COMPARISON OF STRATEGIES FOR ENTERING NEW TECHNOLOGY AREAS USING SYSTEM DYNAMICS

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Abstract:

*Consider a company with a significant technology development capability. Suppose the possibility of a new technology appears on the horizon, and the company decides it wants to get involved in the new technology. This paper studies the question of the most appropriate timing for the company to start investing in the new technology. The early stages of the technology life cycle are expanded in more detail than usual, identifying specific activities typical role players engage in during each stage. An **ithink** model is then used to compare and probe different strategies for timing the start of investment in the new technology.*

Key words:

Emerging technology, Technology life cycle, Investment decision, System dynamics

1 INTRODUCTION

Consider a company with a significant technology development capability. Suppose the possibility of a new technology appears on the horizon, and the company decides it wants to get involved in the new technology. This paper studies the question of the most appropriate timing for the company to start investing in the new technology.

2 STAGES IN THE TECHNOLOGY LIFE CYCLE

Any technological system passes through a number of recognizable generic stages during what is known as the technology life cycle (Day *et al* 2000; Utterback 1994; Kampas

2003). The early stages of the life cycle are emphasized in this paper, for the sake of studying the timing of entry into the new technology. The key points of each stage are as follows:

- ***Discovering stage:***
  The critical task in this stage is to get the technology to work. The development work can include proving concepts, testing subunits or process steps, etc. The main role players in this stage are the technology developers. This stage is considered at its end when a working prototype of the intended technology has been constructed and demonstrated to work. The duration of this stage is unpredictable; it can last indefinitely if a required breakthrough is never achieved.

- ***Probing and learning stage:***
  The critical task in this stage is to develop a commercially viable product and production process. The development work focuses on the product features; typically alternative solutions to the problem are explored, system integration issues sorted out and pilot demonstrations done. The main role players in this stage are still the technology developers, possibly working for or funded by high-tech specialist companies. This stage ends when the first company commits to bringing the product to market. The duration of this stage varies over a range, and may depend on the industry in question; examples inspected so far often take 5-7 years to progress through this stage, although cases of 2-3 years, as well as some where this stage lasted for decades have been found.

- ***Committing stage:***
  The critical task in this stage is to establish the product in some market. The technology is now good enough to warrant commercial interest; from this point forward technology considerations play a lesser role than commercial and marketing considerations. Activities include construction of production and logistics infrastructure, securing of an intellectual property position and finding a market niche for the product. The main role players in this stage are the leading companies in the new industry. This stage ends when sales of the product take off and sales volumes increase several orders of magnitude in a short period. Note that, for sales to take off, the product must be attractive to the pragmatic "early majority" buyer; selling to enthusiastic lead users and in specialist niches can not trigger enough sales for a major take-off. A plausible duration for this stage can be derived from the typical time required for the construction, commissioning and ramp-up of plants for the technology in question.

- ***Market expansion stage:***
  The critical tasks in this stage are to maintain the momentum of market expansion, and to supply product to a fast-growing market. In this stage, the expanding market creates opportunities for follower companies to enter the fray. As fast expansion is easier for more standardized products, a "dominant design" often emerges in this stage, leading to

a shake-out of companies that have backed alternative versions of the technology. This stage ends when market growth starts to slow down as the market nears saturation. The expected duration of this stage can be modelled using market diffusion models (e.g. the Bass model (Bass 1999), using early data points to estimate the parameters).

- ***Developed stage:***
  The critical task in this stage is to compete in a mature market; the product is by now becoming a commodity. Competitors have to continuously improve the reliability, cost and convenience of the offering in order to secure repeat sales. New players appear in the aftermarket, and complementary products appear. Towards the end of this stage, the technology becomes vulnerable to substitution by newer technologies. This stage ends when the market for the product starts to decline, the technology trajectory appears to be exhausted and the best talent starts to move to other fields. This stage is likely to be longer than the previous stages. Estimates of its duration can be based on the progress of possible substituting technologies through the early stages of their life cycles.

- ***Substitution stage:***
  The critical task in this stage is to defend market share for long enough to execute a suitable exit strategy (the exit strategy may include switching to the substitute technology). In this stage, the buyers of the product become very important and many companies turn to value-added services to differentiate their product. In many cases the technology continues to exist in specialised luxury or collectors niches for long periods, but not in commercially significant volumes.

3 TYPICAL ACTIVITIES OF ROLE PLAYERS

The model allows for three role players in the new technology: two leader companies, doing their own technology development, and a follower company. Each company has a fixed investment pool available in each period to invest in the following activities:

Technology development:
During the Discovery stage (§2 above), an idea is developed up to the point where a technology concept has been proven by way of a working prototype or a demonstration in a pilot plant setting. The technology then enters the Probing and learning stage (§2 above). In this stage technology development focuses on ensuring that a product with desirable properties can be manufactured using a process with a cost structure that will allow the product to be sold at a commercially viable price. When the product/process combination reaches a threshold of commercial acceptability, the company can decide to commit to commercializing the technology (enter the Commitment phase). From this point onwards, the rate at which the life cycle of the new technology evolves depends more on commercial than technical issues; the technology development activity continues, but in a more supporting role, focusing on continuous improvement and production support.

***Market development*:**
Once a company has entered the Commitment stage (§2 above), money is invested to develop the market. This involves activities to introduce the new technology to potential users, creating an awareness of the potential benefits of this type of product and creating a pool of potential customers (Warren 2002). The product is not officially available for sale yet; prototypes may be displayed at trade shows, samples may be supplied to potential buyers to allow them to test the new product in their production processes, etc. The market leaders may often collaborate in order to establish a market for the new product. Once there is sufficient market interest and the company's production facilities are coming into place, the next activity may be triggered.

Marketing:
Still during the Commitment stage (§2 above), and once the market development activity has resulted in sufficient market interest, the marketing activity invests to establish and manage the brand, relative to that of the competition. This involves migrating customers through a "chain of conviction" from potential customers to customers loyal to the brand (Warren 2002). Investment in marketing has to continue through all the later stages of the technology life cycle, as long as the company wishes to retain market share, as brand awareness is assumed to decay over time.

Product Development:
This activity may first occur during the Market expansion stage (§2 above) and continues to grow in importance in the Developed stage. Investment is made to develop additional product features, applications, etc as a strategy to grow market share.

In this paper, typical industry ***leader companies*** are assumed to be involved in all four types of activities, i.e. they are assumed to develop and maintain their own proprietary versions of the technology, participate in market development (perhaps jointly with other industry leaders), do marketing and invest in product development. ***Follower companies*** are assumed not to develop technology or participate in market development. They are assumed to gain access to technology once it has been developed, and once a market has been created. Follower companies therefore can only enter the arena of the new technology once the leaders have started marketing. They invest only in marketing and product development.

4 SYSTEM DYNAMICS SIMULATION MODEL

A simulation model was developed in ***ithink*** to study different strategies regarding the timing of entry into the new technology for technology developer companies. The model has been built at a fairly high level of abstraction in order to reach general conclusions.

4.1 Model description

Generic structure:
The model uses a basic goal-seeking structure (shown in Figure 1) for each of the activities described in §3. It is assumed that each activity strives towards some ideal level of performance. For example, technology development would strive to achieve the theoretical limit or a maximum value on a performance index. The difference between the actual performance on the selected metric and the ideal value defines the gap. This performance gap is used to determine the funding required to close the gap. The available funding and the size of the gap limit the extent of the performance improvement activity that can be executed. The improvement activity results in a change of the actual performance. A moderating function with two components describes the effectiveness of the performance improvement activity. Firstly, when a role player has no track record in a specific activity, the impact of a unit of money is assumed to be quite low compared to when the cumulative spending on that activity has been considerable. Secondly, if there is a large performance gap, a large investment in one period will not close the gap, as the effectiveness of the improvement activity is low when the current performance is low. The dynamic result of this structure is an S-shaped performance curve typical of technology and market development.

