A System Dynamics Investigation of Sustainable Growth in the Biotechnology Industry

by

Rajesh A. Anandan

Submitted to the Department of Electrical Engineering and Computer Science
in Partial Fulfillment of the Requirements for the Degree of
Master of Engineering in Electrical Engineering and Computer Science
at the Massachusetts Institute of Technology

May 27, 1996

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May 27, 1996

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ABSTRACT

Most new companies are faced with the dual hurdle of developing their capabilities while dealing with the financial constraints of not having an established revenue stream. This is especially true in the Biotechnology industry, where technological competence in research is a key success factor, but the benefits of this research are often not realized for over a decade. This study uses a system dynamics framework to investigate viable growth strategies for a young biotechnology research company in terms of the expansion of both its technology platform, as well as its proprietary programs.

Thesis Supervisor: James H. Hines
Title: Visiting Associate Professor of Management

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1. Introduction

The basis for this investigation was a system dynamics study of a leading drug discovery company conducted by Rajesh Anandan, Martin Groβmann, and Kevin Agatstein. The company shall remain anonymous in order to preserve the confidentiality under which the original study was conducted.

The said company has been able to develop competencies in very focused areas of the pre-clinical research pipeline. Because of its expertise in these areas, it has been able to embark on collaborative projects with several large pharmaceutical firms. As the company looks ahead, it is faced with critical decisions in terms of investment into the expansion of its technology platform and into its proprietary programs. These investments are expected to significantly increase the company's future revenues. However, the benefits will not be realized for several years, and the company will be forced to rely on outside resources to fund its activities. This uncertainty of access to capital, coupled with the intensely competitive and extremely risky nature of the industry, make it vital for the company to formulate a robust strategy to manage its growth.

Numerous Biotechnology companies have failed in recent years after having experienced an initial period of success. Many firms are presently in a position that is very similar to that of the company. The findings of this investigation will be of interest not only to the company and others like it in the Biotechnology industry, but also to companies in any technology driven industry where there is a significant delay between research investments and the corresponding returns.

The purpose of this study is to investigate possible growth strategies for the said company in terms of both its technology platform as well as its proprietary programs. A system dynamics model was built in order to logically explore the relationships between the company's growth strategy and several hypothesized outcomes. The rest of this

section provides background information on the company and industry, and presents the hypotheses which were explored. Section 2. explains the methods used, and provides a description of the model, Section 3. presents the results obtained by simulating the model, Section 4. contains a discussion of these results, and Section 5. presents the conclusions drawn from this investigation. The Appendix contains a complete listing of the equations used in the model.

1.1. Background

The Industry

The pharmaceutical/biotechnology industry is seeing the emergence of an increasingly popular trend in drug development. The strategy is to combine the discovery efforts of small research focused companies with the drug development, manufacturing, and marketing resources of large corporations (Thayer, 1995). The old paradigm in which small companies aspired to be fully integrated pharmaceutical companies is being replaced by one where most companies are satisfied with being specialized discovery organizations. This approach allows the companies to focus and develop their technology platforms, which can then be used to attract collaborators. Company executives agree that it is a viable strategy, but believe that its success depends on "having a broad enabling technology base, building a range of different programs using that technology to lower risk, and effectively partnering those programs" (Thayer, 1995). However, while the breadth of technology can be a strength, it can also be a weakness, since a company with a broader technology base will require more resources to maintain its platform. After the last downturn in biotechnology stocks, small specialty companies have been finding it increasingly difficult to raise capital (Thayer, 1995). Thus, as companies attempt to expand their technology platforms, resource constraints can lead to a trade-off between the breadth and depth of the technology base. Moreover, companies that attempt to pursue the development of costly proprietary programs while broadening their technology

platform will be even more severely affected by these resource constraints. In either case, the resulting diminishing of technological competency could potentially weaken a company's competitive and financial positions, which may then lead to consolidation, acquisition, or even failure.

Drug Discovery

The drug discovery process is the first stage in the Research and Development (R&D) pipeline of the pharmaceutical/biotechnology industry[1]. Traditionally, the discovery of pharmaceutical drugs involved the random testing of thousands of chemical compounds in drug screens. These tests or "assays" usually employed single proteins, such as receptors, as targets for discovery of drug candidates. These initial screens enabled the identification of lead compounds or "hits", which are those compounds that bind to the target protein and either inhibit or stimulate its activity. Medicinal chemists then optimized these hits to improve potency and specificity. These traditional trial and error approaches to drug discovery not only have a low success rate, but are also extremely time consuming (Groβmann, 1995).

The new discovery technologies have been designed to solve many of the limitations associated with conventional drug discovery. The company's technology platform consists of live-cell assays ("assay development"), and high throughput robotic screening ("screening"), and it is considering expanding this platform to include high speed combinatorial chemistry analoging ("analoging").

Assay development - live-cell screens utilize live cells that express proteins believed to be associated with a particular disease. The company believes that using live-cell assay screens increases the probability of finding promising lead compounds, allows for the definition of a lead compound's key properties earlier in the development process, and

[1] The other stages through which a project must progress before it is launched into the market are pre-clinical testing, phase I clinical trials, phase II clinical trials, phase III clinical trials, and FDA filing (OTA, 1993).

thus, enables the generation of higher quality leads that are more likely to progress through preclinical studies.

Screening - High throughput screening is the practice of rapidly testing hundreds of thousands of test compounds against a target protein. The company believes that as efforts to map and sequence the human genome result in the identification of increasing numbers of target genes, facilitating the development of live-cell assays; and as technologies such as combinatorial chemistry generate millions of new compounds; high throughput screening will be a crucial capability in the discovery process.

Analoging - once a lead compound is obtained, the pharmaceutical properties of that compound must be optimized before clinical development begins. Traditional lead optimization requires medicinal chemists to synthesize new analogs, which is a very slow process. Combinatorial chemistry enables the rapid production of hundreds of chemical analogs.

The Company

The company is a leader in drug discovery technologies. It has been able to develop competencies in live-cell assay development and high throughput robotic screening, which it has been utilizing to discover novel, small molecule pharmaceuticals. The company's discovery efforts have been focused mainly on collaborative programs with large pharmaceutical companies, and to a much lesser extent on its proprietary programs.

Collaborations - the company agrees to perform the assay development, screening (and analoging; if the company is able to achieve a level of competency that is attractive to collaborators) phases of the discovery process, and in return, the collaborator reimburses the company for any costs incurred, and pays some fraction of drug revenues (royalties) if the project is successful. This fraction (or the "terms of collaboration") depends on how much of the discovery process is to be done by the company. By investing in analoging and having a broader technology platform, the company hopes to be able to command better terms of collaboration, which eventually will lead to higher royalties.

Proprietary Programs - the company finances these projects until a late stage in the development pipeline. If a project is successful through to this point, the company then finds a collaborator to undertake further development and marketing. Should the collaborator be successful in getting the drug to market, the company receives some fraction of drug revenues as royalties. These royalties are much higher than for "collaborations", and thus the company has much to gain by investing in proprietary programs.

1.2. Hypotheses

The company has several expectations for it's future. The reference modes in Figure 1. show the company's expectations, as well as its fears, in terms of the factors most important to the company.

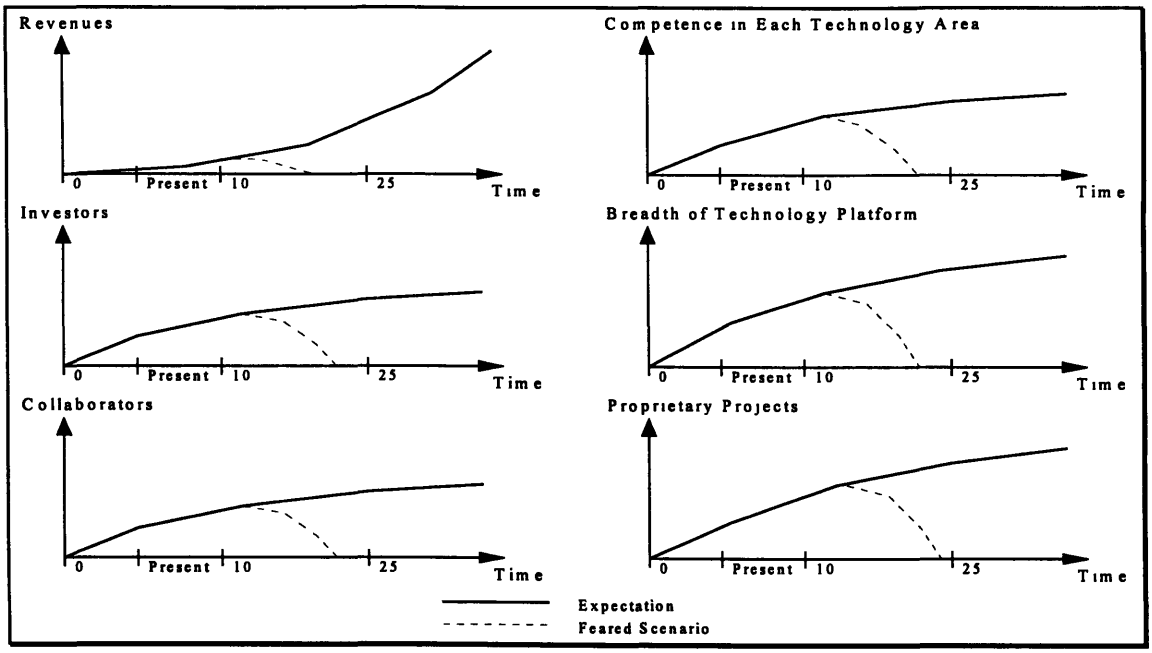
Expectation

The company hopes to gradually expand it's technology platform, allowing it to secure increasingly favorable conditions for collaborations. This makes the company more attractive for investment, which provides a source of financial resources that the company can use to:

- further its competence in the existing technology areas
- expand its technology platform to new areas
- finance its own proprietary drug discovery programs.

Eventually, the company's collaborators' drugs will get to the market and begin to generate revenues, some fraction of which will go to the company. Also, the company's own projects will be successful in identifying promising drug candidates. The company is then able to find collaborators to take these candidates to market, which will provide an additional source of significant revenues. These revenues will allow the company to

FIGURE 1. THE COMPANY'S FUTURE



further expand its technology platform and to maintain its competence in these various areas, thus ensuring continued collaborations, further investments into proprietary projects, and an ever-growing revenue stream.

An Alternative Scenario

The above scenario, while ideal, is but one of several plausible outcomes. Another scenario, one which the company would prefer to avoid, is the following. As the company attempts to grow its technology platform and fund it's proprietary projects, it is unable to devote the resources necessary to stay ahead of its competitors and collaborators in its existing areas of competence. This will result in the loss of collaborations, and consequently, the loss of investments. If the company's collaborative/proprietary projects have not had time to get a drug to market, or if its initial drugs have not been successful, these investments will be its sole source of financial resources, and thus, the company will be unable to finance any further activities.

I have addressed the above scenarios by logically exploring the following hypotheses:

- Growth and Success
- Demise by attempting to sustain too broad a technology platform
- Demise by investing too heavily in proprietary projects

I have represented the above hypotheses in the form of several causal-loop diagrams. These causal loops were developed using the understanding of the environment gained by working with the company's management.

Hypothesis 1: Growth and Success

The Growth and Success hypothesis is represented in the causal loop diagram shown in Figure 2[2]. The highlighted links define the loops that correspond to the hypothesis. These loops are described below:

Competency Growth Loop - The company invests its financial resources in the existing area/s of technology, leading to increased competence in these areas. This results in more collaborations which make the company more attractive for investment, which in turn increases the financial resources available to the company and allow it to further develop its competencies.

Technology Platform Growth Loop - The company invests its resources into new areas of technology, thereby broadening its technology platform. As a result, it is able to secure better contract terms with collaborators. This raises future revenue expectations and attracts more investment, which in turn increases the financial resources available to the company.

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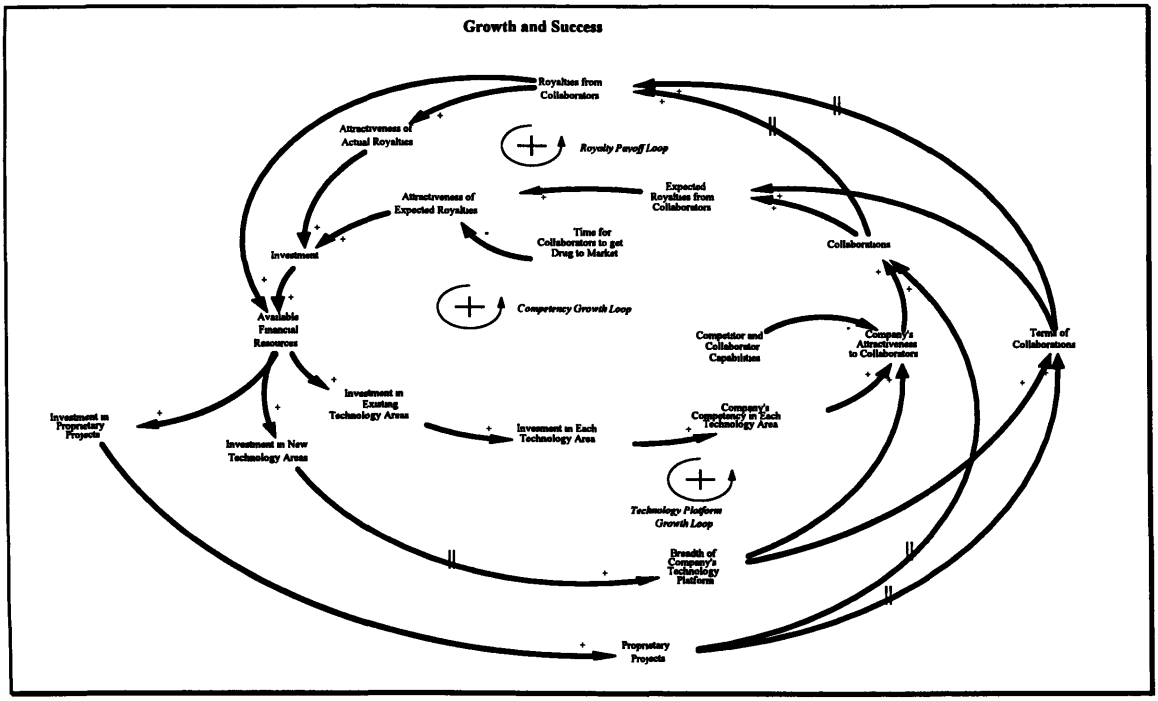
[2] A causal loop diagram is a means of organizing information and showing how different variables affect one another. A "causal effect" is represented by an arrow. An arrow can have a positive (+) or negative (-) polarity. A positive link means that the variable at the head of the arrow will move in the same direction as the variable at the tail, while a negative link means that the variable at the head of the arrow will move in the opposite direction of the variable at the tail. A double slash over a link (||) means that there is a significant time delay before a change in the variable at the tail of the arrow affects the variable at the head. A large positive sign in the middle of a loop indicates a positive feedback loop (or re-enforcing loop) that amplifies change, while a large negative sign in the middle of a loop indicates a negative feedback loop (or balancing loop) that seeks equilibrium.

FIGURE 2. GROWTH AND SUCCESS

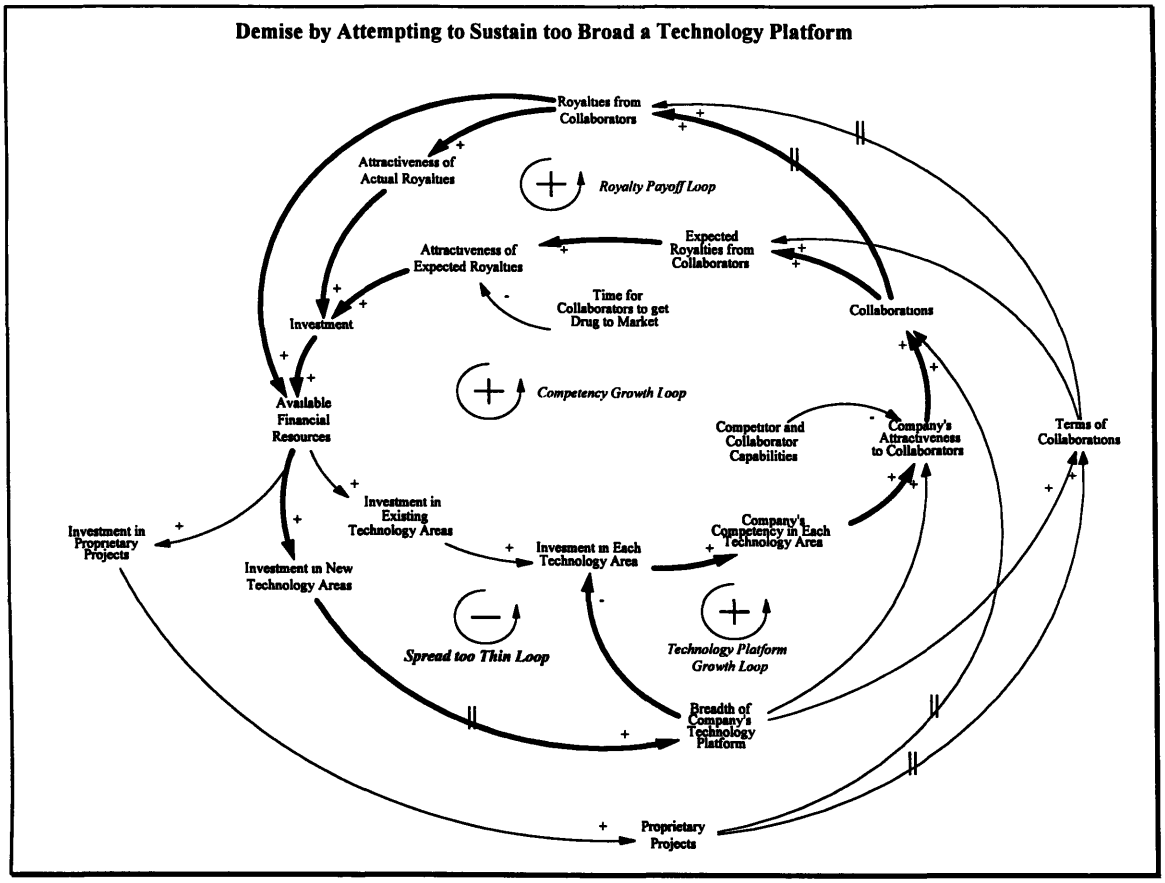


Royalty Payoff Loop - Eventually, the collaborators get the drugs to market which generates a revenue stream for the company. This effect is considerably delayed, due to the long time period needed for drug development. In addition, The company's proprietary projects are successful in identifying promising drug candidates and in taking these compounds through the early development stages. The company is then able to secure collaborations to take these projects to market, which then results in a significant revenue stream. This is also a substantially delayed effect.

