but fully dynamic structure cannot be achieved. In our model we were able to use this freedom to create a network where clear linkages can be built between a technology – product – market. When broadening the scope to strategic research this…

One identified problem in agent based modeling is the high computing requirements in sensitivity analysis (Rahmandad & Sterman 2008). In our modeling efforts we encountered similar problems as the sensitivity analysis done for this model required over a week of modeling time with a single up-to-date desktop computer. Our conclusion is that this problem is real as it significantly complicates especially testing phase of the models, compared to system dynamic models where similar sensitivity runs could be done in matter of minutes, or at most hours. Important question for the development of future modeling methods is the reason for these high resource requirements. Undoubtedly the networked structure in agent models increase the amount of computing exponentially, but some of the blame also might be in the Java environment. One plausible way to speed sensitivity runs is to reduce time-step accuracy in Anylogic-software, but this seems to have an effect on the results in the hybrid model structure which is likely caused by event synchronization with the system dynamic elements.

Overall agent based modeling is an interesting tool. It offers great freedom in model structure that allows simulation on more abstract and less structured modeling tasks. However this freedom comes with a drawback of high hardware requirements. Also the modeling tools are less comprehensive in agent based which increases the requirements set for modelers; in the case of Anylogic the modeler is required to know the basics of java programming. Despite these requirements, we finally conclude that agent based modeling in conjunction with system dynamics offers a strong tool for researchers in the are of strategic management.

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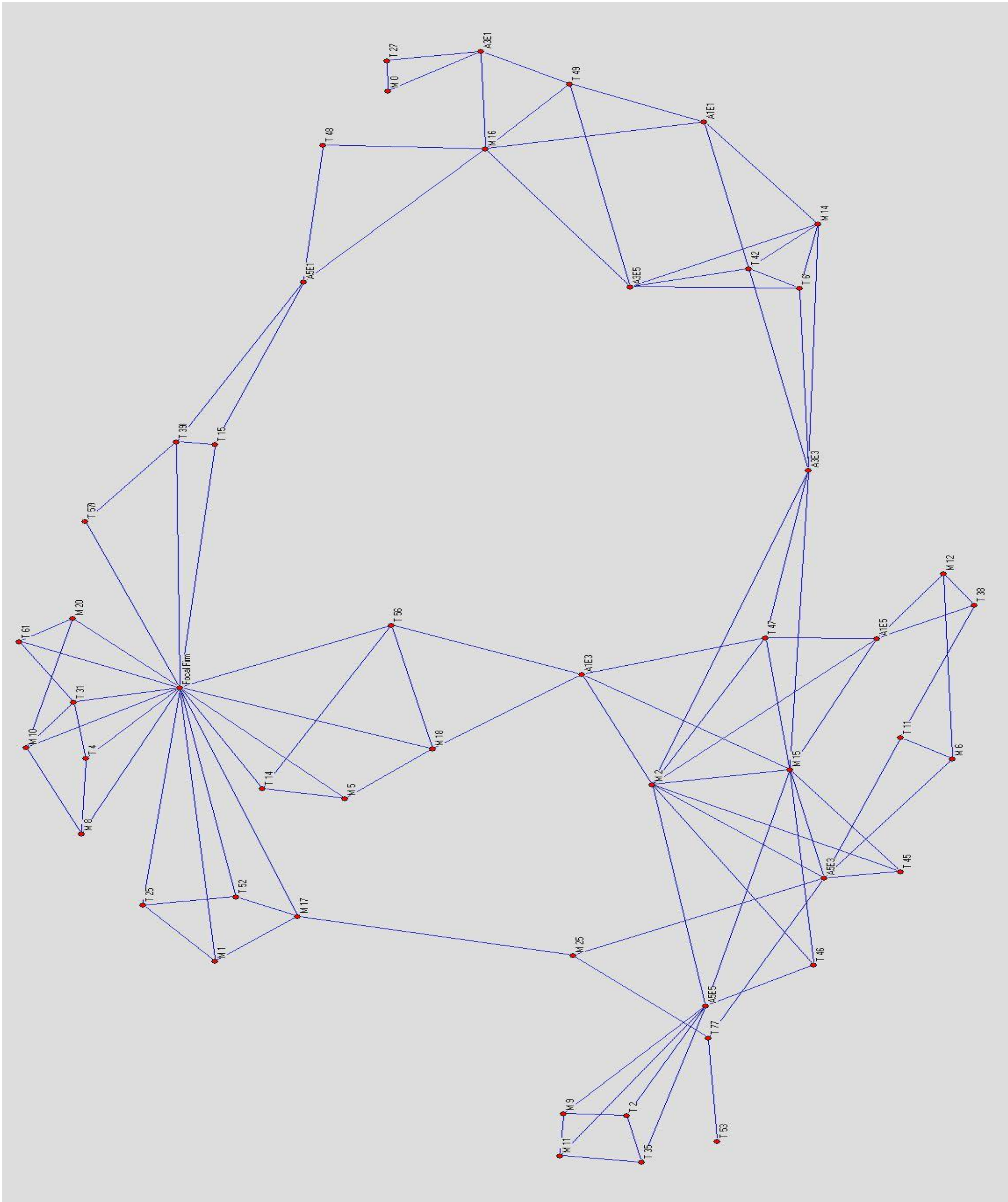
APPENDIX A.



The figure above describes the relationships between firms (e.g. focal firm or A1E1), technologies (Tx), and markets (Mx) is built. The actual relationship with these entities is built through products, which are left out from the figure to make it simpler. Link between firm and market/technology means that firm has made a product based on the technology and to the market. A link between technologies or markets indicates that they are successive.

APPENDIX B.

Variable	F-statistic	Significance
COTD	226,19	0,000
Focal_aggressiveness	11194,86	0,000
Focal_cycle_time	1145,12	0,000
Focal_forecasting_error	28,75	0,000
Initial_cash	16,21	0,000
Initial_market_size	967,42	0,000
Maximum_maturity	5580,22	0,000
Time_on_market	1200,85	0,000
COTD*Focal_aggressiveness	1703,06	0,000
COTD*Focal_cycle_time	168,99	0,000
COTD*Focal_forecasting_error	5,45	0,000
COTD*Initial_cash	4422,72	0,000
COTD*Initial_market_size	687,64	0,000
COTD*Maximum_maturity	22,92	0,000
COTD*Time_on_market	388,61	0,000
Focal_aggressiveness*Focal_cycle_time	913,95	0,000
Focal_aggressiveness*Focal_forecasting_error	14,03	0,000
Focal_aggressiveness*Initial_cash	163,67	0,000
Focal_aggressiveness*Initial_market_size	134,17	0,000
Focal_aggressiveness*Maximum_maturity	144,98	0,000
Focal_aggressiveness*Time_on_market	173,48	0,000
Focal_cycle_time*Initial_cash	524,98	0,000
Focal_cycle_time*Initial_market_size	5,93	0,003
Focal_cycle_time*Maximum_maturity	339,03	0,000
Focal_cycle_time*Time_on_market	65,98	0,000
Focal_forecasting_error*Initial_cash	32,83	0,000
Focal_forecasting_error*Initial_market_size	2,62	0,033
Focal_forecasting_error*Maximum_maturity	11,86	0,000
Focal_forecasting_error*Time_on_market	4,13	0,016
Initial_cash*Initial_market_size	670,35	0,000
Initial_cash*Maximum_maturity	276,11	0,000
Initial_cash*Time_on_market	374,93	0,000
Initial_market_size*Maximum_maturity	164,82	0,000
Initial_market_size*Time_on_market	96,09	0,000
Maximum_maturity*Time_on_market	7,62	0,000