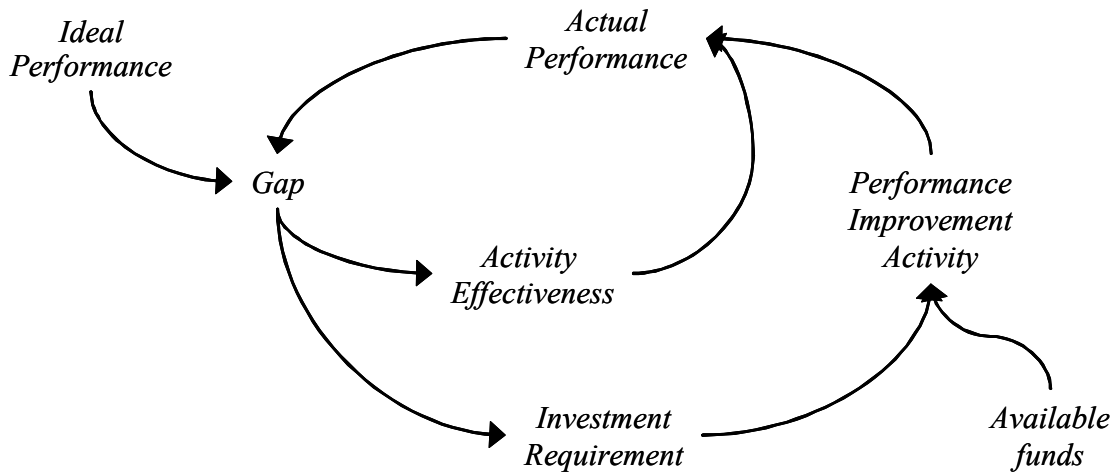


Figure 1: Generic goal seeking archetype

The generic goal seeking archetype therefore has the following three characteristics:

1. Goal – Achieve maximum ideal or theoretical performance;
2. Constraint – Available funding;
3. Moderating function – Performance improvement activity effectiveness, with:
    a. Experience effect component
    b. Difficulty of problem effect component

The goal seeking archetype was applied to each of the activities identified in §3. Modifications were made to accommodate specific metrics for each of the activities, as well as the key differences between activities. For example, it is assumed that the technology development decision is external to the system. The decisions regarding the other activities, however, are a result of having achieved a certain performance level for the preceding activity.

Technology development activity:

The objective of the technology development activity is to achieve a technical performance as close to the theoretical optimum as possible. Examples of theoretical optima include the theoretical yield of a chemical process and the speed of light (see Van Wyk 1999 for a discussion of limits and barriers to technology development). There is a basic assumption that human endeavour will overcome all obstacles; that the technology development will eventually succeed. This assumption is valid as long as the technology being studied is within the domain of feasibility.

The technology development activity is initiated by a decision, external to the system, to start investing in the new technology. The next section of this paper deals with different strategies for taking that decision.

Closing the gap between current performance and the theoretical maximum requires a certain investment, which can be less or more than the available funds for that period. Investing in technology development does not simply result in proportional performance improvement, however. The effectiveness of investing funds in technology development is related to the current level of performance. Initially, when the performance is at its lowest (the performance gap is large), the impact of investment is the highest, as there is lots of potential for improvement. As the gap gets smaller, the impact of investment becomes lower, as the difficulty of the problems encountered increases (also see Table 1). Figure 2 shows the goal seeking archetype adapted for technology development.

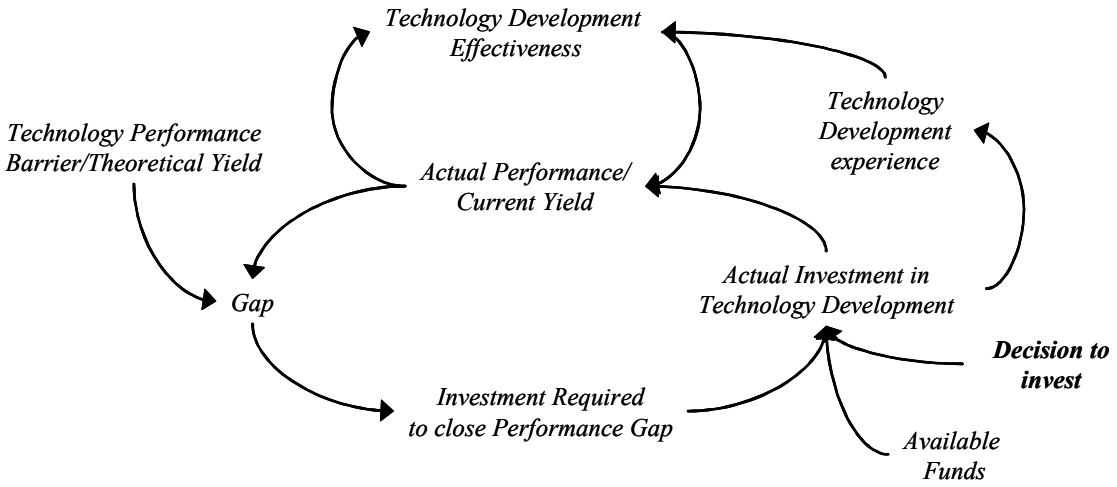


Figure 2: Goal seeking archetype adapted for technology development

Market development activity:
The market development activity seeks to create a pool of potential clients. It is based on the same generic gap model (Figure 1), adapted to reflect the characteristics of the market development activity.

Firstly, the market development activity is not triggered by an external decision, but by the model itself once the conditions are met. Market development requires the technology development activity to have established at least a certain level of technology performance before it can be initiated.

Secondly, while a company protects its own technology and each company must do its own technology development, the benefits of any market development activity are shared by all players in the industry.

Finally, the funding available for both technology development and market development comes from the same investment pool. It is therefore necessary to decide on a prioritization mechanism for investment. The prioritization mechanism selected for the model allocates funds to technology development first, then to market development, followed by the other activities, still to be described below. This allocation rule speeds up precursor activities in order to allow subsequent activities to start. As each precursor activity gets closer to its target, it requires fewer funds, leaving more funds available for the subsequent activity.

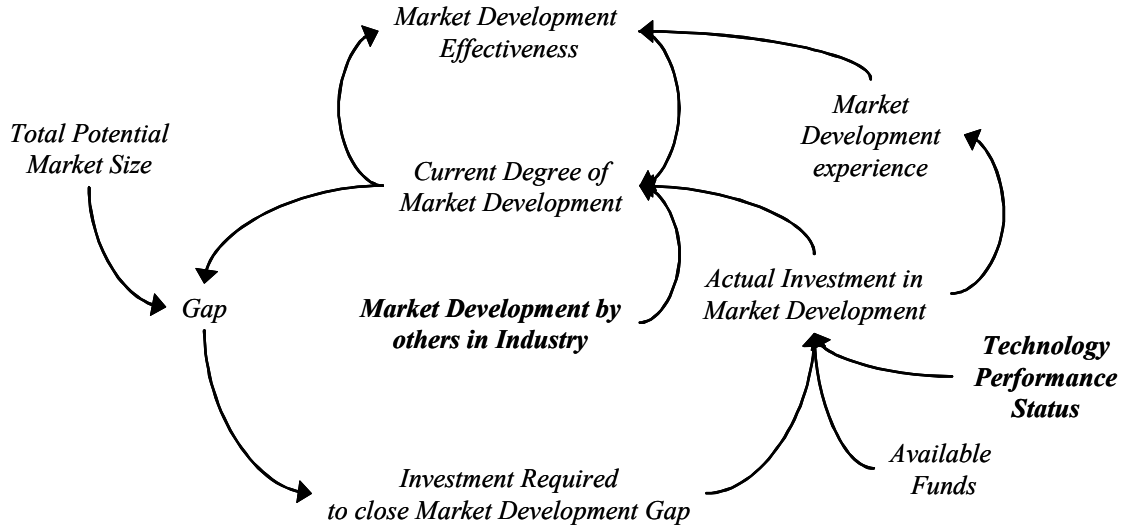


Figure 3: Goal seeking archetype adapted for market development

The effectiveness of investment in market development has been defined to follow a bell shaped curve. When the gap between the actual and ideal performance is large, the effectiveness of investment is low. This reflects the fact that initial market development is

harder than when some awareness of the product already exists, and includes risk aversion and competition with established technologies. Similarly, it becomes progressively harder to unlock the value in the last few, small and specialized market niches once the obvious application areas for the product have been developed.