Hypothesis 2: Demise by attempting to sustain too broad a technology platform

Another possible scenario is represented in the causal loop diagram in Figure 3. *Spread too Thin Loop* - The company invests in new technology areas in order to broaden its technology platform. This depletes the pool of resources available for investment into its existing areas of competence. In addition, a broader platform, once achieved, results in the company having to spread its resources over several areas, which makes it increasingly difficult for the company to maintain its competency in any given area. This

FIGURE 3. DEMISE BY ATTEMPTING TO SUSTAIN TOO BROAD A TECHNOLOGY PLATFORM

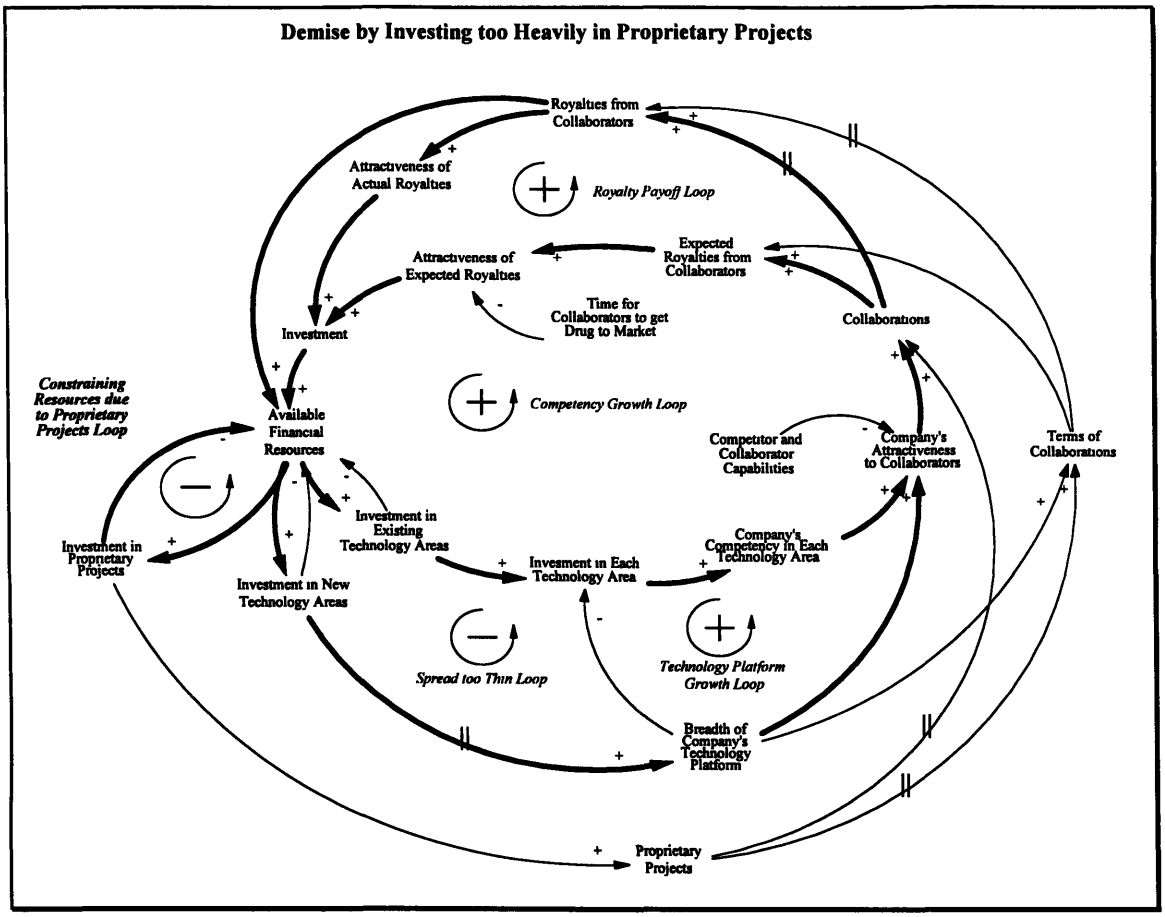


allows competitors and collaborators to "catch up" with respect to these technologies. The end result is that the company loses its collaborations, which eventually leads to the loss of investment in the company. When this happens, if the company's collaborative / proprietary projects have not had time to get a drug to market, or if its initial drugs have not been successful, the company will be unable to continue its activities.

Hypothesis 3: Demise by investing too heavily in proprietary projects

Another possible outcome is represented in the causal loop diagram in Figure 4. *Constraining Resources Due to Proprietary Projects Loop* - The company invests heavily in its proprietary projects, depleting the resources available for investment into new and existing technology areas. Thus, the company finds it difficult to expand or even maintain its competencies, leading to a similar outcome as described in the previous scenario.

FIGURE 4. DEMISE BY INVESTING TOO HEAVILY IN PROPRIETARY PROJECTS



2. Methods

Most strategic decisions are made by managers based on their professional knowledge and experience organized as informal, qualitative, "mental models". These models can sometimes be very sophisticated and insightful. However, they become increasingly deficient as problem-complexity grows and rapid changes in the environment occur (Weil, 1990). An alternative is to build a formal model.

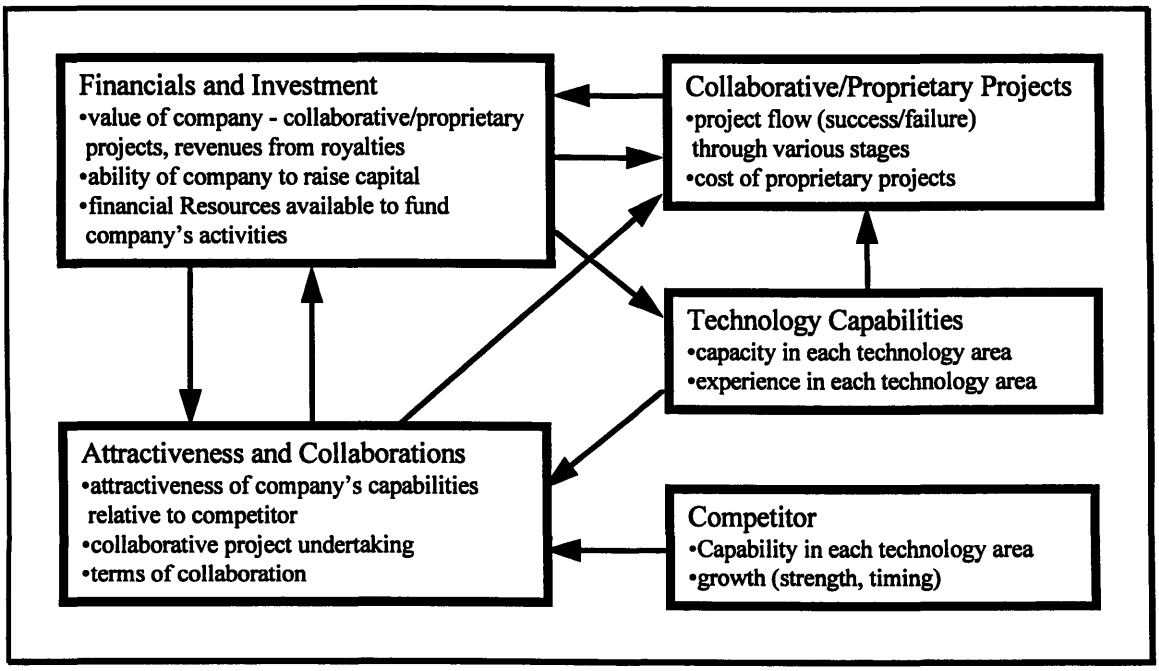
In order to explore the logic of the stated hypotheses, and to better understand the dynamics of the competing causal processes, I built a system dynamics model. System Dynamics models have been successfully applied to the study of the growth of

companies. Forrester's "market-growth model" (Forrester, 1968) is a prime example of how modeling and simulation has provided insight into growth management. This model is in that tradition.

2.1. The Model

The model was designed to represent the key variables and relationships in the environment that the company is operating. It was built and simulated using Vensim DSS Version 1.62-4. A schematic overview of the model is shown in Figure 5.

FIGURE 5. MODEL OVERVIEW



The following is a discussion of the formulations used in the model. The discussion will be organized according to the sections presented in figure 5. Each section will be treated in terms of the modules (or "sectors") that the actual model has been divided into. For each sector, the most important formulations will be addressed below. A complete listing of equations with explanatory comments can be found in the Appendix.

2.1.1. Financials and Investment

The financials and Investment section consists of the Financial and Investment Sector, the Project Valuation Sector, and the Financial Need Planning Sector.

Financial and Investment Sector

Figure 6. shows the model structure associated with the Financial and Investment Sector. The following are the most important formulations in this sector:

- the value of the company
- the potential for new investment, and the actual investment made in the company
- the allocation of the company's financial resources

The value of the company

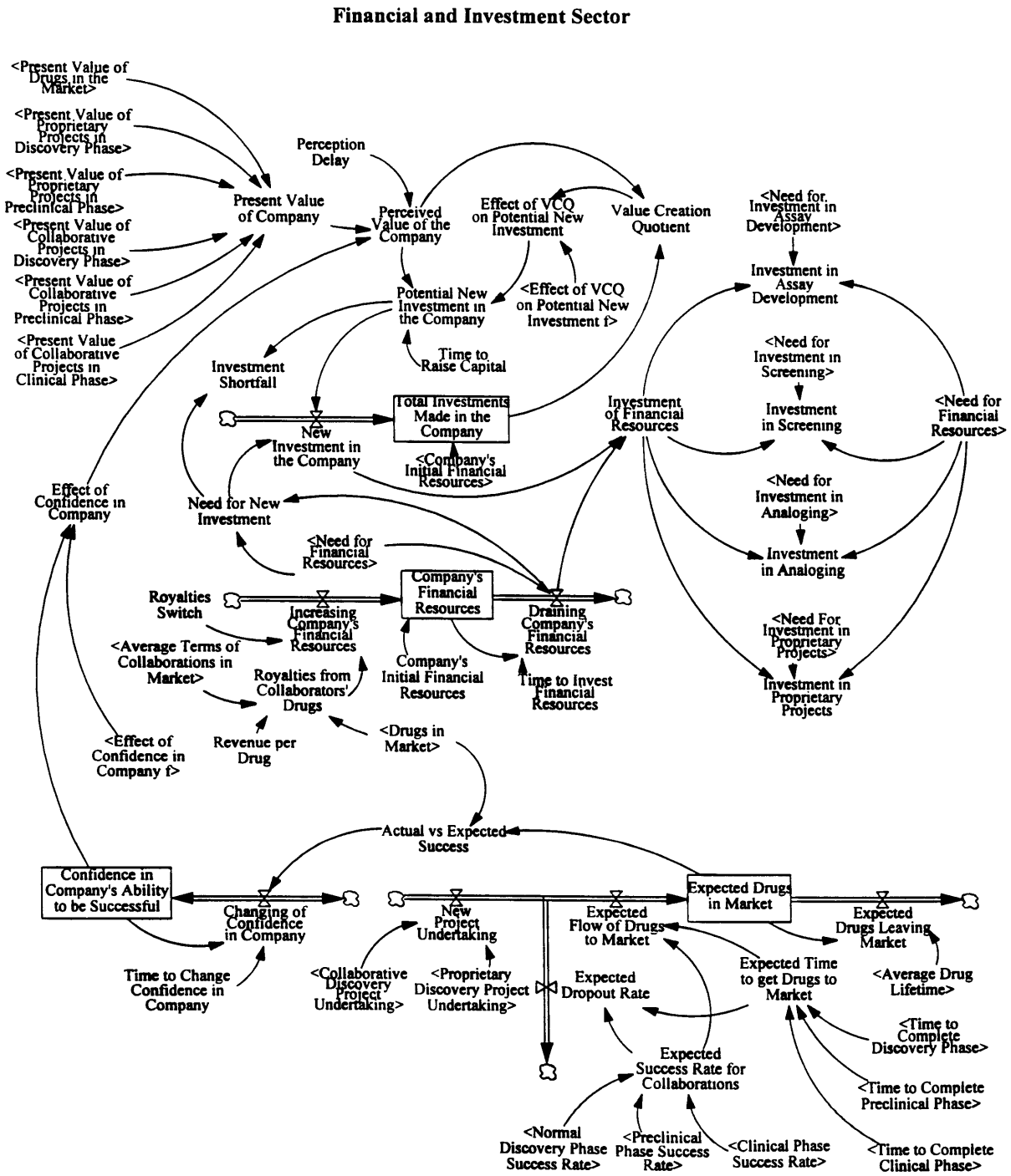
(1) Present Value of Company = Current Value of Collaborative Projects in Discovery Phase + Current Value of Collaborative Projects in Preclinical Phase + Current Value of Collaborative Projects in Clinical Phase + Current Value of Proprietary Projects in Discovery Phase + Current Value of Proprietary Projects in Preclinical Phase + Current Value of Drugs in the Market

The Present Value of the Company is the "actual" value of the company, and is calculated as being the sum of the present value of all projects (collaborative and proprietary) currently in the pipeline, and all projects that have successfully made it to market (see the Project Valuation Sector below for a more detailed explanation of the methods used in calculating these values). The value of property, equipment, etc. is not considered, since these factors do not play a significant role in the hypotheses being investigated by the model.

(2) Perceived Value of the Company = SMOOTH(Present Value of Company, Perception Delay)* Effect of Confidence in Company

The Perceived Value of the Company is a simplified representation of the market value of the company, and is proportional to the Present Value of the Company. It is "smoothed" by a Perception Delay in order to take into account the time lag associated

FIGURE 6. FINANCIAL AND INVESTMENT SECTOR



with the market becoming aware of the company's actual value, and multiplied by the Effect of Confidence in Company. This confidence effect reflects the level of confidence in the company, based on its performance (in terms of Drugs in Market), relative to the market's expectations (Expected Drugs in Market), and can cause the Perceived Value to be higher or lower than the actual value.

The potential for new investment, and the actual investment made in the company

The potential for new investment in the company (i.e. the amount of capital it would be able to raise) has been simplified to be dependent on two variables -- the Perceived Value of the Company, and the Total Investments made in the Company (the amount of capital it has already raised). There are various other factors that affect potential investment, such as the state of the economy, but the above two variables were determined to be the factors most crucial to the dynamics being investigated in this model. The central idea used in formulating potential investment is that of the value creation quotient.

(4) Value Creation Quotient = XIDZ(Perceived Value of the Company, Total Investments Made in the Company, 1)

Coggan (Coggan, 1996) uses the term Value Creation Quotient (VCQ) to refer to the ratio of a company's current market value (Perceived Value of the Company) to the amount of capital it has raised (Total Investments Made in the Company -- the modeled company is assumed to be 100% equity financed). The above formulation sets the VCQ equal to the ratio of the Perceived Value of the Company to the Total Investments Made in the Company, except when the denominator is zero, in which case the VCQ is set to be 1.

(5) Potential New Investment in the Company = (Perceived Value of the Company*Effect of VCQ on Potential New Investment)/Time to Raise Capital

Potential New Investment in the Company represents the amount of capital that the company will be able to raise at any given point in time. This is modeled to be

proportional to the Perceived Value of the Company -- the higher the value of the company, the more capital it will be able to raise. The potential for investment is also dependent on the Effect of VCQ, which restricts this potential based on how much capital the firm has already raised relative to its Perceived Value. The Time to Raise Capital, as the variable name implies, reflects that some time is needed for the company to raise capital.

(6) New Investment in the Company = MIN(Need for New Investment, Potential New Investment in the Company)

The amount of capital that the company actually raises (New Investment in the Company) is the lesser of the amount of capital it needs to raise (Need for New Investment), and the maximum amount it could raise (Potential New Investment in the Company).

(7) Need for New Investment = Need for Financial Resources - Draining Company's Financial Resources
(8) Draining Company's Financial Resources = MIN(Company's Financial Resources/Time to Invest Financial Resources, Need for Financial Resources)
(9) Need for Financial Resources = Need for Investment in Assay Development + Need for Investment in Screening + Need for Investment in Analoging + Need For Investment in Proprietary Projects
(10) Investment Shortfall = MAX(Need for New Investment - Potential New Investment in the Company,0)

The amount of capital the company needs to raise (Need for New Investment) is the amount of the company's total financial need (Need for Financial Resources) that cannot be met by using its own resources (Draining Company's Financial Resources). The company's need for financial resources is determined by summing its need for resources in each of its technology areas and its proprietary programs. The Investment Shortfall is used as an indicator of the company's ability (or inability) to meet its financial needs.

Note: Collaborative projects do not add to these needs, since the company will be re-imbursed for any costs incurred in fulfilling these collaborations. Also, other costs, such

as SG&A costs, have not been included since they are not of interest for the purposes of this model.

The allocation of the company's financial resources

(11) Investment in Assay Development = Investment of Financial Resources*(Need for Investment in Assay Development/Need for Financial Resources)

The company allocates the financial resources it has gathered (which, based on its needs, its own resources, and the resources it was able to raise, may be less than or equal to its actual needs) according to the relative need of each investment area. For example, the fraction of resources invested in Assay Development is proportional to the ratio of the need for resources in this area (Need for Investment in Assay Development) to the company's total financial needs.

Project Valuation Sector

Figure 7. shows the model structure associated with the Project Valuation Sector. The following are the most important formulations in this sector:

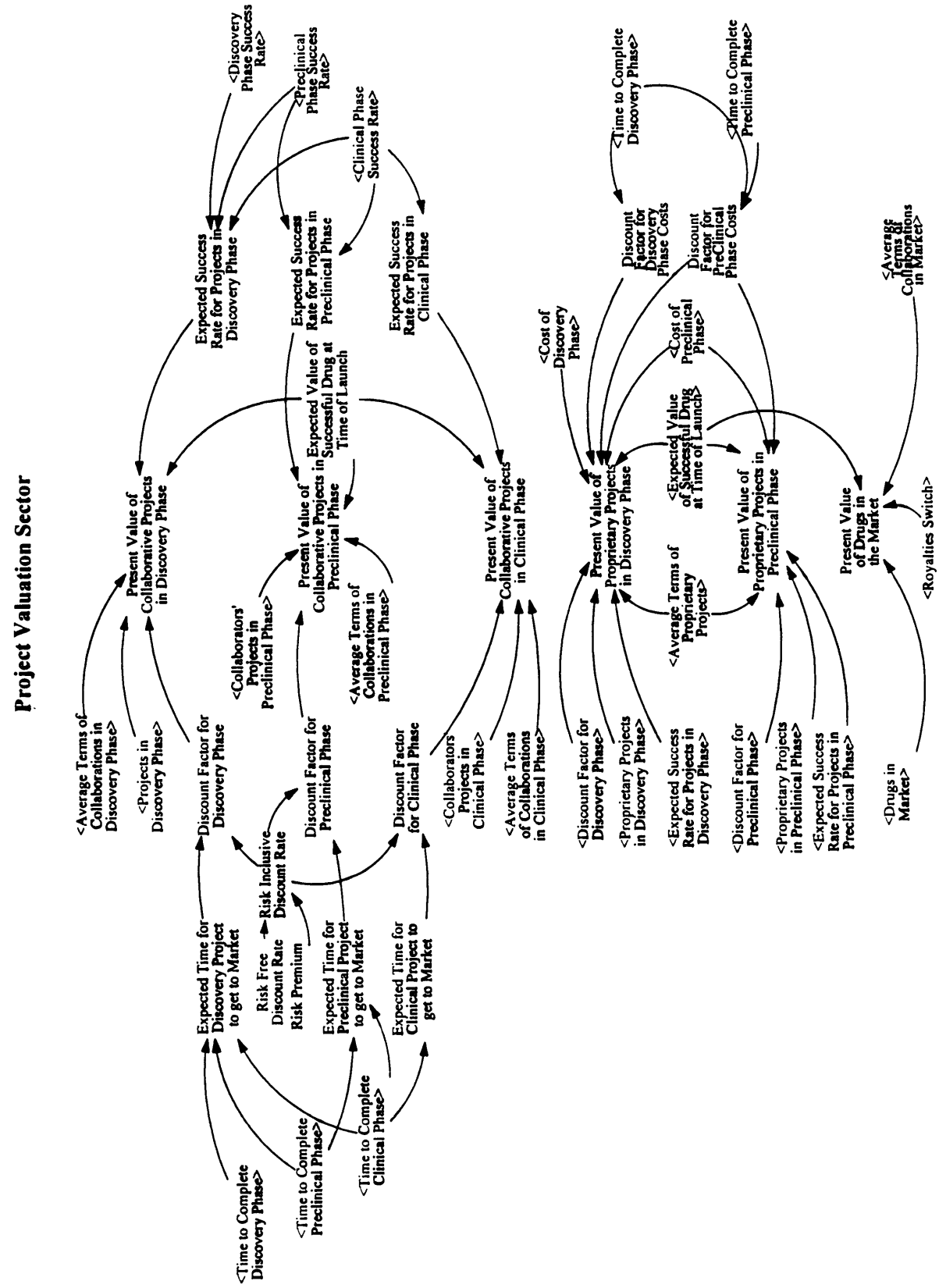
- the value of collaborative projects in discovery, preclinical, and clinical phases
- the value of proprietary projects in discovery and preclinical phases

The value of collaborative projects in discovery, preclinical, and clinical phases

A new biotech company is not likely to have any sales or profits, since its research activities will not lead to drugs in the market for many years. Conventional valuation methods such as price-earnings ratios, yields and cash flows are inappropriate in this case. One approach that has been widely accepted by fund managers, analysts, and the pharmaceutical industry is the following (Green, 1996):

- Consider a point in the future when the drug is on the market,

FIGURE 7. PROJECT VALUATION SECTOR



- value the drug as a mature product, taking into account the advantages the new drug will have over rivals on the market and in development,
- Discount this value back to the present, taking into account the time value of money, and the chances of the drug being successful (e.g. in clinical tests).

As a company's projects successfully pass each phase, their chances of reaching the market is greater, and thus, according to the above approach, their market valuation should be correspondingly higher. Green (Green, 1996), writing on the day before the results from the trials of a UK biotechnology company's drug became known, observes exactly this phenomenon "Tomorrow (the company's) valuation could, according to analysts, rise by one third or fall by half, depending on the latest results from trials."

(1) Present Value of Collaborative Projects in Discovery Phase = Projects in Discovery Phase*Average Terms of Collaborations in Discovery Phase*Expected Success Rate for Projects in Discovery Phase*Discount Factor for Discovery Phase*Expected Value of Successful Drug at Time of Launch
(2) Discount Factor for Discovery Phase =EXP(-Risk Inclusive Discount Rate*Expected Time for Discovery Project to get to Market)

The basic ideas described above provided the basis for the value formulations used in the model. The expected future cash flows (i.e. royalties, which equals Expected Value of Successful Drug at Time of Launch*Average Terms of Collaboration) are discounted using a cost of capital appropriate for the cash flows' risks (Risk Inclusive Discount Rate) and the appropriate time horizon (Expected Time for Discovery Project to get to Market) -- costs are not included in the formulations used to value collaborative projects, since any costs associated with these projects are borne by the collaborators. The discounted value is then multiplied by the probability of being successful in getting to market (Expected Success Rate) to arrive at the Present Value for a particular project. The present value of all projects in a given phase can then be calculated by multiplying the above Present Value by the number of projects in that phase.

The value of proprietary projects in discovery and preclinical phases

(3) Present Value of Proprietary Projects in Discovery Phase = ((Expected Value of Successful Drug at Time of Launch*Discount Factor for Discovery Phase) - (Cost of Discovery Phase*Discount Factor for Discovery Phase Costs) - (Cost of Preclinical Phase*Discount Factor for PreClinical Phase Costs))* Proprietary Projects in Discovery Phase*Average Terms of Proprietary Projects*Expected Success Rate for Projects in Discovery Phase

(4) Discount Factor for Discovery Phase Costs = EXP(-Risk Free Discount Rate*Time to Complete Discovery Phase)

(5) Discount Factor for PreClinical Phase Costs = EXP(-Risk Free Discount Rate*(Time to Complete Discovery Phase+Time to Complete Preclinical Phase))

The formulation used to calculate the present value of a proprietary project is similar to that of collaborative projects. The only difference is that the discounted value of expected (future) costs must be subtracted from the discounted expected cash flows. Discounted costs are calculated using a risk free discount rate, since these costs can be considered as being "fixed".

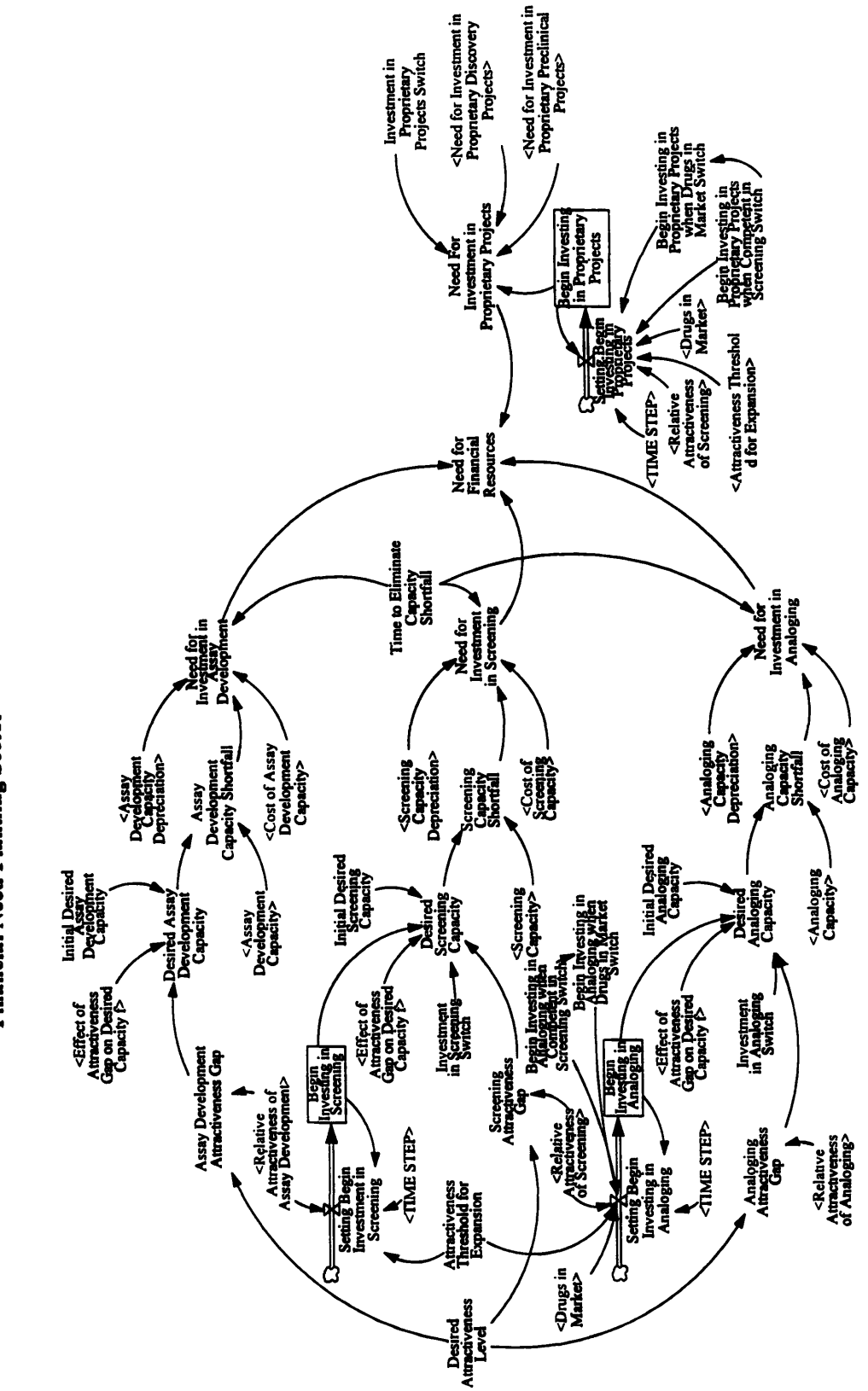
Financial Need Planning Sector

Figure 8. shows the model structure associated with the Financial Need Planning Sector. The most important formulation used in this sector is determining when the company begins investing in a new technology area / proprietary projects

Beginning to invest in a new technology area / proprietary projects

Investment in screening begins when the attractiveness threshold for expansion is reached in assay development. This expansion threshold represents the level of competency in existing technology areas (in this case assay development) that the company requires before expanding into a new technology area (screening). The threshold is also indicative of the aggressiveness/willingness of the company to grow. Depending on the strategy being tested, investment in analoging and/or in proprietary programs begins either when the attractiveness threshold for expansion is reached in screening, or when the company gets its first successful drug to market.

FIGURE 8. FINANCIAL NEED PLANNING SECTOR



2.1.2. Attractiveness and Collaborations

Attractiveness and Collaborations Sector

Figure 9. shows the model structure associated with the Attractiveness and Collaborations Sector. The following are the most important formulations in this sector:

- Relative attractiveness of technology Area
- Total attractiveness to collaborators
- New Collaborations

Relative attractiveness of technology Area

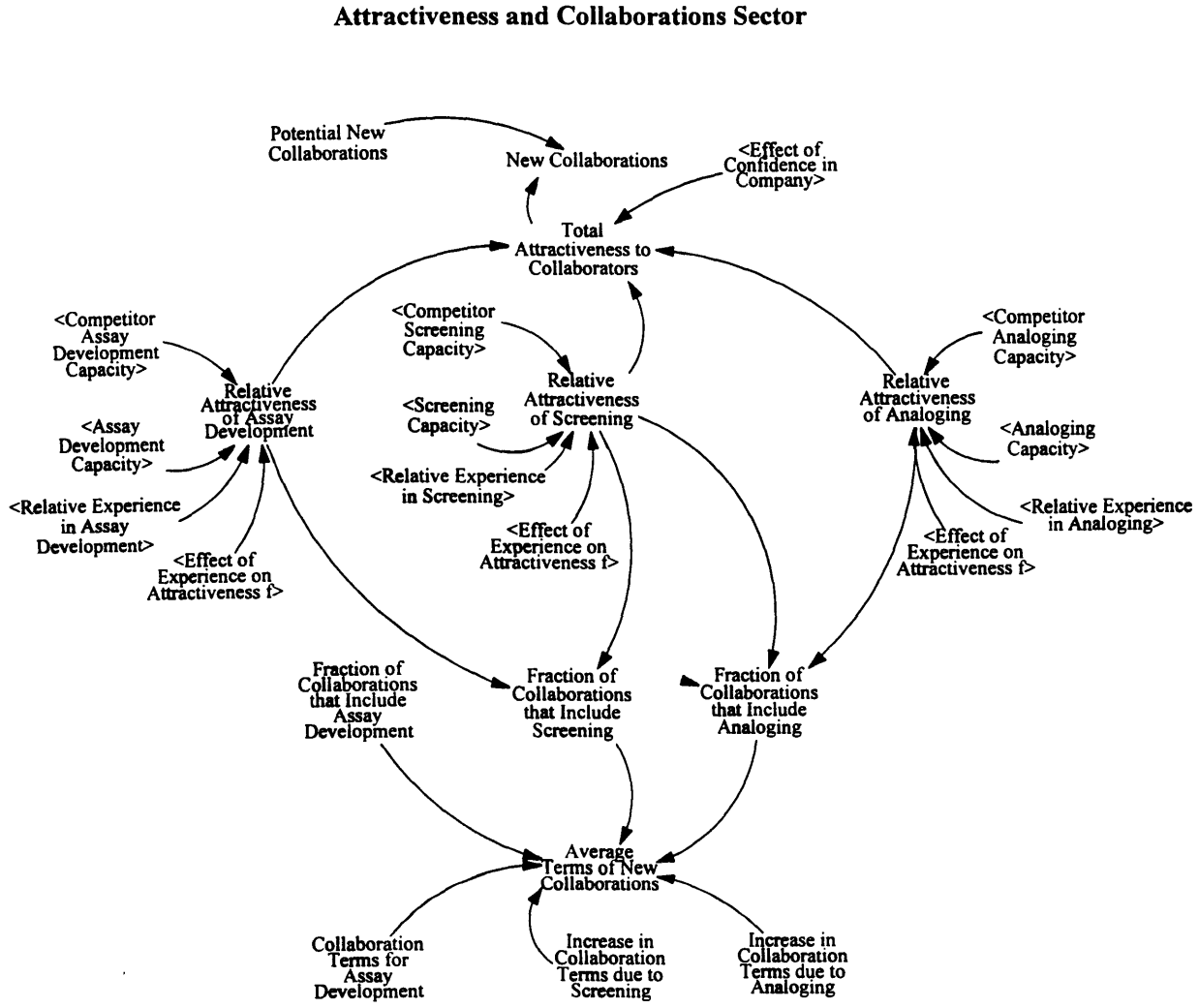
(1) Relative Attractiveness of Assay Development = Effect of Experience on Attractiveness f(Relative Experience in Assay Development)*Assay Development Capacity / ((Effect of Experience on Attractiveness f(Relative Experience in Assay Development)*Assay Development Capacity) + Competitor Assay Development Capacity)

The relative attractiveness of a technology area represents the company's capabilities in that area relative to its competitors. This depends on both the company's capacity, as well as its experience in this area, relative to its competitor (the competitor is assumed to have the "normal" amount of experience -- i.e. a relative experience of 1). The Effect of Experience on Attractiveness is used to incorporate the idea that the company becomes more attractive to collaborators as it gains more experience in a particular area.

Total Attractiveness to Collaborators

(2) Total Attractiveness to Collaborators = Effect of Confidence in Company*(Relative Attractiveness of Assay Development + (Relative Attractiveness of Assay Development*Relative Attractiveness of Screening) + (Relative Attractiveness of Assay Development*Relative Attractiveness of Screening*Relative Attractiveness of Analoging))/3

FIGURE 9. ATTRACTIVENESS AND COLLABORATIONS SECTOR



The attractiveness of the company to collaborators depends on the confidence in the company (based on its track record in terms of successful R&D efforts), and on the attractiveness of its competencies relative to competitors. Three types of collaborations are considered by the company - Assay development, Assay Development & Screening, and Assay Development, Screening, & Analoging. The number of assay development collaborations depends solely on the attractiveness of assay development; the number of assay development & screening collaborations depends on both the attractiveness of assay development as well as the attractiveness of screening; and so on. These collaboration types reflect the evolution of the company's technology platform. According to this formulation, assay development is the most important factor in determining the company's "total" attractiveness. This is true from the collaborators' point of view as well, since the quality of the assay will ultimately determine the quality of the output of the discovery phase.

New Collaborations

(3) New Collaborations = Potential New Collaborations*Total Attractiveness to Collaborators

The number of new collaborations the company is able to secure depends on its attractiveness to collaborators, and the potential for new collaborations. The potential for new collaborations has been simplified to contain 1 of each of the three types of collaborations that the company undertakes. The company agrees to complete the particular combination of the above phases that a given collaborator wishes, and in return, it is re-imbursed for any costs incurred during the project. The company also receives some fraction of drug revenues (determined by the terms of collaboration) should the project lead to a successful drug.

2.1.3. Collaborative/Proprietary Projects

Collaborative Projects Sector

FIGURE 10. COLLABORATIVE PROJECTS SECTOR

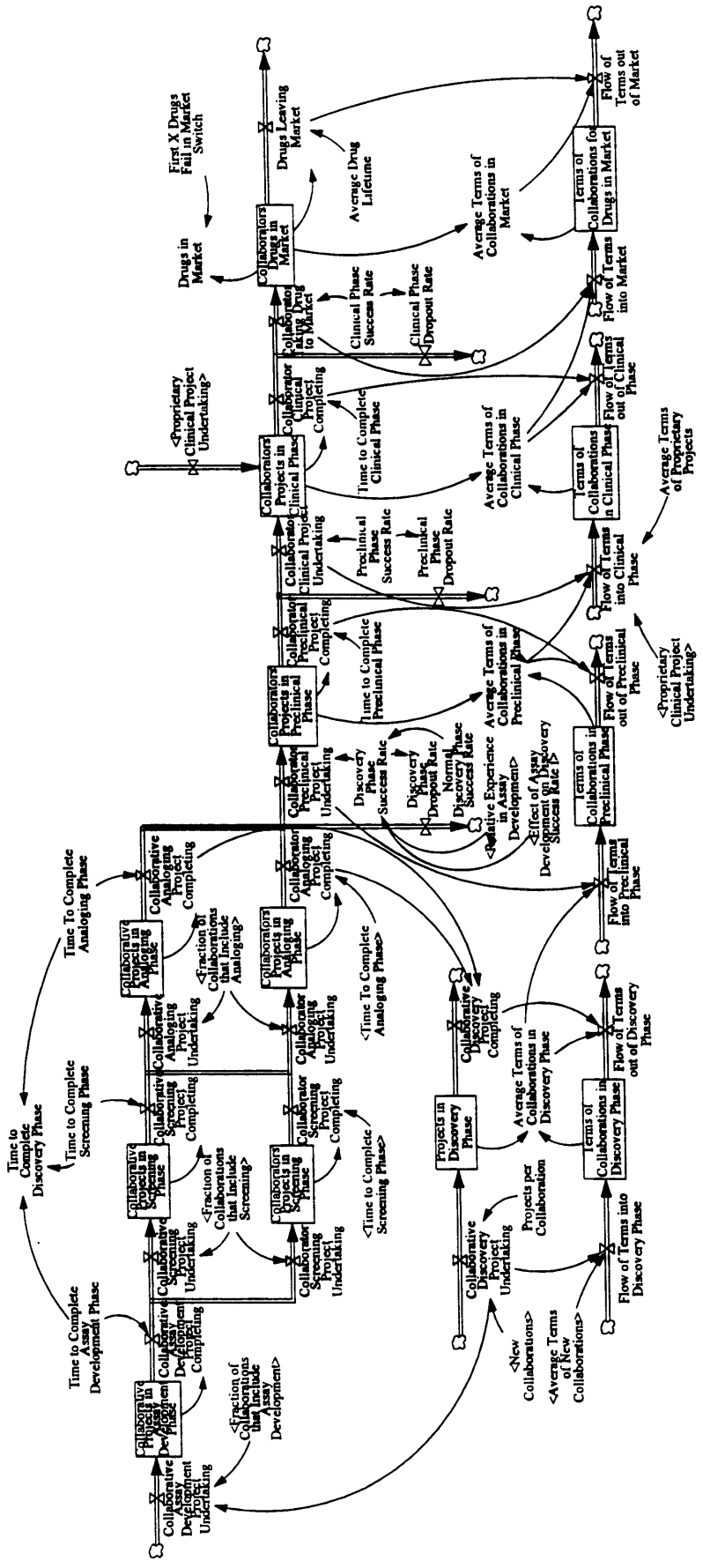


Figure 10. shows the model structure associated with the Collaborative Projects Sector. The most important formulation in this sector is the calculation of the flow of terms of collaboration.