The degree of success of the market development activity is indicated using an index. It is possible to visualize a maximum potential market for the product. The value of the index can be interpreted as the degree to which awareness of the product has penetrated into the potential market, or as the proportion of the potential market that has been successfully moved into the "potential customers" resource in the terminology used by Warren 2002.

The causal loop diagram for the market development activity is shown in Figure 3.

Marketing Activity:

The objective of the marketing activity is to position the company in the mind of the client, relative to its competitors. Positioning includes all the activities required to "develop potential customers into ***our*** customers" (Warren 2002), e.g. branding, pricing and quality. Together with the next activity, product development, marketing determines the share of first purchases secured by the company.

Similar to market development, which can only commence once technology development has resulted in a minimum technical performance, the marketing activity is initiated only once a certain level of market development has taken place. The marketing activity has a lower priority than market development, as actual sales can only commence once potential clients have been generated.

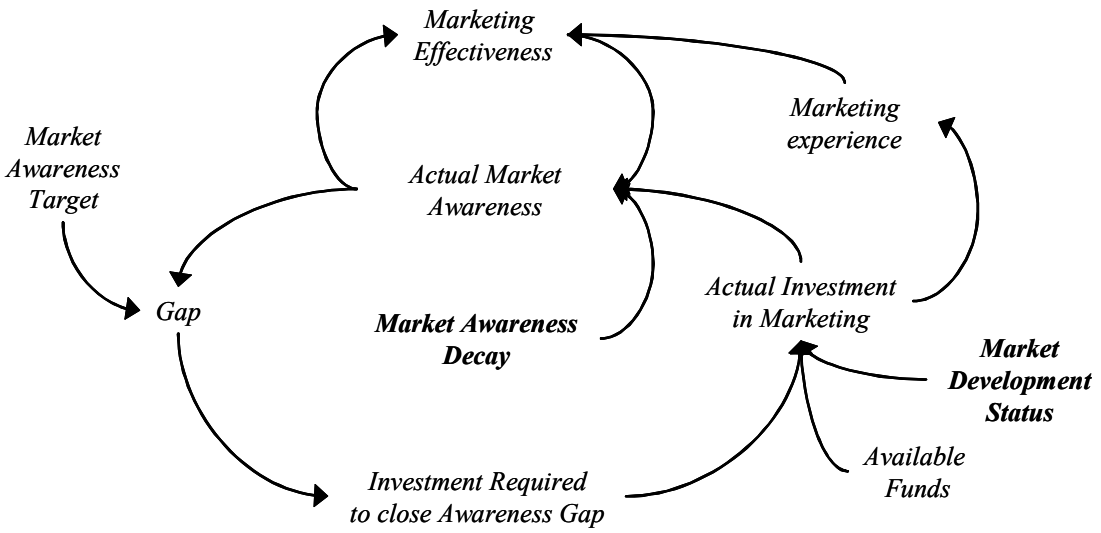


Figure 4: Goal seeking archetype adapted for Marketing

The effectiveness moderating function of marketing investment follows the same type of bell curve as that of market development (also see Table 1). The reasoning is similar. It is difficult to attract the initial clients; as the market becomes saturated, it also becomes more difficult to attract new clients than in the market expansion phase. A unique element of the marketing activity is that people soon forget a marketing campaign, resulting in decaying brand awareness over time. This increases the gap between the desired brand position and the actual position, requiring more investment to maintain the company's relative position. Marketing success therefore requires constant replenishment of investment to keep the company's brand in the forefront of awareness in the market place. Consequently, the impact of historical spending on marketing is assumed to be lower than for the other activities.

The causal loop diagram for the marketing activity is shown in Figure 4.

Product Development Activity:

The product development activity seeks to develop and improve product features and applications, thereby increasing the attractiveness of the product to first-time buyers, and consequently increasing the market share of the specific company.

Product development will only be initiated once a certain level of marketing has taken place. The priority of the product development activity is lower than that of any of the other activities.

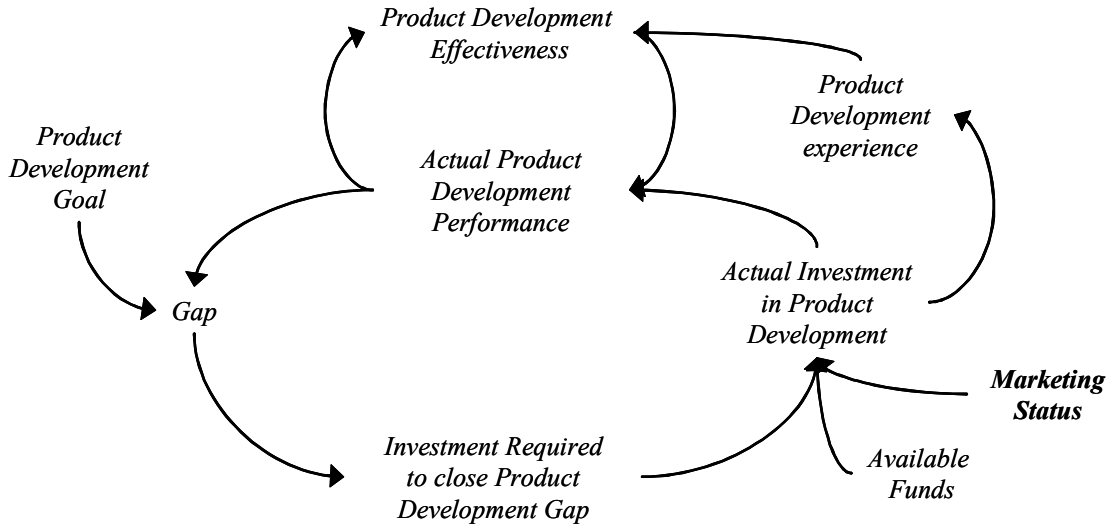


Figure 5: Goal seeking archetype adapted for product development

The effectiveness of funding once again follows a bell curve (see also Table 1). It costs more money to initiate the product proliferation process than to add additional features or applications once the process is rolling along (the effectiveness of a unit of spending is low when the product development performance is low, compared to when the gap has been

partially closed). Once a suite of features and applications have been developed, it becomes progressively harder to add additional benefit for the customer to the product. The causal loop diagram for product development is shown in Figure 5.

Closing the Loops:

Figure 6 shows the combination of the technology development and market development activities. Market development is linked to technology development through the requirement that technical performance must reach a certain level before market development can start. All four activities are linked together by their dependence on the same investment pool for funding. The causal loop diagram for the whole sequence of activities is an extension of Figure 6.