Flow of terms of collaboration

A co-flow structure is used to keep track of the average terms of collaboration corresponding to the projects in each phase of the pipeline. This method of accounting allows for the value of the projects in any given phase to be calculated, and is used in the Project Valuation Sector.

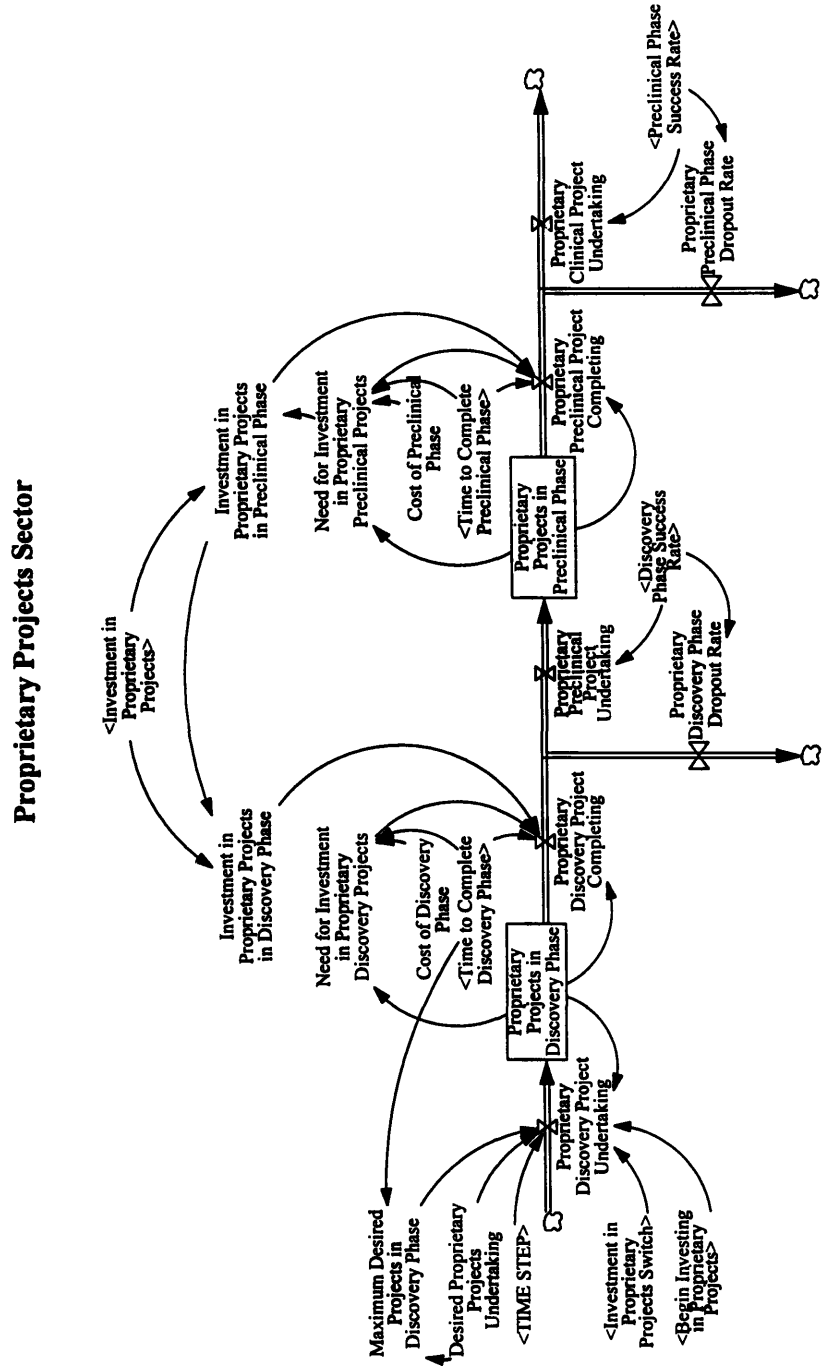
Proprietary Projects Sector

Figure 11. shows the model structure associated with the Proprietary Projects Sector. Proprietary projects are those programs which the company uses its own resources to finance upto a certain stage in the pipeline -- the later clinical stages are too costly for smaller firms. If the project is successful up until that stage, the company finds a collaborator to take the project through to market. The proprietary projects are categorized in the model as follows. The company completes the discovery and preclinical phases of a project, and then finds a collaborator to take over. From this point on, the company incurs no further costs. However, the flow of projects through the discovery and preclinical phases do require significant investments from the company, and failing to fund these projects adequately will lead to significant delays in their progression.

Proprietary Discovery Project Completing = ZIDZ(Proprietary Projects in Discovery Phase, (Time to Complete Discovery Phase*(Need for Investment in Proprietary Discovery Projects/Investment in Proprietary Projects in Discovery Phase)))

The flow of proprietary projects is determined as follows. If the company is able to invest the resources needed into the proprietary projects in any particular stage of the

FIGURE 11. PROPRIETARY PROJECTS SECTOR



pipeline (Need for Investment for Proprietary Projects), it will be able to move them along in the "normal" time needed for that particular phase (the Time to Complete Phase). Otherwise, these projects will take relatively longer, based on how much the company is able to invest relative to how much is needed to maintain a "normal" flow.

2.1.4. Technology Capabilities

Capacity and Learning Sector

Figure 12. shows the model structure associated with the Capacity and Learning Sector. The following are the most important formulations in this sector:

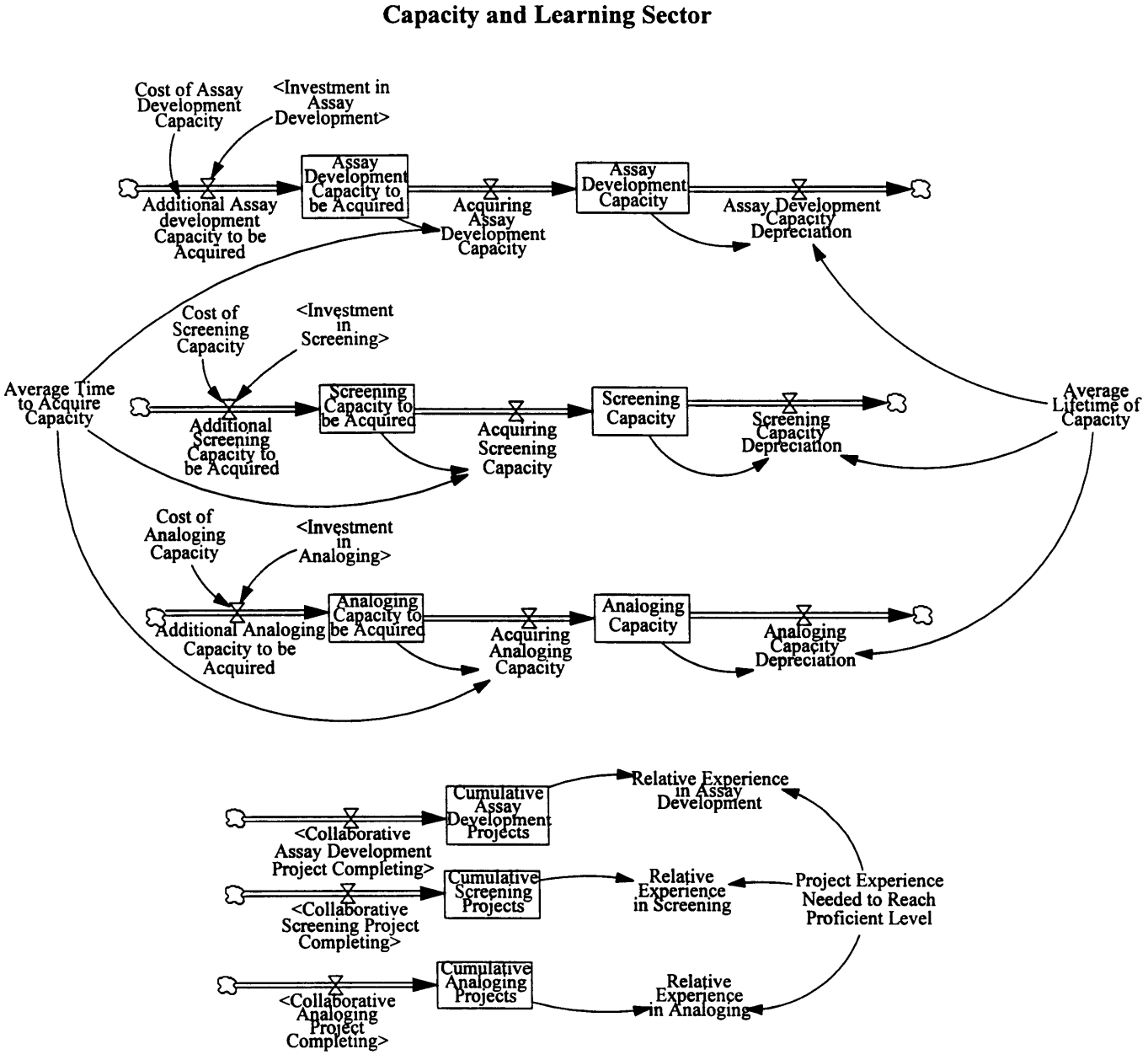
- Capacity of each technology area
- Relative Experience

Capacity of each technology area

Assay Development Capacity represents the company's ability to develop assays. This "capacity" is primarily in the form of scientists/researchers, but also includes the necessary labs/equipment. Screening Capacity represents the company's ability to screen compounds against target assays. This "capacity" is in the form of screening robots and scientists/researchers. Analoging Capacity represents the company's ability to analog lead/hit compounds for further development. This "capacity" is in the form of scientists/researchers and labs/equipment. These "capacities" are modeled to depreciate based on an average useful lifetime. This depreciation represents both the depreciation of equipment, as well as the "depreciation" of the technology (i.e. the technology used becoming obsolete).

Relative Experience

FIGURE 12. CAPACITY AND LEARNING SECTOR



(1) Relative Experience in Screening = Cumulative Screening Projects / Project Experience Needed to Reach Proficient Level

Relative experience reflects the company's level of experience relative to a "proficiency" level. The level of experience is measured in terms of the number of projects that the company has done in a particular technology area, and the proficiency level represents the number of projects that need to be done in that area to become proficient.

2.1.5. Competitor

Competitor Sector

Figure 13. shows the model structure associated with the Competitor Sector. Competitors are modeled exogenously, and are attributed characteristics of an initial level of capability, a growth rate for this capability, and the starting period for the growth. A competitor represents not only other biotechnology firms that the company may be competing against for new collaborations, but also the collaborators themselves.

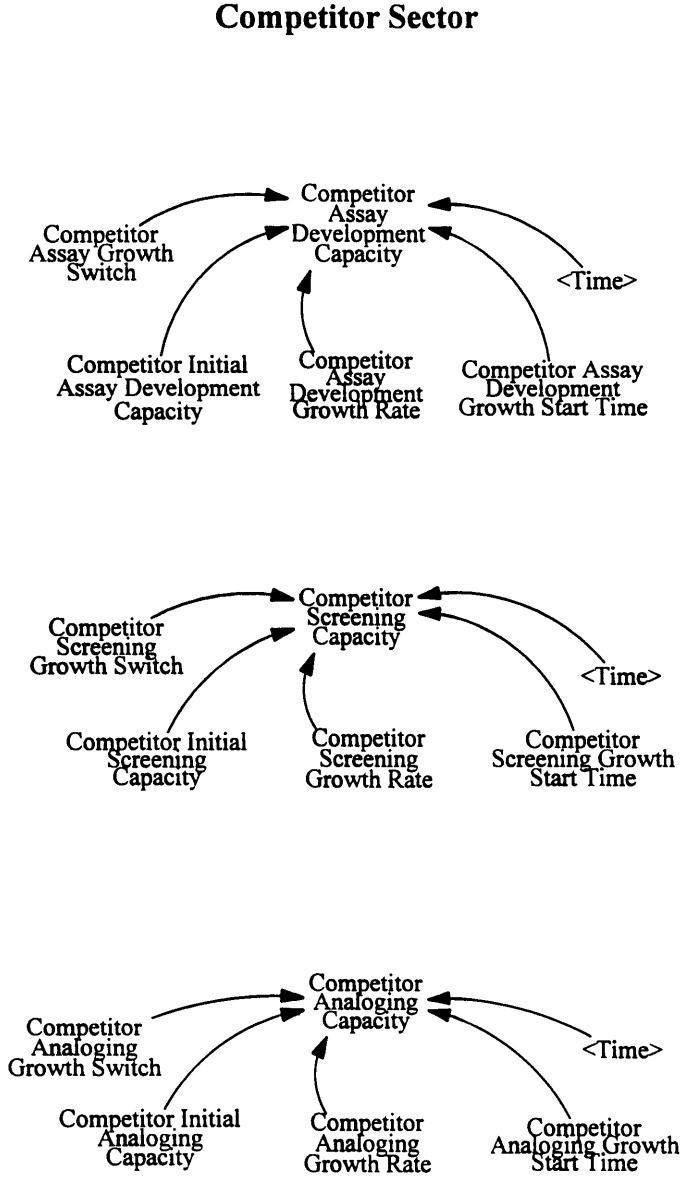
2.1.6. Variable Estimations

Many of the constants used in the model were estimated either from the available literature or from the actual values used in the company. Listed below are the most important of these variables. A complete listing of model equations can be found in the Appendix.

Revenues and Costs

(1) Expected Value of Successful Drug at Time of Launch = $250 million. The lifetime earnings of drugs can vary considerably, based on drug quality, competition, regulatory changes, etc. The value used in

FIGURE 13. COMPETITOR SECTOR



the model corresponds to the "average" case. The simplification is appropriate in this case, because the "expected" value is most likely to correspond to an average figure. Estimated from average drug lifecycle revenues used by Grabowski and Vernon (Grabowski, Vernon, 1990).

(2) Revenue per Drug = $40 million/year. While drug revenues will vary during any drug's life-cycle, an average figure for these life-cycle revenues was assumed to be sufficient for the purposes of this model. Estimated from average drug lifecycle revenues used by Grabowski and Vernon (Grabowski, Vernon, 1990).

(3) Discount Rate = 15%. Estimated from the discount rate calculated (in real terms) for "small" pharmaceutical firms by Myers and Shyam-Sundar (Myers, and Shyam-Sundar, 1991).

(4) Cost of Discovery Phase = $15 million. Estimated from figures used by Lehman Brothers (Lehman Brothers, 1996).

(5) Cost of PreClinical Phase = $5 million. Estimated from figures used by Lehman Brothers (Lehman Brothers, 1996).

(6) Cost of Capacity = $1 million/asssay/year (Assay Development), $1 /compound/year (Screening), $1 /compound/year (Analoging). The costs of capacity have been based on data from the company, but have been altered slightly to make it so that an equal amount of resources are required to reach a given level of competence (attractiveness relative to the competitor) in each area.

Time Constants

(7) Average Drug Lifetime = 10 year. The "useful" lifetime of a drug is represented here as its patent protected period. Estimated from the mean effective patent life of NCEs approved 1985-1989 (OTA, 1993).

(8) Time to Complete Assay Development Phase = 0.5 year. Estimated from Thayer (Thayer, 1995).

(9) Time to Complete Screening Phase = 0.5 year. Estimated from Thayer (Thayer, 1995).

(10) Time to Complete Analoging Phase = 0.5 year. Estimated from Thayer (Thayer, 1995).

(11) Time to Complete Preclinical Phase = 1.5 year. Estimated from figures used by Bienz-Tadmor (Bienz-Tadmor, 1993).

(12) Time to Complete Clinical Phase = 7 year. Estimated from figures used by Bienz-Tadmor (Bienz-Tadmor, 1993).

Success Rates

(13) Discovery Phase Success Rate = 1. The transition probability from the discovery phase to the preclinical phase, estimated from figures used by OTA (OTA, 1993).

(14) Preclinical Phase Success Rate = 0.3. The transition probability from the preclinical phase to the clinical phase, estimated from figures used by OTA (OTA, 1993).

(15) Clinical Phase Success Rate = 0.6. The transition probability from the clinical phase to market, estimated from figures used by OTA (OTA, 1993).

3. Results

In order to explore the hypotheses stated in Section 1.2., several simulations were conducted using various growth strategies and environment conditions. The growth strategies tested were as follows:

- aggressive growth -- investment into analoging and/or proprietary programs begins as soon as the company reaches an acceptable level of competence in screening; this is representative of the company's intended strategy, and is considered to be the "base case."
- cautious growth -- investment into analoging and/or proprietary programs begins only after the company has a successful drug in the market.
- no growth -- the company does not invest in analoging and/or proprietary projects.

The environment conditions tested were chosen to represent future uncertainties in terms of possible competitive scenarios as well as the success/failure of the company's drugs. The conditions tested were the following:

- favorable environment conditions -- competitors do not grow, and drugs that are launched into the market perform as expected.
- unfavorable environment conditions -- the company's first drug to be launched is a failure and/or the company is faced with growing competitors in screening and in analoging.

3.1. Favorable Environment Conditions

Base Case

Growth Strategy
Base Case -- invest in analoging and proprietary projects once attractiveness threshold is reached in screening.
Environment
No failures of drugs in market, No competitors.