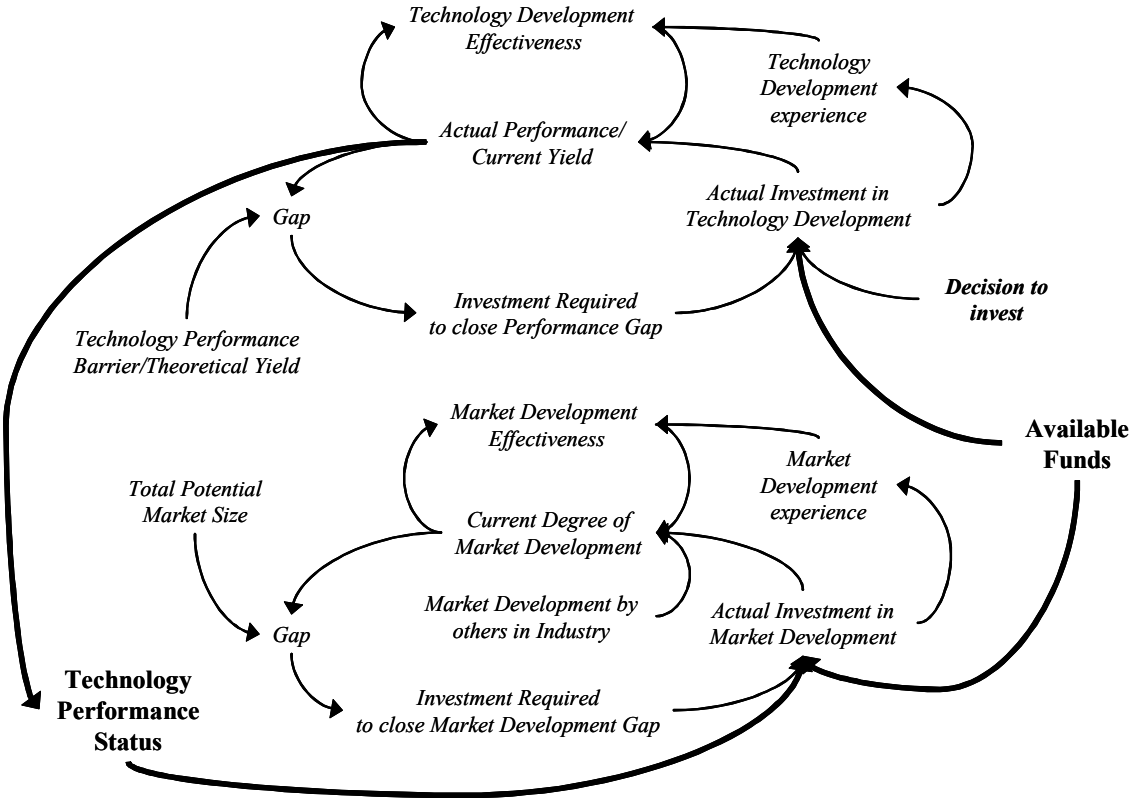
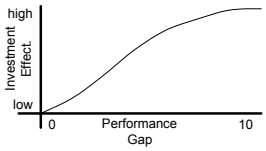
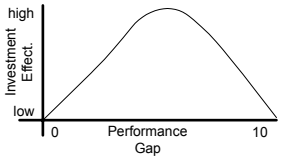
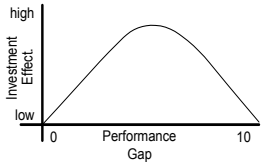
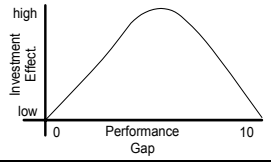


Figure 6: Integration of technology and market development segments

The total system loop is closed once the product reaches a saturation point that initiates the development of the next generation technology. Substitution of the technology of interest by a second generation of technology or substitute product has not been investigated for the purposes of this study; only one cycle of the technology life cycle is modelled here. Substitution has been modelled successfully in a separate study, however, and will be included in further work on this topic.

Summary:
The characteristics of the various activities are given in Table 1:

Table 1: Summary of key characteristics of each activity

Activity	Goal	Constraining Factor	Investment Effectiveness
Technology Development	Theoretical Limit - *Performance Value of 10*	Investment Pool, Shared between all Activities	
Market Development	Industry Establishment and General Awareness of Technology - *Index Value of 10*	Investment Pool, Shared between all Activities	
Marketing	Market Awareness of Specific Offering - *Index Value of 10*	Investment Pool, Shared between all Activities	
Product Development	Establish Enhanced Product Portfolio - *Index Value of 10*	Investment Pool, Shared between all Activities	

The model structure above is repeated for each of three role players: the leader, the player and the follower. Both technology developers (the leader and the player) contribute to market development, i.e. to establish a pool of potential customers. All three players compete with each other for capturing first sales from the same pool of potential customers.

The size of the investment made in each of the activities for each decision period depends on the following main factors:

- The strategy of the company – e.g. the leader and the player will invest in technology development, while a follower company would not (this is the main topic of the following sections);
- Whether the predecessor activities have reached their minimum threshold levels in order to trigger this activity;

- The size of the gap: the model will attempt to assign an amount of money to an activity up to twice the size of the gap (this is to allow a role player to invest more than apparently required in order to speed up development time);
- The priority of the activity when applying for funds to the investment pool. All four activities compete for funds from the same investment pool. Technology development is assumed to have first claim on the funds, followed by market development, marketing and product development, in that order. This is to enable the new technology to proceed through the necessary initiating activities as fast as possible.

In the case of follower companies, another condition comes into play: technology access. As a follower company is assumed not to develop its own proprietary technology, it has to obtain access to the technology by e.g. licensing it. This is modelled using a technology access delay parameter, expressed as the number of time units that have to elapse after the first leader company has started marketing (i.e. market development has passed the critical threshold) before the follower company can obtain a technology license. Consequently, a follower company can only start marketing once it has obtained a technology licence, which happens a specified time after the leader companies have created a market and started marketing (the market development threshold has been passed).

The role of price in attracting customers is not included in this model, as the objective was to study the timing of entry into new technologies. The first customers of new technologies are usually sophisticated early adopters (Day *et al* 2000; Utterback 1994; Kampas 2003) who are not price sensitive. For the new product to enter the Market expansion stage (§2 above), cost (and therefore price) of the product has to be low enough to ensure mass appeal, but this requirement applies to all the role players. The fast-growing market during the expansion stage allows room for many players; price as a differentiating factor between role players only becomes critical in the developed stage. In the model pricing is therefore treated as a marketing strategy and the associated costs included in the continued investment in marketing.

4.2 Running the model

In the simulation studies, time was assumed to start at the point when the probing and learning phase starts, i.e. time starts from the demonstration of a working prototype. Time is measured in arbitrary time units, say months. Sales, investment, etc are also measured in arbitrary units, as the intent is to study general principles. It would be possible to calibrate the model with actual data to study specific cases, under a few general assumptions regarding e.g. the shapes of the moderating functions.

Designate the company whose strategy is being investigated, the "player". The player is assumed to be a technology developing company. Designate the company that starts technology development as soon as the concept is proven the "lead competitor" or "leader".

For the current investigation, the three companies have been assumed to have investment pools of comparable size available to spend on the technology in question. Note that this does not imply that the companies are necessarily of the same size; a larger company may be involved in many technologies, spending only a fraction of its total development budget on a specific technology. For a smaller company, the technology may be its core business, requiring it to spend all its effort on the particular technology.

For each decision period, the model calculates

- the gaps between actual and desired performance levels of each of the activities for each of the role players;
- the investment by each role player in each of the activities, and
- the impacts of those investments on the performance levels of each role player.

The model then sets the flags indicating which activities have reached the critical levels permitting subsequent activities to take place. As output it tallies total sales, taking into account initial sales and repeat sales occurring after an average product life.

Repeat sales are assumed to commence two months after the first initial sales throughout, to simulate the situation where clients buy two months' worth of inventory at a time. It is assumed for simplicity that once an initial sale has been made, the client buys its repeat purchases from the same role player (i.e. the model only considers all customers to be "loyal customers" – see Warren 2002). As a result, the model realistically treats the early stages of an industry based on a new technology as a race to dominate the new market (Type 1 rivalry - Warren 2002).

All simulations are run for 240 months (20 years) in order to allow the dynamics to play out sufficiently.

4.3 Validation runs

The main object of study of the model is the pace at which the industry around a new technology evolves to the Developed stage (§2 above), and the levers that can be used by role players to position themselves in that new industry. In the validation runs, the parameter values or functional shapes of input variables that represent constraints on the system were varied to test whether the model reproduced the expected behaviour. Some examples of behaviours that the model was expected to reproduce are described below:

- Constraining investment will slow down technology development, while increased spending or prior investment will speed up technology development.
- All subsequent activities require that technology performance crosses a minimum threshold first; consequently, decreasing or increasing the rate of technology development (e.g. by decreasing or increasing investment, adding prior investment or

changing the effectiveness of the investment by changing the impact functions) will slow down or bring forward the onset of subsequent activities.

- Market development also requires significant investment, resulting in an appreciable delay before marketing commences. Consequently, if funding is insufficient, market development may be triggered, but never reach the limit required to trigger the marketing activity. When funds are constrained, potential customers may therefore never be converted to actual sales and the technology does not take off in the marketplace.
- As the follower does not have to spend money on technology development or market development, it can outspend the technology developer companies on marketing and product development as soon as the market is developed and it can get access to technology. Under favourable circumstances (successful market development by the other players and sufficiently early access to the technology) the follower can therefore capture the entire market before the technology developers are "ready".

All the above effects were observed in validation runs. Figures 7 and 8 show the performance levels of the main activities (technology development, market development, marketing and product development) over time for two fairly extreme cases. For Figure 7 the investment pool for each role player was set at 5 units per time period (representing a constrained situation where only the follower reaches the threshold required for product development), while Figure 8 shows the results when the investment pool was set at 30 units per time period for each role player (representing an essentially unconstrained situation). In the latter case, the activities follow each other in rapid succession and the market is saturated in a short period of time. The base case for the simulation runs below assumed an investment pool of 10 units per time period for each role player.

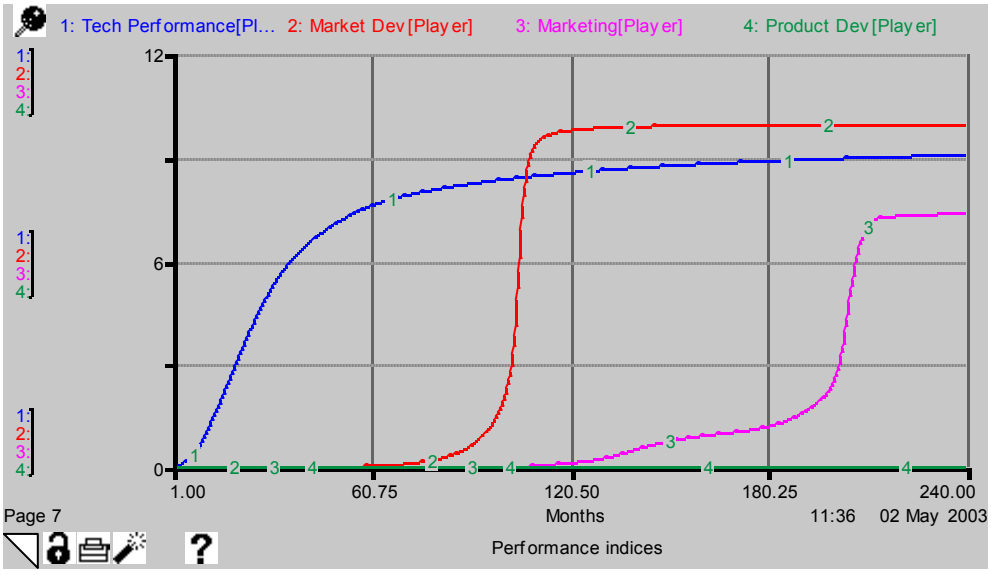


Figure 7: Validation runs for constrained case – onset of activities delayed

Also note in Figure 8 that technology performance approaches the theoretical limit asymptotically, and that the marketing gap is never completely closed because of the assumed decay in market awareness.

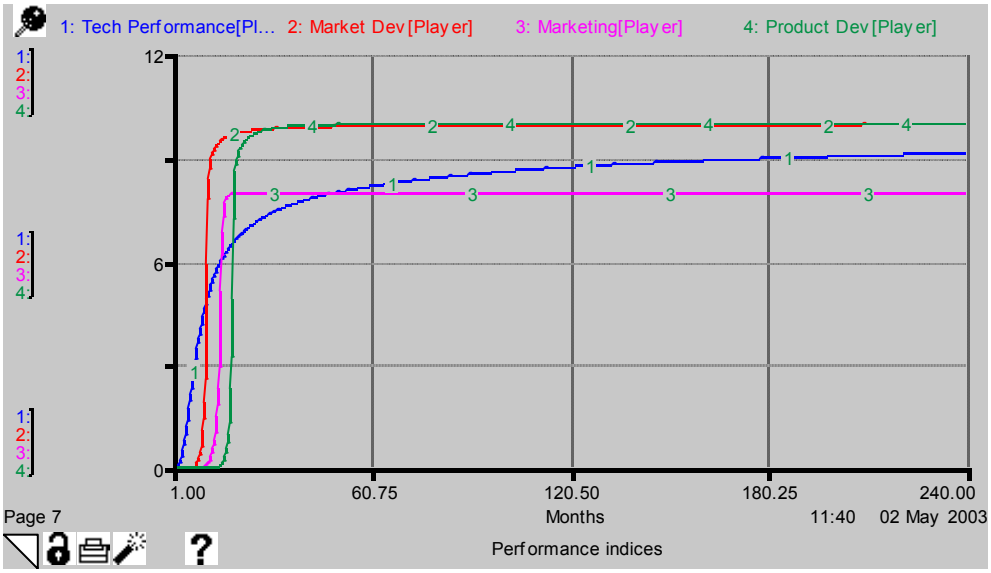


Figure 8: Validation runs for unconstrained case – activities accelerated

Similarly, when the effectiveness of investment on the different activities was varied by changing the shapes of the impact functions (e.g. by multiplying them with different constants), the rate at which the different activities proceeded also changed as expected.

5 RESULTS

5.1 Base case:

In the base case, all three role players are assumed to start with the same investment pool, and take the decision to get involved in the new technology when the simulation starts. Both the leader and the player start development immediately, and are indistinguishable for the duration of the simulation. The technology access delay for the follower was set at 18 months, so that the follower could only obtain a license and start marketing 18 months after the two technology developers had each developed their own technology, have jointly developed a market and have started marketing.

Figures 9 and 10 show how the technology landscape unfolds (Figure 9 shows the investment patterns and Figure 10 the resulting market penetration and sales). The technology reaches the set performance threshold after 10 months and both lead companies start market development. The market is sufficiently developed that both lead companies can start marketing by month 31. The follower company can only start marketing in month

49. Sales for the two lead companies start coming in from month 54 and ramps up to the eventual level quickly. Sales for the follower starts only 3 months after sales for the leader companies, but takes slightly longer to ramp up.