FIGURE 14. ATTRACTIVENESS TO COLLABORATORS -- BASE CASE UNDER FAVORABLE ENVIRONMENT CONDITIONS

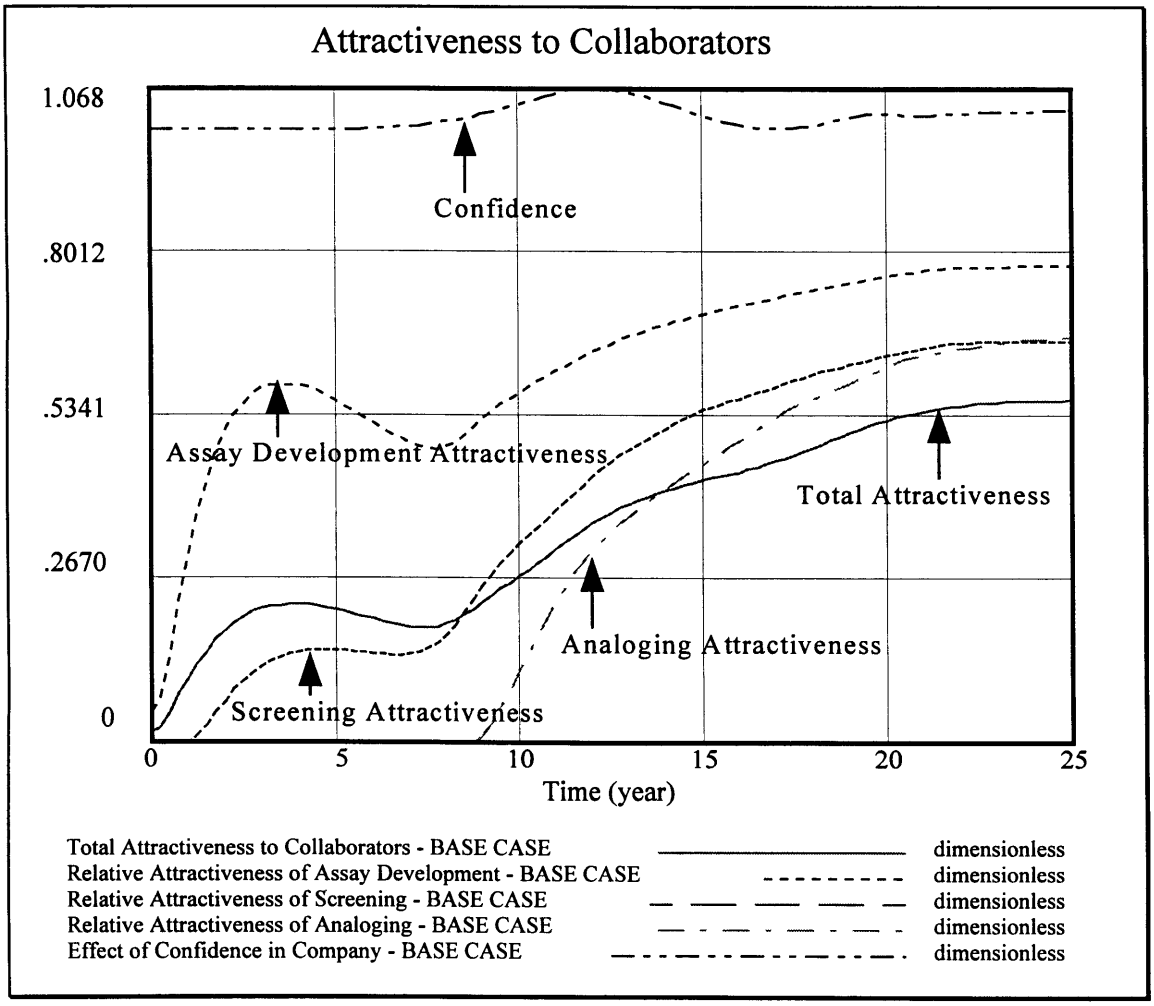


FIGURE 15. INVESTMENT AND REVENUES -- BASE CASE UNDER FAVORABLE ENVIRONMENT CONDITIONS

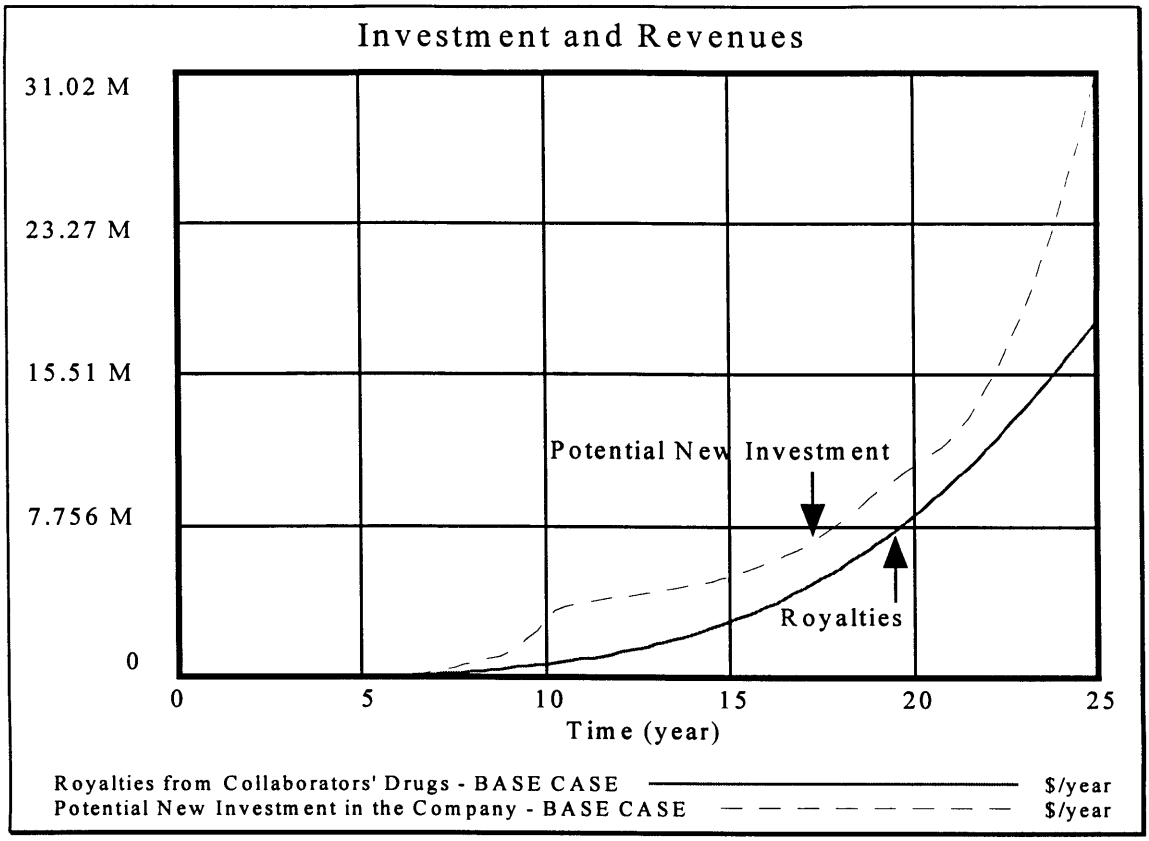
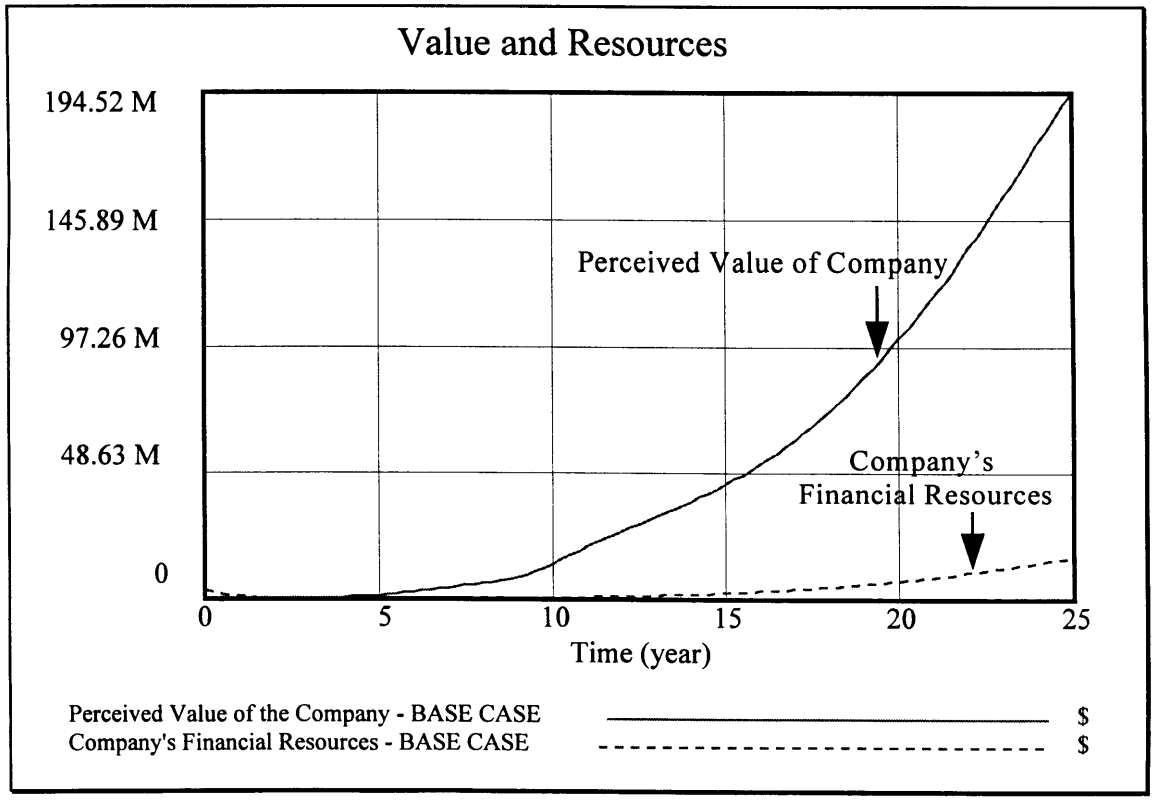


FIGURE 16. VALUE AND RESOURCES -- BASE CASE UNDER FAVORABLE ENVIRONMENT CONDITIONS



Proprietary program growth strategies

Growth Strategy

Late Prop -- Invest in analoging once attractiveness threshold is reached in screening, invest in proprietary projects when the first successful drug gets to market.

No Prop -- Invest in analoging once attractiveness threshold is reached in screening, do not invest in proprietary projects.

Environment

No failures of drugs in market, no competitors.

FIGURE 17. ATTRACTIVENESS TO COLLABORATORS -- PROPRIETARY PROGRAM GROWTH STRATEGIES UNDER FAVORABLE ENVIRONMENT CONDITIONS