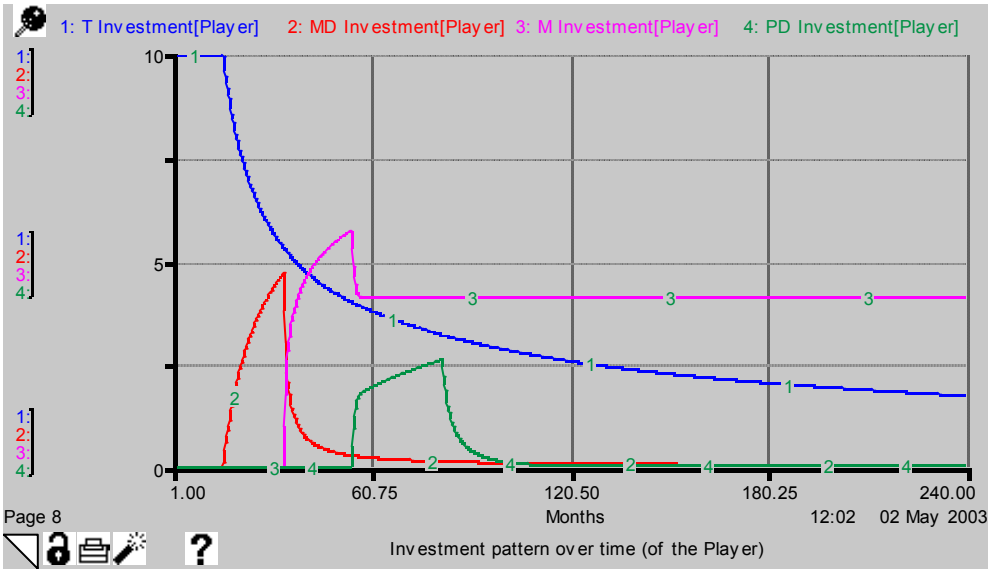


Figure 9: Investment pattern of the player over time

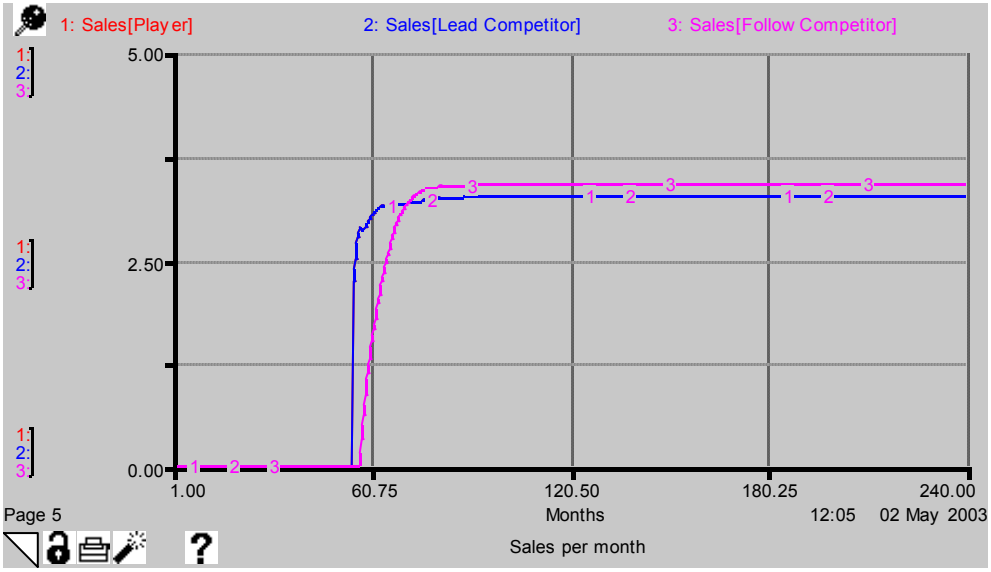


Figure 10: Sales per month of each competitor in base case – equal market shares

At the end of the base case simulation, after 240 months, all three companies end up with approximately equal shares of the monthly and total sales.

The follower has a cost advantage, however: under the assumption that all three role players have the same investment pool available, the follower manages to catch up to the leader companies in terms of sales 6 years into the simulation, while investing less than half the amount they had to invest. This is because the follower gets the benefit of the technology and market development, while only having to invest in marketing and product development himself. Of course, the price of the technology license would also have to be figured into this equation; this highlights the importance of not providing technology to follower companies too cheaply or too easily (i.e. the importance of protecting technology through patents and/or trade secrets).

5.2 Strategies for the "player":

The early stages of an industry based on a new technology carry considerable risk: the technology may never work or it may not take off in the market place. The player has to trade off the risks of perhaps investing too early in the new technology against the risks of waiting too long and being excluded from the market.

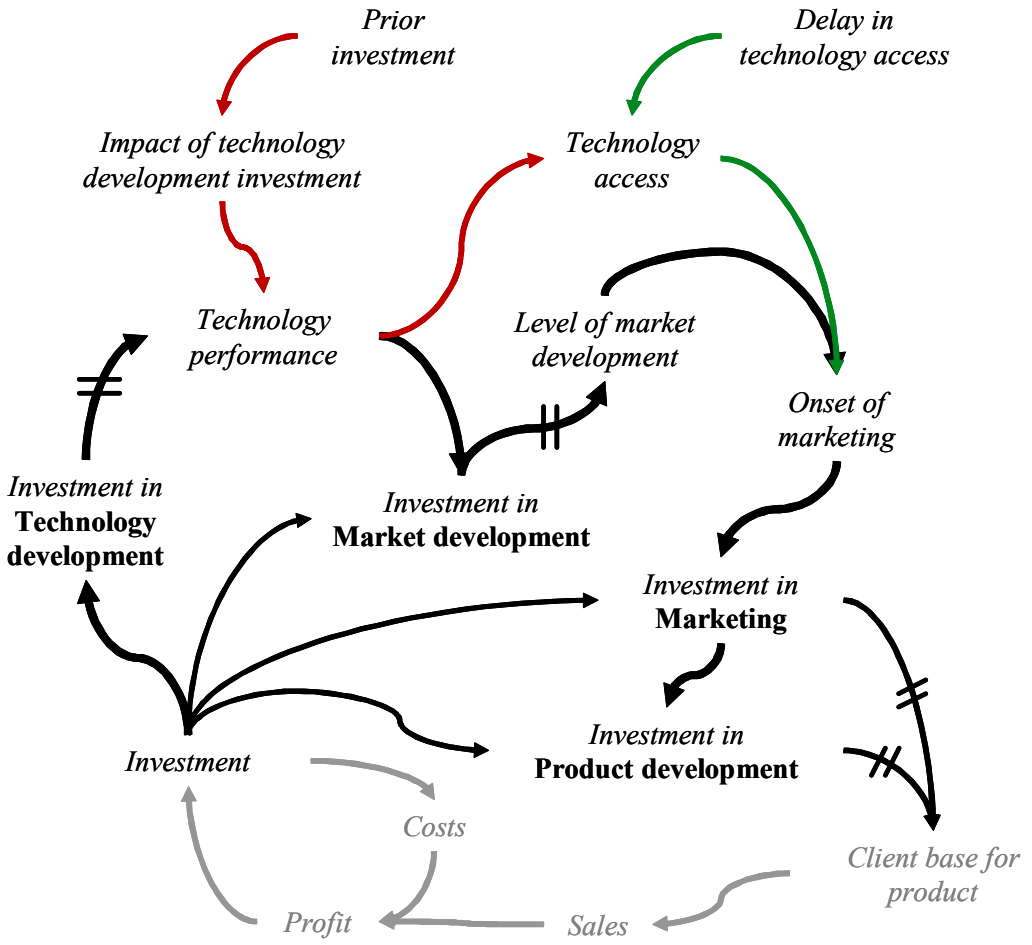


Figure 11: High level logic of the situation

Figure 11 shows the high-level logic of the situation for a single player, with the typical route taken a by technology developer shown by the heavy black arrows. If the player decides to wait before investing, he has to have a strategy to reduce some of the time delays shown in Figure 11 in order to catch up to or pass the other players before they capture the entire market. Some of these options are shown by the red arrows in Figure 11; if the player can initially delay investment but can manage to catch up to the leader while the leader is developing the market, for example, the player may perhaps start marketing after minimal time spent on market development.