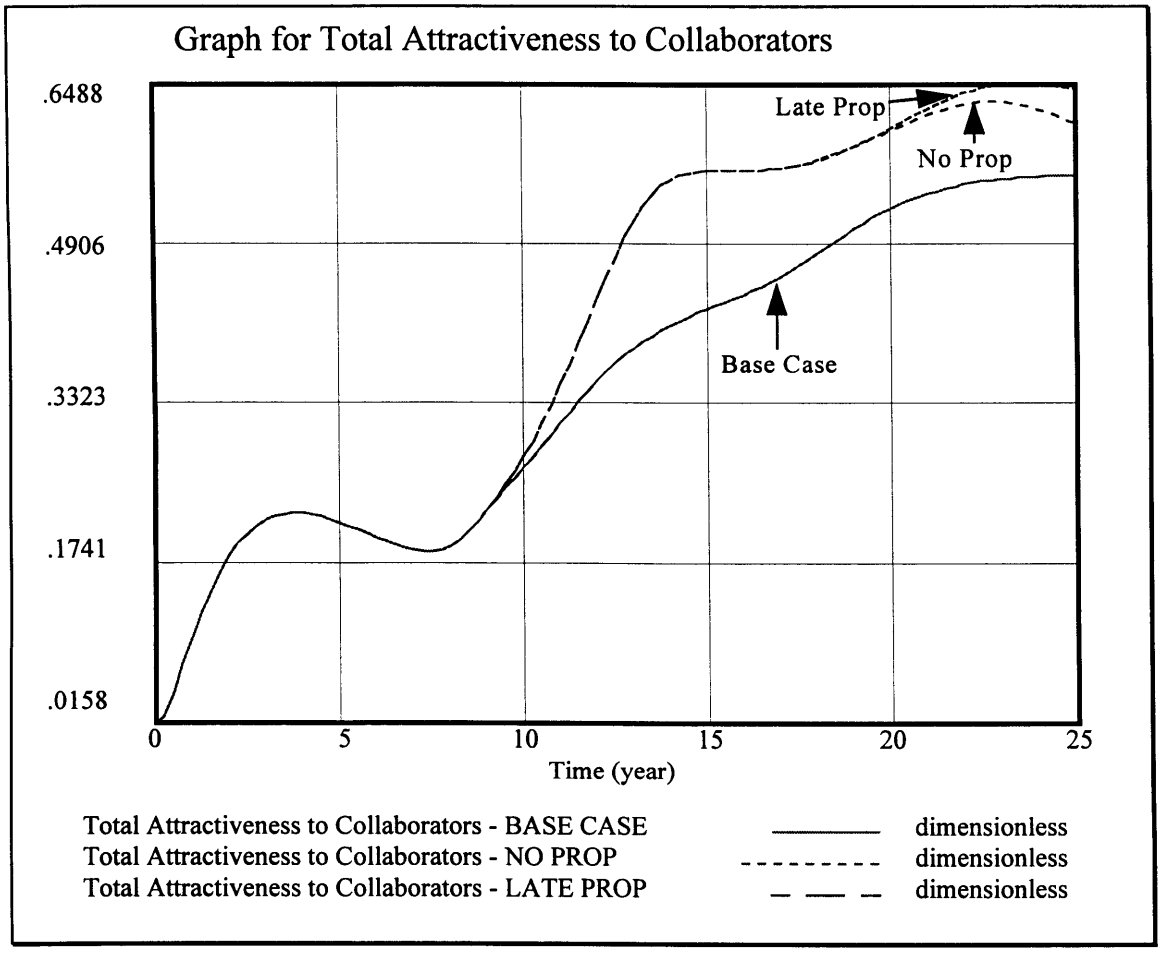


FIGURE 18. PERCEIVED VALUE -- PROPRIETARY PROGRAM GROWTH STRATEGIES UNDER FAVORABLE ENVIRONMENT CONDITIONS

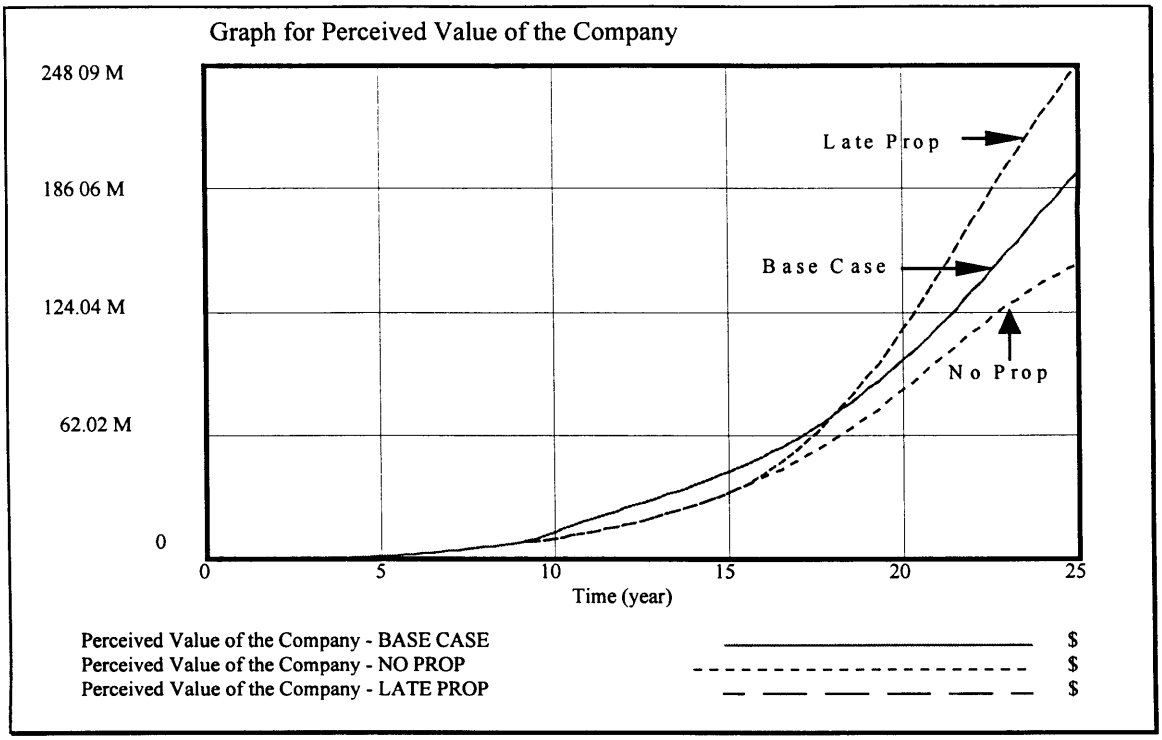


FIGURE 19. POTENTIAL NEW INVESTMENT -- PROPRIETARY PROGRAM GROWTH STRATEGIES UNDER FAVORABLE ENVIRONMENT CONDITIONS

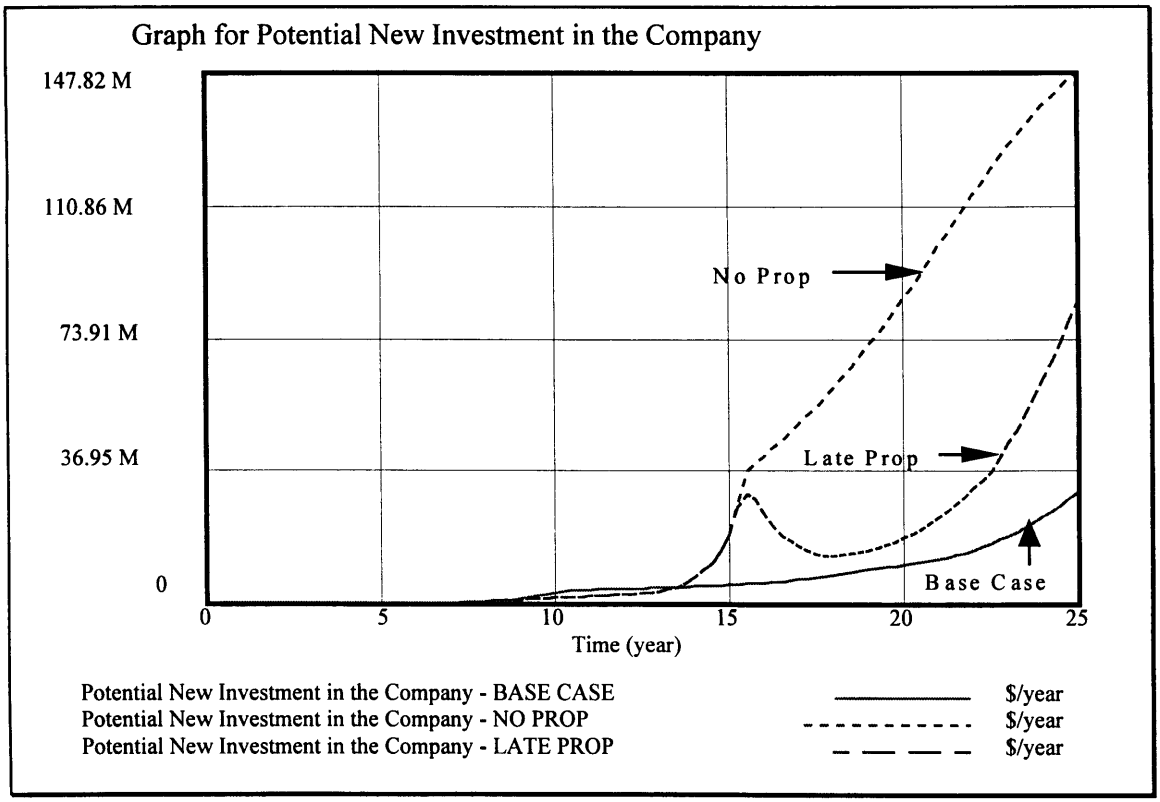
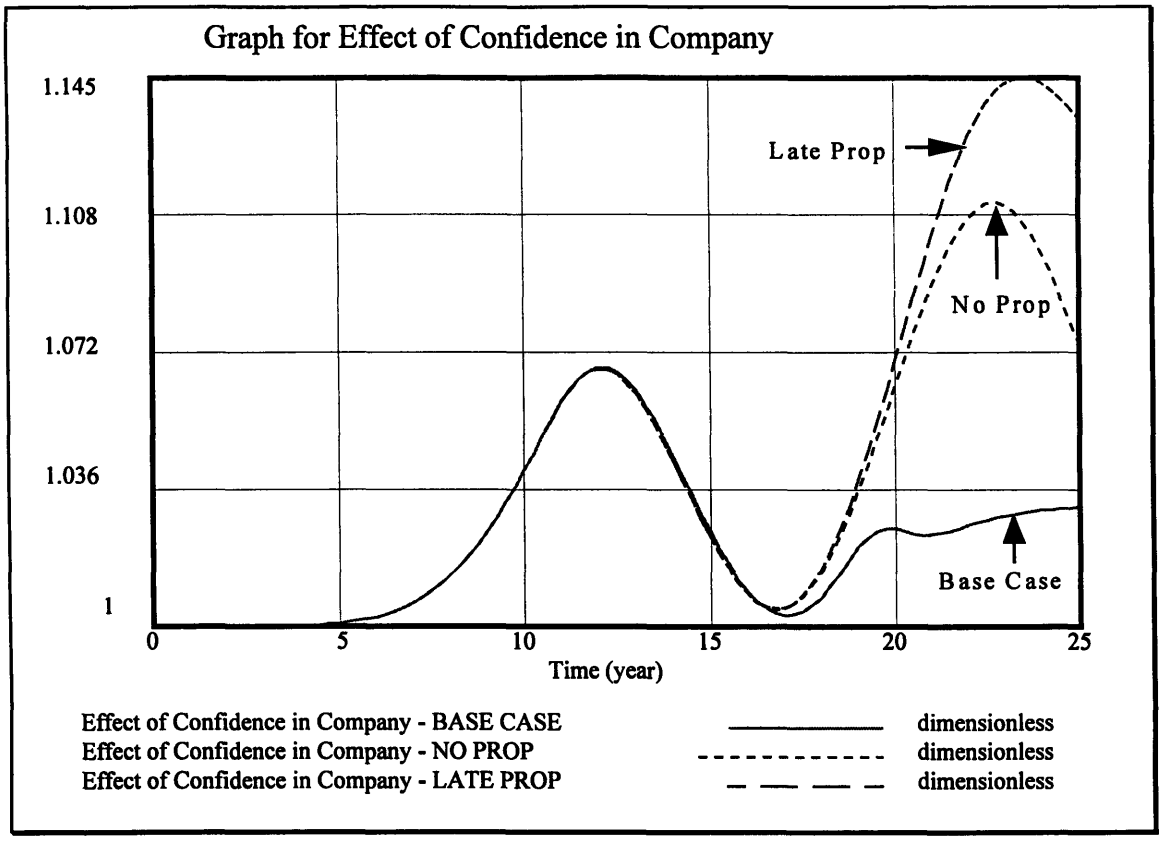


FIGURE 20. CONFIDENCE -- PROPRIETARY PROGRAM GROWTH STRATEGIES UNDER FAVORABLE ENVIRONMENT CONDITIONS



Proprietary program and technology platform growth strategies in combination

Growth Strategy

LateP NoAnalog -- Do not invest in analoging, invest in proprietary projects when the first successful drug gets to market.

LateP LateAnalog -- Invest in analoging and proprietary projects when the first successful drug gets to market.

Environment

No failures of drugs in market, no competitors.

FIGURE 21. ATTRACTIVENESS TO COLLABORATORS -- PROPRIETARY PROGRAM AND TECHNOLOGY PLATFORM GROWTH STRATEGIES UNDER FAVORABLE ENVIRONMENT CONDITIONS

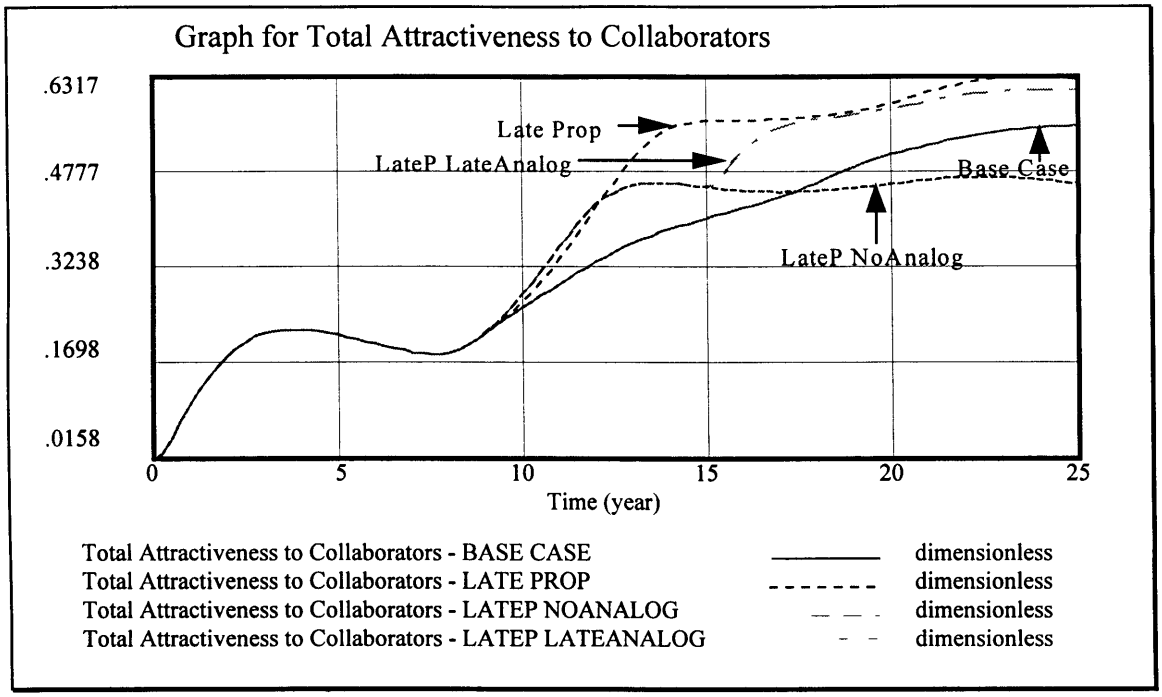
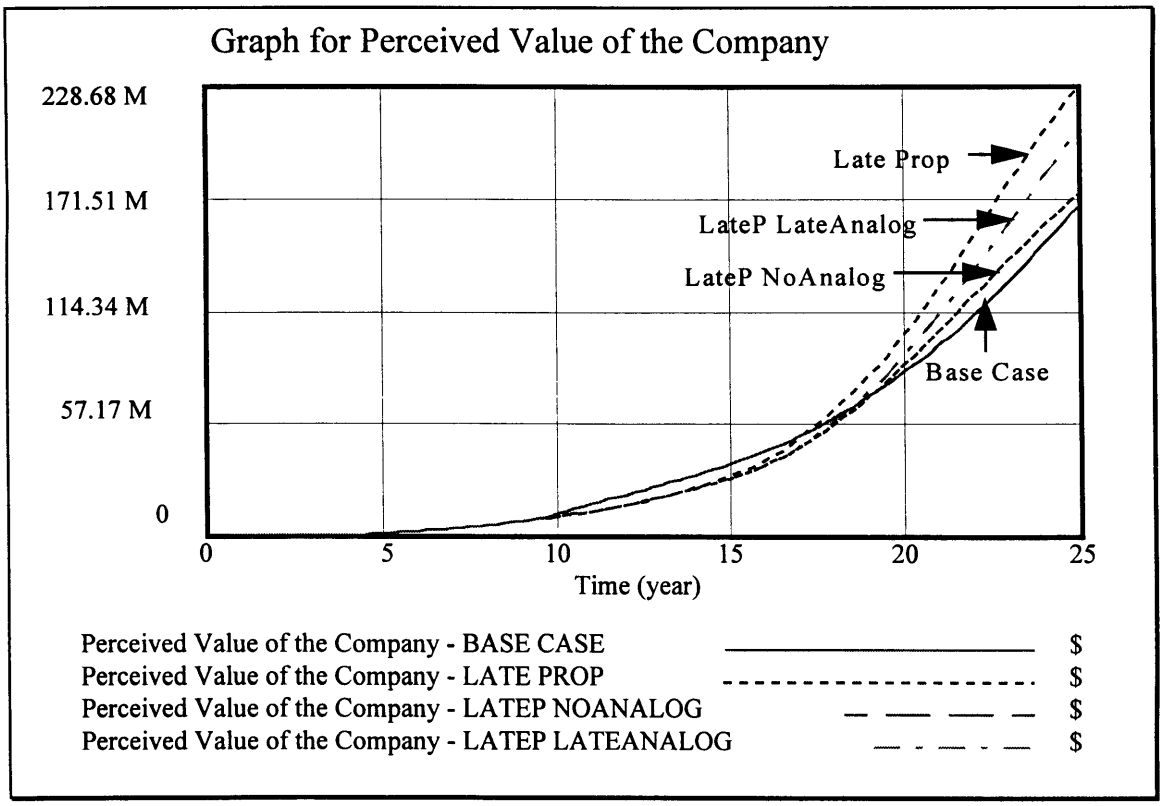


FIGURE 22. PERCEIVED VALUE -- PROPRIETARY PROGRAM AND TECHNOLOGY PLATFORM GROWTH STRATEGIES UNDER FAVORABLE ENVIRONMENT CONDITIONS



3.2. Unfavorable Environment Conditions

The strategies used in the previous runs (Base Case, Late Prop, LateP LateAnalog, and LateP NoAnalog) were tested under "unfavorable" environment conditions, in order to further explore the hypotheses stated in section 1.2.

3.2.1. Strong competitor

Figure 23. Attractiveness to Collaborators -- Proprietary program and technology platform growth strategies with a strong competitor

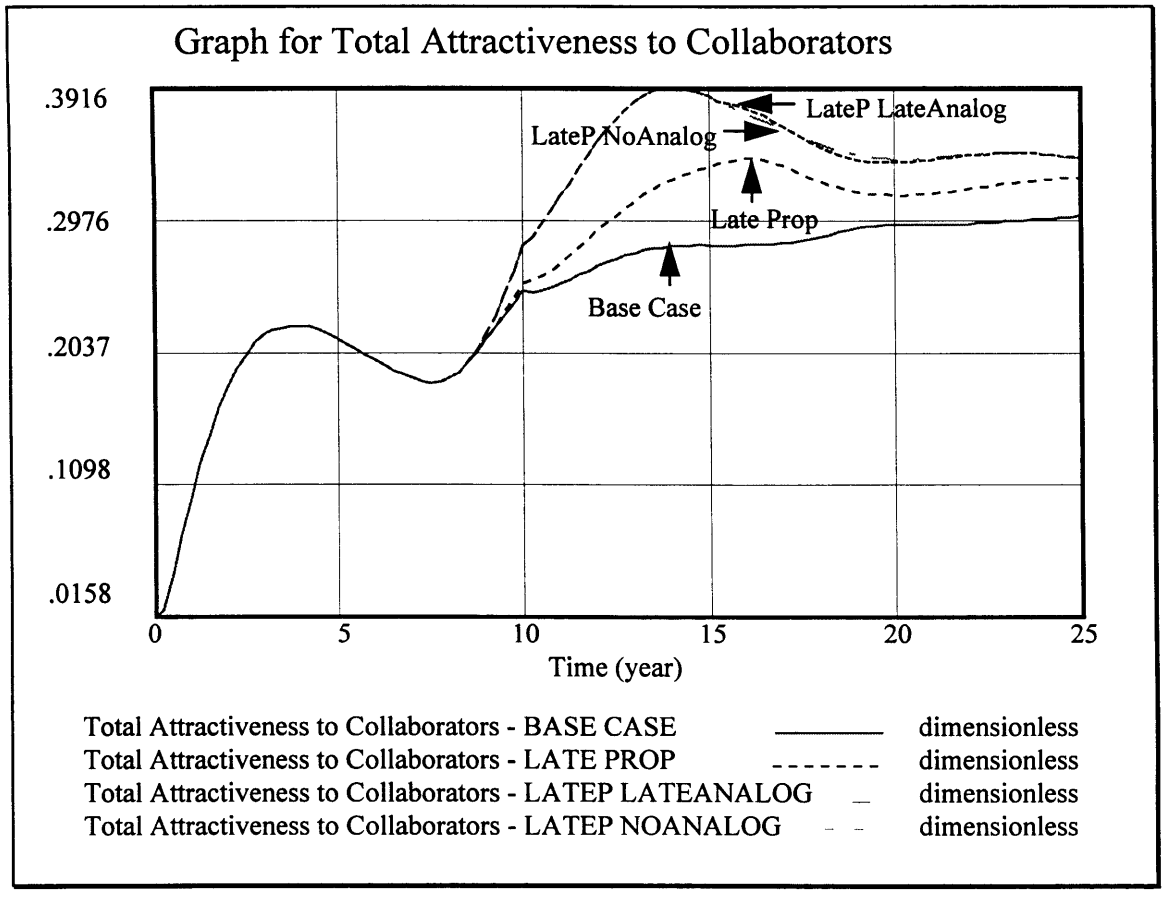
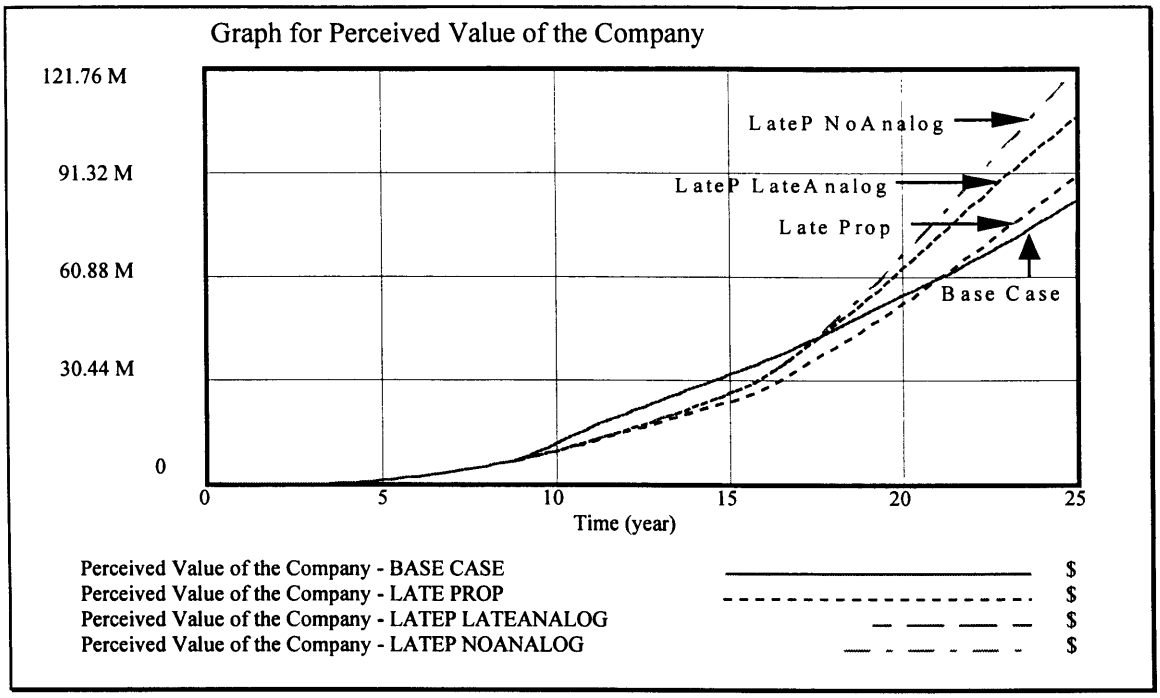


FIGURE 24. PERCEIVED VALUE -- PROPRIETARY PROGRAM AND TECHNOLOGY PLATFORM GROWTH STRATEGIES WITH A STRONG COMPETITOR



3.2.2. Failure of initial drugs in market

FIGURE 25. ATTRACTIVENESS TO COLLABORATORS -- PROPRIETARY PROGRAM AND TECHNOLOGY PLATFORM GROWTH STRATEGIES WITH FAILURE OF FIRST DRUG IN MARKET