A series of simulation runs were done assuming that the leader follows the route indicated by the heavy arrows in Figure 11, and varying the strategy of the player. Arbitrary units were used, as in the base case, in order to test general concepts. It would of course be possible to test different strategies in a real life situation by calibrating the model to the specific characteristics of the technology, competitors and industry in question. A summary of the simulation results appears in Table 2 and Figure 12:

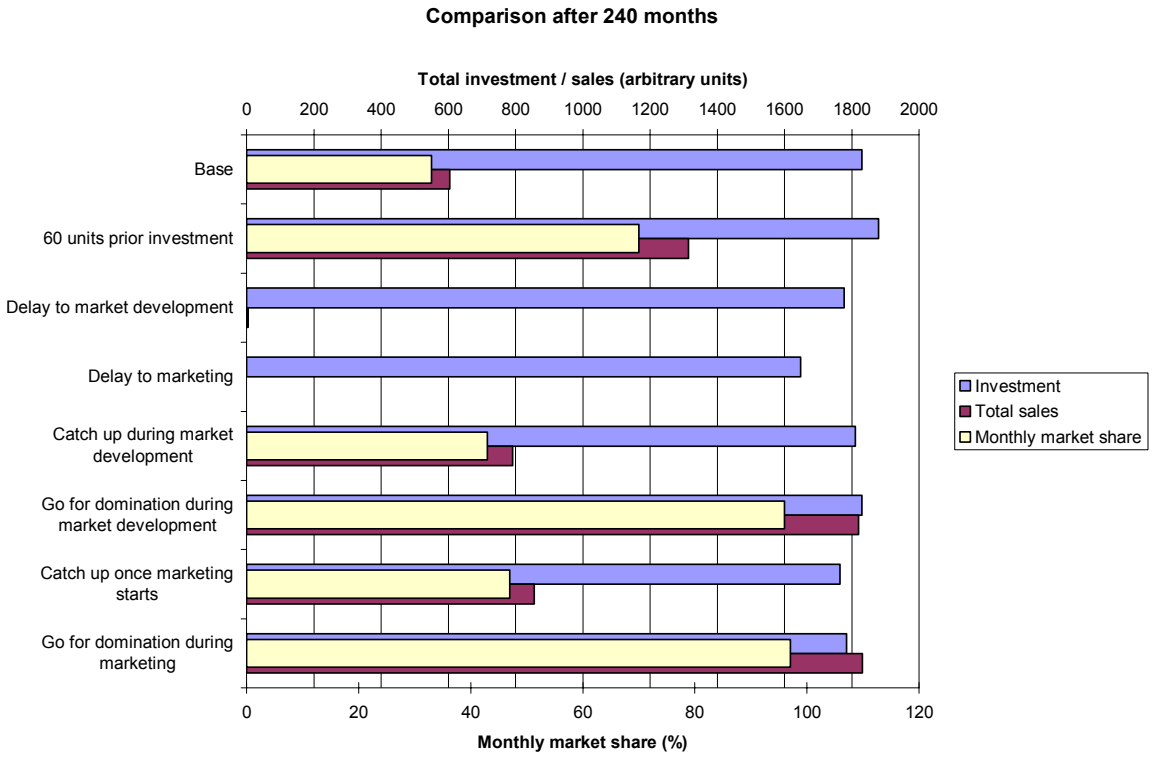


Figure 12: Comparison of strategies for the player

It is clear that, with more or less comparable outlay in terms of total investment, the outcome for the player can differ considerably depending on the strategy followed. If the player just starts investing at a later stage without any effort to catch up to the other players, it never makes any significant sales, as could be anticipated.

Table 2: Results of simulation runs demonstrating strategies for the player

Case	Monthly investment pool *(player, leader, follower)*	Prior invest= ment *(player)*	Techno= logy access delay *(follower)*	Start of investment *(player)*	Total sales *(player)*	Total investment *(player)*	Market share of monthly sales *(player)*	Outcome
Base	10; 10; 10	0	18	Matching leader from the start	604	1830	33%	All players equal market share
Prior investment	10; 10; 10	60	18	Matching leader from the start	1314	1879	70%	Player "wins"
Delay to market development	10; 10; 10	0	18	When leader starts market development	5	1777	0%	Leader wins
Delay to marketing	10; 10; 10	0	18	When leader starts marketing	1,5	1648	0%	Leader wins
Catch up during market development	11,15; 10; 10 12; 10; 10	0 0	18 18	When leader starts market development	791 1820	1811 1830	43% 96%	Player passes leader Player dominates
Catch up once marketing starts	16,8; 10; 10 20; 10; 10	0 0	18 18	When leader starts marketing	855 1831	1765 1784	47% 97%	Player passes leader Player dominates

A moderate prior investment (e.g. by investing in capacity building projects or by capitalizing on prior transferable experience in other related technologies) gives a significant advantage, in that a prior investment of around 60 units (i.e. the size of the investment pool for 6 months) is enough to give the player a market share of about 70%. With the parameters and impact functions used, higher prior investment did not impart any additional advantage, however.

In Figure 13, strategies to start investing later all require increased investment by the player, at least for a period. The later the player starts investing, the higher the peak investment rate is. The more constraining the player's investment pool is, the longer investment remains at the maximum level.

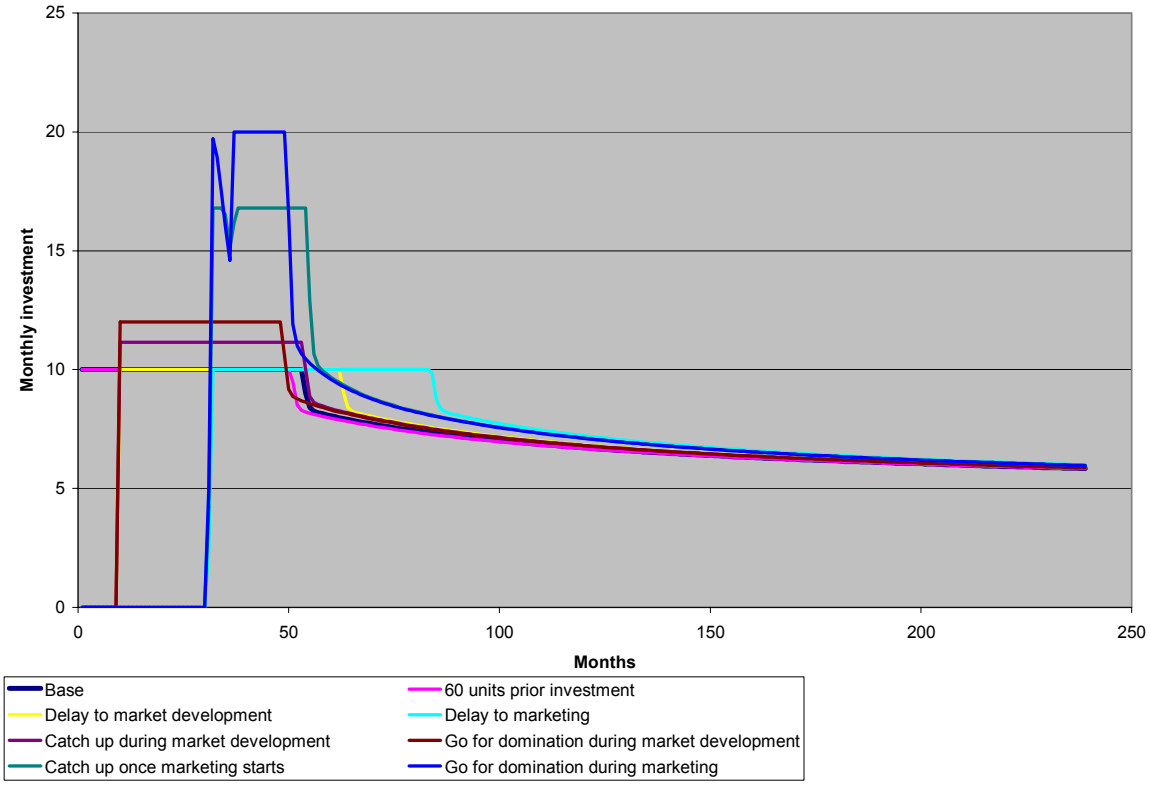


Figure 13: Investment profile over time of the player following different strategies

The player's ability to catch up by "throwing money at the problem" may in reality depend on practical considerations. The ability to perform high throughput research or run many aspects of the development programme in parallel would be a prerequisite for the player to successfully follow this strategy. It should also be possible for the player to sufficiently differentiate his technology from that of the leader in order to secure freedom to operate

from an intellectual property point of view. In addition, with the parameters and function shapes used in these runs, it was possible for the leader to develop the market almost on its own. If this was not the case and the minimum market development could not be reached for marketing to start without the participation of the player, the whole industry would fail to take off if the player delayed investment too much.