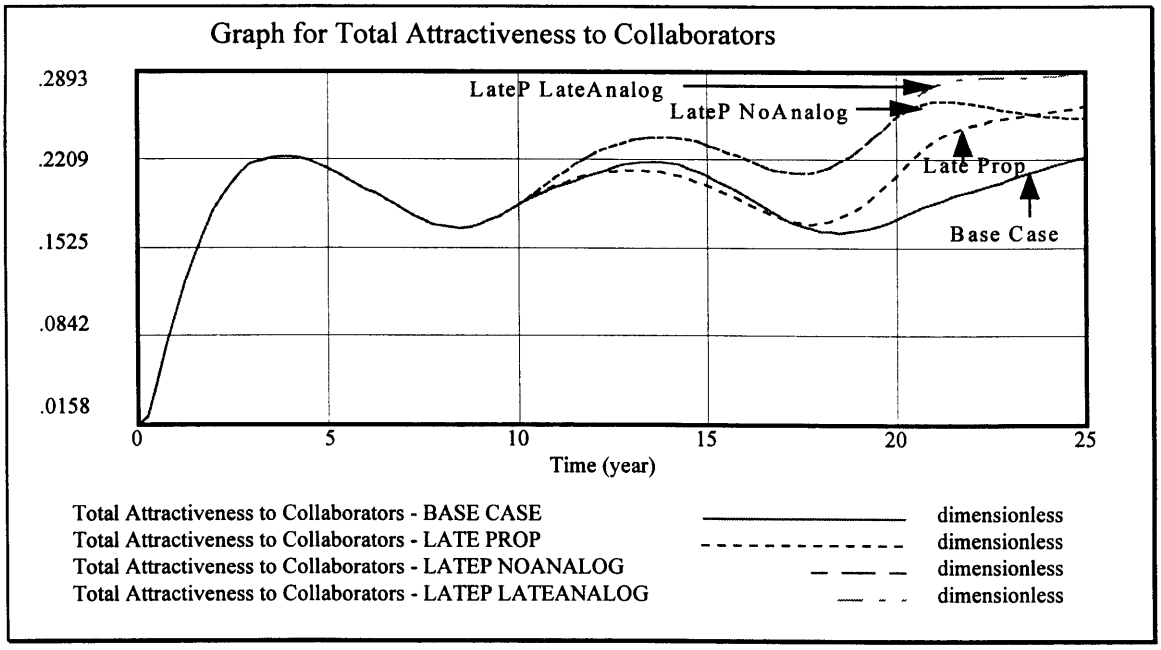
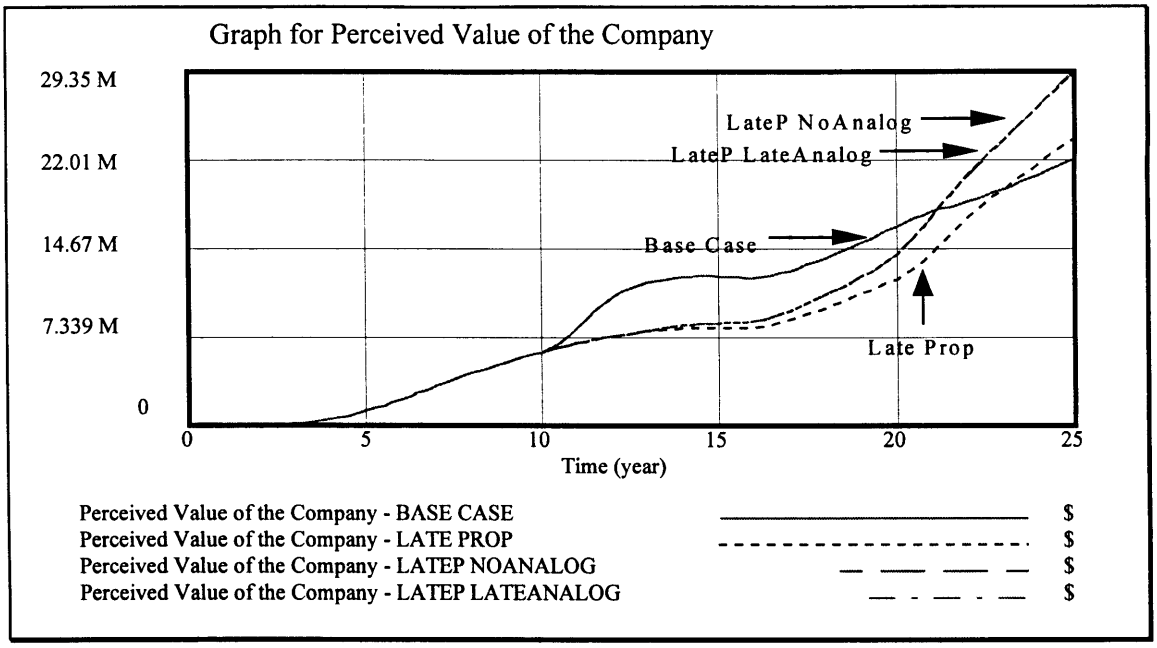


FIGURE 26. PERCEIVED VALUE -- PROPRIETARY PROGRAM AND TECHNOLOGY PLATFORM GROWTH STRATEGIES WITH FAILURE OF FIRST DRUG IN MARKET



3.2.3. Failure of initial drugs and strong competitor

FIGURE 27. ATTRACTIVENESS TO COLLABORATORS -- PROPRIETARY PROGRAM AND TECHNOLOGY PLATFORM GROWTH STRATEGIES WITH FAILURE OF FIRST DRUG IN MARKET AND STRONG COMPETITORS

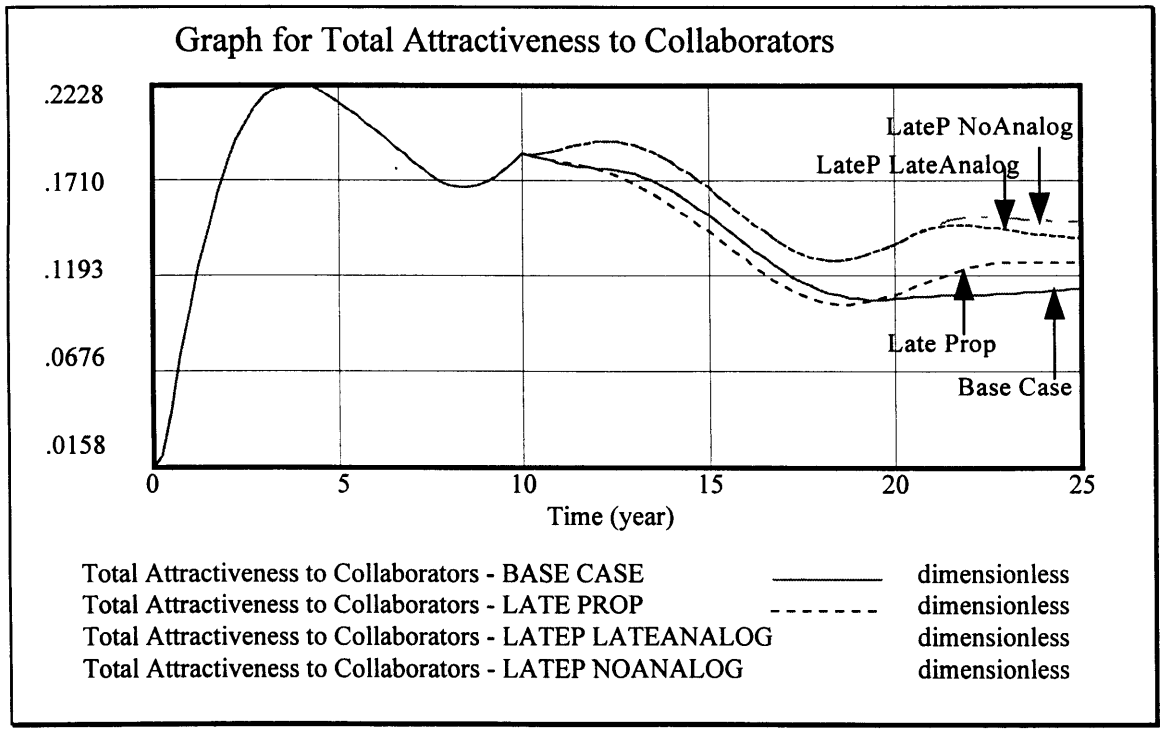
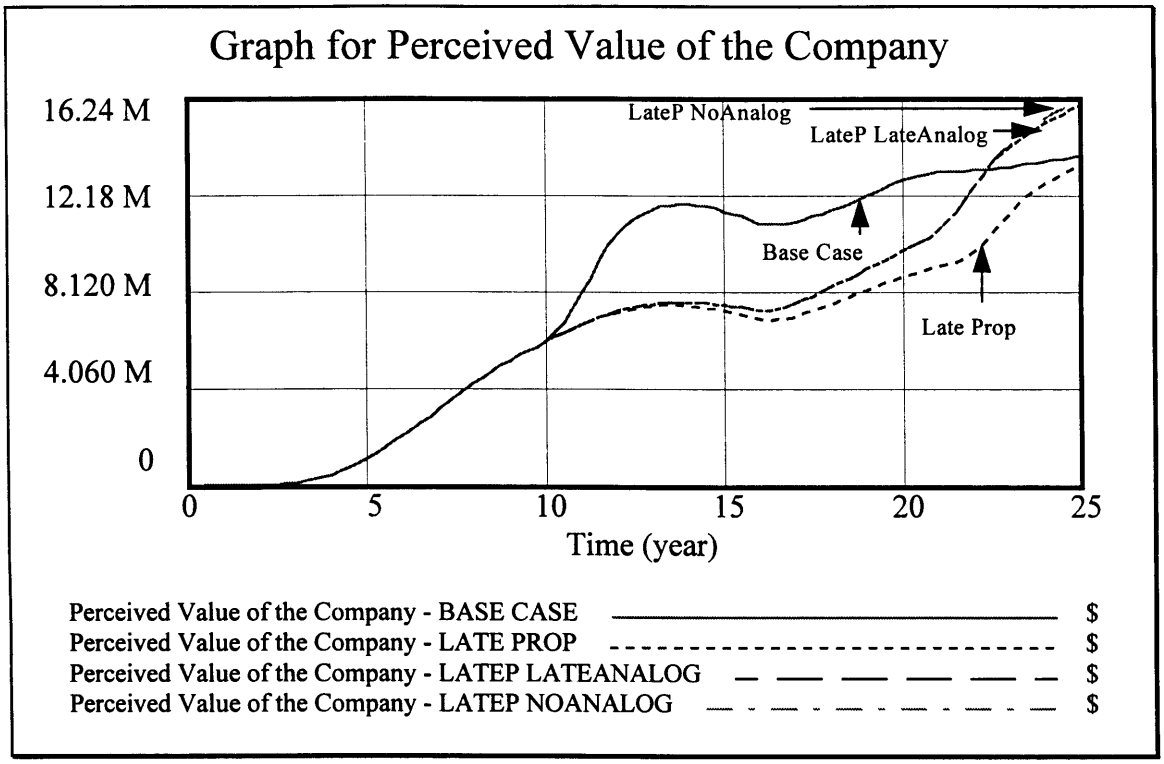


FIGURE 28. PERCEIVED VALUE -- PROPRIETARY PROGRAM AND TECHNOLOGY PLATFORM GROWTH STRATEGIES WITH FAILURE OF FIRST DRUG IN MARKET AND STRONG COMPETITORS



3.3. Summary of results

Table 1. summarizes the relative performance of the strategies listed below (the strategies are ranked based on the company's attractiveness to collaborators and its perceived value):

- Base Case -- Invest in analoging and proprietary projects once attractiveness threshold is reached in screening.
- Late Prop -- Invest in analoging once attractiveness threshold is reached in screening, invest in proprietary projects when the first successful drug gets to market.
- LateP LateAnalog -- Invest in analoging and proprietary projects when the first successful drug gets to market.
- LateP NoAnalog -- Do not invest in analoging, invest in proprietary projects when the first successful drug gets to market.

TABLE 1. SUMMARY OF RESULTS

	WEAK COMPETITION	STRONG COMPETITION
INITIAL DRUG IS SUCCESSFUL	1. Late Prop	1. LateP NoAnalog
	2. LateP LateAnalog	2. LateP LateAnalog
	3. Base Case	3. Late Prop
	4. LateP NoAnalog	4. Base Case
INITIAL DRUG IS A FAILURE	1. LateP LateAnalog	1. LateP NoAnalog
	2. LateP NoAnalog	2. LateP LateAnalog
	3. Late Prop	3. Base Case
	4. Base Case	4. Late Prop

4. Discussion

4.1. Favorable Environment Conditions

This section analyses the simulations run under "favorable" environment conditions - i.e. weak competitors, and no drug failures. The next section explores the simulations where these conditions do not favor the company.

Base Case

These simulations were run to explore the behavior of the model under the "base case" scenario, which closely reflects the company's expectations for the future (explained in Section 1.2. and presented in Figure 1.). The results of these runs are presented in Figures 14., 15., and 16.

Growth Strategy

Base Case -- invest in analoging and proprietary projects once attractiveness threshold is reached in screening.

Environment

No failures of drugs in market, no competitors.

Initially, the company starts with some amount of resources which it uses to develop its assay development capabilities, and is able to secure some collaborations (see Figure 14.). Shortly thereafter, it moves on to screening, further improving its collaborative status. However, as the company gradually depletes its initial resources (see Figure 16.), it begins to find it difficult to maintain its competencies in these two areas, and its ability to attract new collaborations begins to decline. Fortunately, the collaborations the company has embarked on thus far begin to get the markets' attention, raising the company's perceived value, and allowing it to raise capital to finance its technologies (see Figure 15. and Figure 16.). The company is then able to further its competencies in assay development and screening, attract more collaborations, increase its perceived value, and raise more capital (this process corresponds to the *competency growth loop* in Figure 2.). At this point, the company begins investing in analoging and proprietary projects. Its newly developed analoging capabilities, make the company more attractive to collaborators, which, coupled with the increase in the company's perceived value due to it's proprietary projects, allow for much needed capital to be raised (this process corresponds to the *Technology Platform Growth Loop* in Figure 2.) . This enables the company to further both its technology capabilities, as well as its proprietary programs. Finally, some of the initial collaborations are successful in getting drugs to market, and the company begins to earn royalties (this process corresponds to the *Royalty Payoff Loop* in Figure 2.). The company's success raises its perceived value, and thus also improves its ability to raise capital. Eventually, the company is able to finance itself completely using its own resources (which were earned in the form of royalties).

While the above scenario closely mirrors the company's expectations, it produces a behavior that had not originally been anticipated. Confidence in the company begins to rise as the some of the company's collaborations prove to be successful. However, this level of confidence plateaus, and then begins to decrease (see Figure 14.). This decline

can be traced back to the company's initial undertaking of proprietary projects, when it was unable to adequately fund these early programs. The projects are delayed in progressing through the pipeline, which eventually leads to the company being unable to meet the initial expectations of the market.

Proprietary program growth strategies

These simulations were run to explore the behavior of the model under two alternative growth strategies for proprietary projects. The results of these runs are presented in Figures 17., 18., 19., and 20.

Growth Strategy

Late Prop -- Invest in analoging once attractiveness threshold is reached in screening, invest in proprietary projects when the first successful drug gets to market.

No Prop -- Invest in analoging once attractiveness threshold is reached in screening, do not invest in proprietary projects.

Environment

No failures of drugs in market, no competitors.

At the point where the company begins investing in proprietary projects in the base case run, the relative attractiveness of the company's technology areas begins to lag behind attractiveness in the Late Prop and No Prop runs, while its perceived value begins to rise above the other two runs (see Figure 17. and 18.). Investment in proprietary projects adds to the market's expectations of the company and thus lead to a higher perceived value (see Figure 18.). As a result, the company is able to raise more capital. However, because the company's proprietary programs significantly drain its financial resources, it actually invests less in its technologies (this process corresponds to the *Constraining Resources Due to Proprietary Projects Loop* in Figure 4.).

While this is a plausible scenario, the outcome depends on the relative magnitudes of the costs of the proprietary programs, the costs of maintaining competence in

technology areas, and the additional resources the company is able to raise because of the increase in the company's perceived value due to the proprietary programs. Another possible scenario is that the additional capital that the company is able to raise due to its proprietary programs is more than sufficient to fund both its proprietary programs as well as its technology areas. However, it is reasonable to assume that the proprietary programs will indeed result in lowered investment in technology. This leads to lower competence in these areas, and thus adversely affects the company's new collaborations. Thus, in the long run, fewer new collaborations will lead to a lower market value, thus decreasing the potential investment available to the company (see Figure 19) -- the difficulty in raising capital will be worsened because the company has already raised significant capital in order to fund its proprietary projects.

Another (possibly more significant) effect that occurs is that because the company is not able to sufficiently fund its proprietary projects to ensure their timely progression through the R&D pipeline, these projects do not produce results in the time frame that the market had expected (another reason that these programs may not perform as expected, one that is not considered in the model, is that the company lacks the necessary experience and expertise outside of the discovery phase). This leads to a loss of confidence in the company (see Figure 20.), which then results in a decrease in the company's perceived value. Again, the end result is that both the company's new collaborations, and its ability to raise capital will suffer. The oscillatory behavior pattern that confidence follows is a result of the discrepancy between the market's expectations and the company's actual successes -- while the market expects a continuos stream of successful projects (based on new project undertakings in the past), the company's actual successes are periodic.

In the two cases where the company does not rush into the proprietary programs (Late Prop run, and No Prop run), it is able to focus on its technologies and develop them without the severe resource constraints placed by proprietary programs. The company becomes more attractive to collaborators, which eventually leads to a higher perceived

value, which in turn allows the company to raise more capital. In the Late Prop run, the company begins investment in proprietary programs after it has a drug in market and thus has revenues flowing in. These revenues, along with the additional capital that the company can raise because of the increase in its perceived value because of the successful projects, allow the company to adequately fund its proprietary programs without drawing resources away from its technology areas. Also, in the long run, the company is better able to meet the markets expectations, leading to higher confidence, and consequently a higher perceived value.

Proprietary program and technology platform growth strategies in combination

These simulations were run to explore the behavior of the model under two additional growth strategies which combined the Late Prop policy described in previous runs with two alternative policies for investment in proprietary projects. The results of these runs are presented in Figures 21., and 22.

Growth Strategy
LateP NoAnalog -- Do not invest in analoging, invest in proprietary projects when the first successful drug gets to market.
LateP LateAnalog -- Invest in analoging and proprietary projects when the first successful drug gets to market.
Environment
No failures of drugs in market, no competitors.

The graphs in Figures 21., and 22. show that the Late Prop strategy yields better results than both of the other strategies (LateP NoAnalog and LateP LateAnalog). It was expected that the LateP LateAnalog strategy would yield better results than the Late Prop strategy, by virtue of avoiding the *Spread too Thin Loop* presented in Figure 3. However, since the company is operating in ideal environment conditions (i.e. no competitors and no failed drugs), and since it has not begun to invest in proprietary programs, it is able to raise the additional capital needed to build its analoging capabilities without having to take resources away from assay development or screening. Thus, the company becomes more attractive to collaborators earlier on, which leads to a higher perceived value, which in turn places the company in a better position to raise capital when needed. When the

company then begins to invest in proprietary projects, it is better able to invest the resources needed to push these projects through the pipeline. This will eventually lead to higher confidence, higher perceived value, and better access to capital.