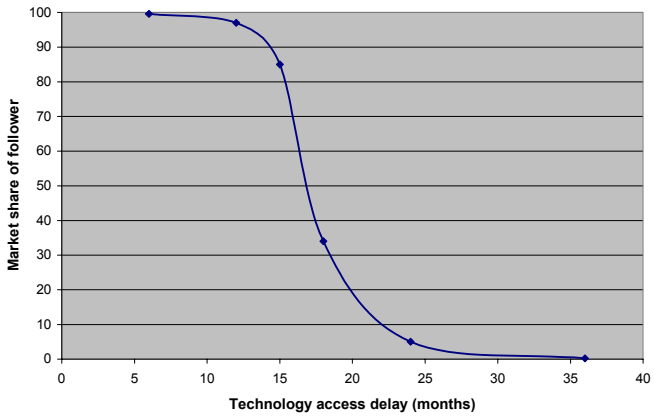
On the basis of these generic simulation runs, it would appear that a strategy of waiting until the leader has crossed the technology hurdle and has started marketing before starting to invest in its own technology development, and then accelerating development by increasing the investment pool temporarily, can provide good economic return for the player while balancing the different kinds of risks to some extent. Although waiting even later can also result in commercial success, additional risks come into play. While prior investment that can be applied in the present case is an advantage to a company, it does not guarantee dominance in the new industry.

5.3 Strategies for the follower

The base case clearly demonstrates the advantages of the follower: it sells almost the same total number of units and has a similar market share than the two leader companies, at less than half the total investment cost.

The follower can only start marketing once the other role players have sufficiently developed the market and once it has acquired access to the technology. The follower's options are shown by the green arrows in Figure 11. As suggested in the discussion of the validation runs, the critical issue for the follower is therefore to get technology access at the earliest possible time.

Figure 14 shows the results of varying the technology access delay (time that has to elapse after the first technology developer starts marketing before the follower can get a technology license):



It shows clearly that the follower company can completely exclude any technology developing company from the market, if it can get technology access in less than roughly 15 months. Note that the follower company cannot start marketing before the leader companies have developed the technology and the market; i.e. the leader companies have to do the hard

Figure 14: Effect of technology access delay on follower's market share

development work and investment only to be wiped out in the market place by the follower. This result highlights the importance of intellectual property management for technology developing companies.

If the follower company takes longer than 18 months to get access to the technology, it has no chance of gaining significant market share.

Say the follower manages to get technology access in 6 months after the leader companies start marketing. Is there a strategy whereby the player can fend off the follower? Figure 15 shows the investment profile required for the player to (a) catch up exactly with the follower and (b) dominate the follower in this case:

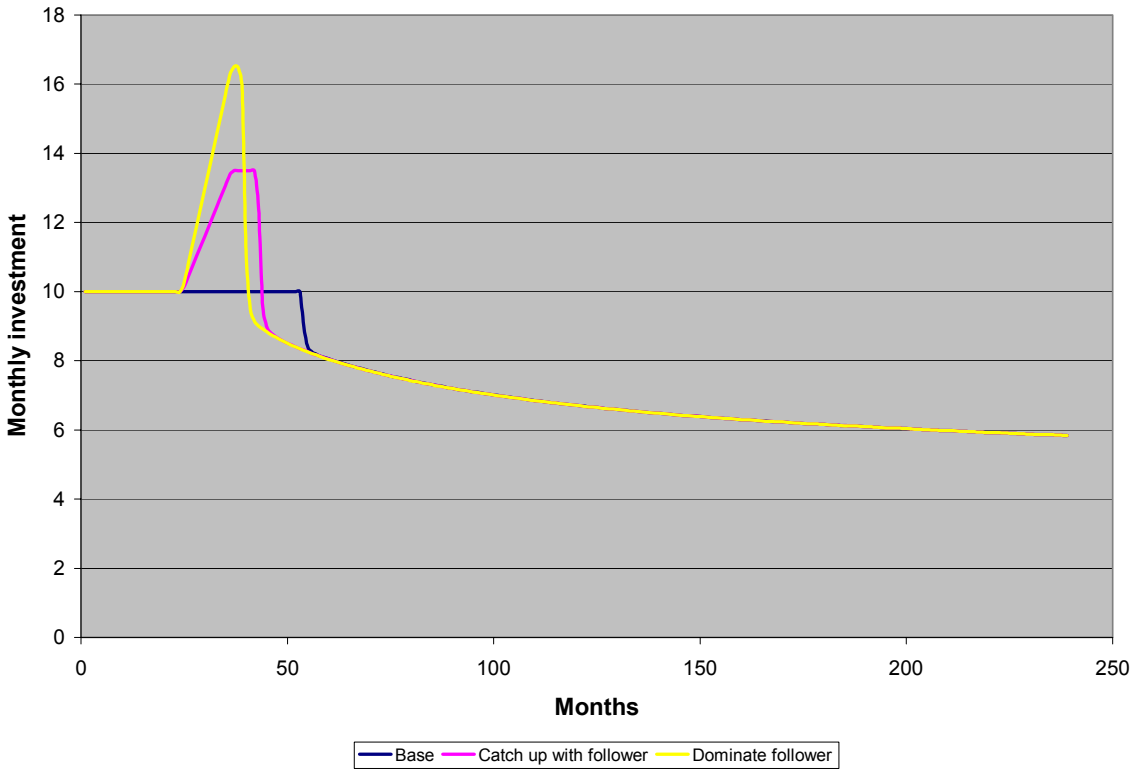


Figure 15: Investment profile required to catch up if the follower gets technology access 6 months after the technology developers start marketing

In case (a) the player and the follower each gets 50% of the total market share. The player sells 953 units in total, at a total investment cost of 1861 units. In case (b) the player achieves 96% of the market share, selling 1917 units, at a total investment cost of 1873 units. As discussed in §5.2 above, it becomes a question of whether the player is practically able to accelerate development as much as required by case (b). These

outcomes are fairly similar to the ones described in Table 2. Unlike in §5.2, the market is already developed in this case.

6 CONCLUSION

The above generic simulation runs served to deepen our understanding of the issues around the timing of entry into a new technology field. The importance of restricting technology access of follower companies was highlighted. It was shown that in principle it is possible for a technology development company to delay investment in a new technology until the leader in the new field has crossed certain hurdles, as long as the player company is willing and able to invest more than the leader for a period of time, and some practical constraints are taken into account. It would appear from the results that the best balance between different types of risk is achieved by waiting at least until the leader starts market development, but to start investing possibly before the leader enters the marketing stage.

A myriad of additional options and extensions of the model could be studied. Possible future extensions include adding the transition to a second generation or substitute of the technology, as well as adding a more comprehensive treatment of competition between players to the model (e.g. Type 2 rivalry – tug of war to make established customers switch, and Type 3 rivalry – fighting for share of business to non-exclusive customers (Warren 2002), both appropriate to more mature industries). This was not done in the current version, as explained in §4.1 above, as the focus was primarily on the early stages of the life cycle, where competition for customers is not a key factor. The model could also be extended by including industry specific structures with appropriate calibration.

Additional applications of the model would include testing a range of further strategic options, e.g. by exploring the use of technology alliances for joint technology development, extending the follower category to specifically study strategies for "aftermarket suppliers", etc.

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Back to the Top