4.2. Unfavorable Environment Conditions

The strategies used in the previous runs (Base Case, Late Prop, LateP LateAnalog, and LateP NoAnalog) were tested under "unfavorable" environment conditions, in order to further explore the hypotheses stated in section 1.2.

4.2.1. Strong competitor

An "unfavorable" competitive scenario was constructed by having growing competitors in both screening and analoging. (Screening Competitor: Growth Rate =1, Growth Start Time = 10; Analoging Competitor: Growth Rate =1, Growth Start Time = 5). This competitive profile reflects a very likely scenario, because even though the company has been able to maintain a clear superiority in assay development, there are already several companies who have begun to develop high throughput screening capabilities, and many of the larger pharmaceutical firms already have significant capabilities in high speed analoging.

As Figures 23. and 24. show, when the company adopts the Late Prop strategy and invests in analoging early on, it is worse off than when it follows the Latep NoAnalog or LateP LateAnalog strategies. When faced with strong competition in screening, the company needs to invest heavily into this area to remain attractive to collaborators. Thus, if the company moves into analoging, it drains much needed resources away from screening, allowing the competitors in this area to catch up, and possibly offsetting any increase in attractiveness that could have occurred from analoging

(this process corresponds to the *Spread too Thin Loop* in Figure 3.). Furthermore, if there is strong competition in analoging as well, the company's resource constraints will be doubly severe. In the cases where the company does not rush into analoging (LateP NoAnalog and LateP LateAnalog), it is better able to defend its screening competencies, and thus remains attractive to collaborators.

While the company's attractiveness is similar for both the LateP NoAnalog and the LateP LateAnalog runs, it is better off in terms of its perceived value when it adopts the LateP NoAnalog strategy (see Figure 24.). The LateP LateAnalog policy has two shortcomings. Firstly, by waiting to expand its platform into analoging, the company will have allowed the competitor to develop its competency in this area, and thus will find it difficult to become attractive to collaborators (in analoging). Thus, the company's investments into analoging will not have any significant positive effect on its overall attractiveness. On the other hand, despite the revenues coming in from royalties, the attempt to catch up to the competitor will require significant resources, some of which will be taken away from the company's other technology areas. This will have a negative impact on overall attractiveness to collaborators. Also, these investments will detract from the company's investments into proprietary projects, which will result in a lower perceived value. Eventually, these shortfalls in investing into proprietary projects will lead to lowered confidence, which will then further lower the company's perceived value.

4.2.2. Failure of initial drugs in market

The purpose of these simulations (see Figures 25. and 26.) was to allow for the misfortunes that may come about from the tremendous uncertainties involved in the performance of a drug once it gets to market. The net result of a drug failure is that the company is severely resource constrained, both due to the lack of the royalties that would have resulted had the drug been successful, and due to the effect of the lowered confidence in the company. Thus, as Figure 25. shows, investing in analoging early on (Base Case and Late Prop runs) leads to a manifestation of the "spread too thin" effect,

which results in a decrease in overall attractiveness. Once the second drug gets to market however, the company can invest in analoging without significantly affecting its other technology areas, and is thus able to raise its overall attractiveness to collaborators. This accounts for the difference in attractiveness levels between the LateP LateAnalog and the LateP NoAnalog runs towards the end of the simulation.

A somewhat surprising result is that, initially, the Base Case run does better than the other 2 strategies in terms of the perceived value of the company. When the company invests in proprietary programs, this drains resources away from it technology areas, leaving them worse off. However, the proprietary projects have a significant effect on the company's perceived value, because of higher expectations on the market's behalf. The company is then able to raise more capital, and to a certain extent support its technologies. Eventually however, because the company does not have the resources to push its proprietary projects through the pipeline, the market's expectations are not met, and the resulting lowered confidence brings down both the company's perceived value, as well as its attractiveness to collaborators.

4.2.3. Failure of drugs and strong competitor

This scenario combines both the strong competitors and the failed initial drug to represent a worse case scenario in terms of the environment. The simulation results are presented in Figures 27. and 28. The relative performance of each of the strategies is qualitatively similar to the behavior observed in the previous run -- adding strong competition to the failed drug scenario simply serves to worsen the company's resource constraints, and does not change the relative effectiveness of the various strategies.

5. Conclusions

The purpose of this study was to investigate possible growth strategies for a young biotechnology company in terms of its technology platform and its proprietary programs. A system dynamics model was built in order to logically explore the relationships between the company's growth strategy and several hypothesized outcomes. While the model was designed to represent a particular company in the biotechnology industry, the results and conclusions drawn from it are applicable to companies in any technology driven industry where there is a significant delay between research investments and the corresponding returns.

5.1. Implications for the company

The primary concern for a young company is its resource constraints. Until it is able to get its products to the marketplace and begin generating revenues, it will be forced to rely on outside elements to finance its activities. The strategies used in investing these scarce resources will play a crucial role in determining the short term and long term success of the company. While it is difficult to plan over long time horizons when immediate needs must be met, policies that either ignore future consequences, or neglect to consider uncertainties in the environment, may eventually prove to be disadvantageous.

Proprietary Projects

Investment in proprietary programs do not offer the company a reliable growth opportunity during its early years. Embarking on proprietary projects can be used as a tool to boost a company's market value in the short run by raising expectations of the company's future revenues. This enables the company to raise much needed capital, which it can invest in its proprietary projects, and also in its technology platform.

However, until the company begins to realize the benefits of its work, it will be severely resource constrained. Thus, it is unlikely that the additional capital raised will be sufficient to ensure the continued progress of these proprietary projects while still maintaining the company's technological competencies.

During the early years of the company's lifetime, it does not have an established "track record". Thus, the perceived value of the company, and consequently its ability to raise capital, depend primarily on its ability to secure new collaborations, and on the undertaking of new proprietary projects. In the long run however, the most important factor will be the company's ability to deliver results, of the expected magnitude and within the expected time-frame. If the company invests in proprietary programs at an early stage and is unable to fund them adequately, these projects will not be able to follow a normal progression through the pipeline. Thus, they will not produce results when expected, and the market, as well as potential collaborators, will begin to lose confidence in the company. This can potentially have a drastic effect on the company's perceived value, and as a result, severely limit the company's access to capital. Moreover, the immense cost of these proprietary programs will most likely result in less resources being invested into the company's technology platform. This will result in a decline in the company's capabilities in these areas, and consequently decrease its attractiveness to collaborators. Also, if strong competitors emerge in these areas, the company will not be in a position to defend its competencies, which will further impair its ability to secure new collaborations. Thus, the company will be placed in a vulnerable position not only financially, but also in terms of its technical competencies.

Investment in proprietary projects during its early years can be detrimental to the company. A much more robust strategy would be to begin these programs once the company begins to realize the benefits from its successful collaborations, and is less constrained in terms of its resources. At this point, the company will be in a much better position to ensure the success of its proprietary programs, while still maintaining its technological competencies.

Technology Platform

The benefits of investing into the growth of the company's technology platform will be highly dependent on the competitive scenario it encounters. As long as the company is faced with resource constraints, a broader platform will lead to a trade-off in terms of the depth (i.e. competency in any one area) of its technology base. If the company is significantly ahead of its competitors in each of its technology areas, the effect of the decrease in competency will be far outweighed by the benefits of having a broader platform -- the company will be more attractive to collaborators and be able to secure better terms of collaboration, which will lead to higher expectations of future earnings, which in turn will enable the company to have better access to capital. However, if competitors aggressively build capabilities in any of these areas, a broader platform will significantly decrease the company's ability to defend its competencies. A robust expansion strategy must take into account any possibilities of future competitive developments. In the case of the said company, competitors are likely to begin developing strong capabilities in the company's established areas of expertise. The company needs to be able to aggressively invest into these technology areas if and when the need arises, and given its resource constraints, having a focused technology base will better enable it to do so.

Investing in a broader technology base during its early years can be detrimental to the company, especially if there is a likelihood of strong competition. A better strategy would be for the company to maintain a focused technology base until it begins to realize the benefits from its successful collaborations. At this point, the company will be much less constrained in terms of its resources, and thus will be in a better position to invest into new technology areas without weakening its existing competencies.

5.2. Implications for the industry

Companies who maintain a focused technology base during their early years will be much better equipped to deal with increased competition, as well as any contingencies that may arise from the uncertainties inherent to the industry. Once a company begins to generate revenues from royalties, it will be in a much better position to manage a broader technology platform. However, because of the long time delay involved in realizing these benefits, it is likely that others will have been able to develop strong capabilities in the areas that the company wishes to expand into. Thus, despite the availability of resources to invest into the new technologies, the company may find it difficult to "catch up" to the established competitors in those areas. This will be especially true if the competitors themselves have been maintaining a focused platform, and thus are in a better position to defend their competencies. The resulting implication is that companies may need to be increasingly focused in order to stay competitive. This could lead to an increasingly fragmented R&D pipeline, where a particular project will be worked on by several highly specialized companies during the various phases of its development cycle. Further investigation of these implications may prove valuable to the industry.

Acknowledgments

I would like to express my utmost gratitude to Professor James Hines who has been exceedingly accommodating in his supervision of my work. I would also like to acknowledge the consideration and assistance given me by Martin Groβmann and by members of the company's management team. Finally, I offer my sincerest thanks to Padmi Manel and Rajan Jei for their unyielding and continued support.

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Appendix: Model Equations

(001) Acquiring Analoging Capacity = Analoging Capacity to be Acquired/Average Time to Acquire Capacity
Units: compound/(year*year)

(002) Acquiring Assay Development Capacity = Assay Development Capacity to be Acquired/ Average Time to Acquire Capacity
Units: assay/(year*year)

(003) Acquiring Screening Capacity = Screening Capacity to be Acquired/ Average Time to Acquire Capacity
Units: compound/(year*year)

(004) Actual vs Expected Success = Drugs in Market - Expected Drugs in Market
Units: dimensionless
The difference between actual drugs in market and expected drugs in market is used as a measure of how the company's projects fair relative to what was expected, and is used to determine the level of confidence that collaborators and the market have in the company.

(005) Additional Analoging Capacity to be Acquired = Investment in Analoging/Cost of Analoging Capacity
Units: compound/(year*year)

(006) Additional Assay development Capacity to be Acquired = Investment in Assay Development/ Cost of Assay Development Capacity
Units: assay/(year*year)

(007) Additional Screening Capacity to be Acquired = Investment in Screening/Cost of Screening Capacity
Units: compound/(year*year)

(008) Analoging Attractiveness Gap = Desired Attractiveness Level-Relative Attractiveness of Analoging
Units: dimensionless
The Gap is the difference between desired and actual attractiveness. This gap can be negative, which represents the case where the company exceeds its own expectations.

(009) Analoging Capacity = INTEG(Acquiring Analoging Capacity-Analoging Capacity Depreciation, 0)
Units: compound/year
Analoging Capacity represents the company's ability to analog lead/hit compounds for further development. This "capacity" is in the form of scientists/researchers and labs/equipment.

(010) Analoging Capacity Depreciation = Analoging Capacity/Average Lifetime of Capacity
Units: compound/(year*year)
Depreciation represents both the depreciation of equipment, as well as the "depreciation" of the technology (i.e. the technology used becoming obsolete).

(011) Analoging Capacity Shortfall = MAX(Desired Analoging Capacity-Analoging Capacity,0)
Units: compound/year

(012) Analoging Capacity to be Acquired = INTEG(+Additional Analoging Capacity to be Acquired -Acquiring Analoging Capacity,0)
Units: compound/year

(013) Assay Development Attractiveness Gap = Desired Attractiveness Level-Relative Attractiveness of Assay Development
Units: dimensionless
The Gap is the difference between desired and actual attractiveness. This gap can be negative, which represents the case where the company exceeds its own expectations.

(014) Assay Development Capacity = INTEG(Acquiring Assay Development Capacity -Assay Development Capacity Depreciation, 0.1)
Units: assay/year
Assay Development Capacity represents the company's ability to develop assays. This "capacity" is primarily in the form of scientists/researchers, but also includes the necessary labs/equipment.

(015) Assay Development Capacity Depreciation = Assay Development Capacity/Average Lifetime of Capacity
Units: assay/(year*year)
Depreciation represents both the depreciation of equipment, as well as the "depreciation" of the technology (i.e. the technology used becoming obsolete).

(016) Assay Development Capacity Shortfall = MAX(Desired Assay Development Capacity-Assay Development Capacity,0)
Units: assay/year

(017) Assay Development Capacity to be Acquired = INTEG (+Additional Assay development Capacity to be Acquired - Acquiring Assay Development Capacity,0)
Units: assay/year

(018) Attractiveness Threshold for Expansion = 0.2
Units: dimensionless
The attractiveness level of existing technology areas that the company requires before expanding into a new technology area / proprietary projects. This reflects the aggressiveness/willingness of the company to expand its technology platform and to invest in proprietary projects.

(019) Average Drug Lifetime = 9.6
Units: year
The "useful" lifetime of a drug is represented here as its patent protected period. Source: Estimated from the mean effective patent life of NCEs approved 1985-1989 (OTA, 1993).

(020) Average Lifetime of Capacity = 5
Units: year
Average Lifetime represents the useful life of the "capacity", due to usage, as well as due to technological obsolescence.

(021) Average Terms of Collaborations in Clinical Phase = ZIDZ(Terms of Collaborations in Clinical Phase,Collaborators' Projects in Clinical Phase)
Units: 1/Project

(022) Average Terms of Collaborations in Discovery Phase = ZIDZ(Terms of Collaborations in Discovery Phase,Projects in Discovery Phase)
Units: 1/Project

(023) Average Terms of Collaborations in Market = ZIDZ(Terms of Collaborations for Drugs in Market,Collaborators' Drugs in Market)
Units: 1/Project

(024) Average Terms of Collaborations in Preclinical Phase = ZIDZ(Terms of Collaborations in Preclinical Phase, Collaborators' Projects in Preclinical Phase)
Units: 1/Project

(025) Average Terms of New Collaborations = (Fraction of Collaborations that Include Assay Development*Collaboration Terms for Assay Development) + (Fraction of Collaborations that Include Screening*Increase in Collaboration Terms due to Screening) + (Fraction of Collaborations that Include Analoging*Increase in Collaboration Terms due to Analoging)
Units: 1/Project
The average terms of collaborations for each new project being undertaken.

(026) Average Terms of Proprietary Projects = 0.5
Units: 1/Project

(027) Average Time to Acquire Capacity = 1
Units: year
The average time needed from planning to acquisition of capacity.

(028) Begin Investing in Analoging = INTEG(Setting Begin Investing in Analoging,0)
Units: dimensionless
Depending on company strategy, investment in analoging begins either when the attractiveness threshold for expansion is reached in screening, or when the company gets its first successful drug to market.

(029) Begin Investing in Analoging when Competent in Screening Switch = 0
Units: dimensionless
When switch is on, investment in analoging begins when attractiveness threshold for expansion is reached in screening. When switch if off, investment in analoging begins when the company gets its first successful drug to market.

(030) Begin Investing in Analoging when Drugs in Market Switch = (1-Begin Investing in Analoging when Competent in Screening Switch)
Units: dimensionless
When switch is on, investment in analoging begins when the company gets its first successful drug to market. When switch if off, investment in analoging begins when the attractiveness threshold for expansion is reached in screening.

(031) Begin Investing in Proprietary Projects = INTEG(Setting Begin Investing in Proprietary Projects, 0)
Units: dimensionless
Depending on company strategy, investment in proprietary projects begins either when the attractiveness threshold for expansion is reached in screening, or when the company gets its first successful drug to market.

(032) Begin Investing in Proprietary Projects when Competent in Screening Switch = 0
Units: dimensionless
When switch is on, investment in proprietary projects begins when attractiveness threshold for expansion is reached in screening. When switch if off, investment in proprietary projects begins when the company gets its first successful drug to market.

(033) Begin Investing in Proprietary Projects when Drugs in Market Switch =

(1-Begin Investing in Proprietary Projects when Competent in Screening Switch)
Units: dimensionless
When switch is on, investment in proprietary projects begins when the company gets its first successful drug to market. When switch if off, investment in proprietary projects begins when attractiveness threshold for expansion is reached in screening.

(034) Begin Investing in Screening = INTEG(Setting Begin Investment in Screening,0)
Units: dimensionless
Investment in screening begins when the attractiveness threshold is reached in assay development.

(035) Changing of Confidence in Company = (Actual vs Expected Success - Confidence in Company's Ability to be Successful)/Time to Change Confidence in Company
Units: 1/year

(036) Clinical Phase Dropout Rate = Collaborator Clinical Project Completing*(1-Clinical Phase Success Rate)
Units: Project/year

(037) Clinical Phase Success Rate = 0.6
Units: dimensionless
The transition probability from the clinical PhaseI through to market. estimated from figures used by OTA (OTA, 1993).

(038) Collaboration Terms for Assay Development = 0.05
Units: 1/Project
The fraction of drug revenues that the company receives by doing the assay development phase of a given project.

(039) Collaborative Analoging Project Completing = Collaborative Projects in Analoging Phase/ Time To Complete Analoging Phase
Units: Project/year

(040) Collaborative Analoging Project Undertaking = Collaborative Screening Project Completing* Fraction of Collaborations that Include Analoging
Units: Project/year
The company does the analoging phase for some fraction of its collaborative assay development & screening projects, depending on how many of these collaborations included the analoging phase. The analoging phase for the rest of the assay development & screening projects are done by the collaborator/competitor

(041) Collaborative Assay Development Project Completing = Collaborative Projects in Assay Development Phase/Time to Complete Assay Development Phase
Units: Project/year

(042) Collaborative Assay Development Project Undertaking = Collaborative Discovery Project Undertaking*Fraction of Collaborations that Include Assay Development
Units: Project/year

(043) Collaborative Discovery Project Completing =Collaborative Analoging Project Completing + Collaborator Analoging Project Completing
Units: Project/year

(044) Collaborative Discovery Project Undertaking = New Collaborations*Projects per Collaboration
Units: Project/year

(045) Collaborative Projects in Analoging Phase = INTEG(+Collaborative Analoging Project Undertaking - Collaborative Analoging Project Completing, 0)
Units: Project
The projects for which the company has undertaken to analog the hit/lead compounds identified during screening for a collaborator.

(046) Collaborative Projects in Assay Development Phase = INTEG(+Collaborative Assay Development Project Undertaking - Collaborative Assay Development Project Completing,0)
Units: Project
The projects for which the company has undertaken to develop assays for a collaborator.

(047) Collaborative Projects in Screening Phase = INTEG(+Collaborative Screening Project Undertaking - Collaborative Screening Project Completing, 0)
Units: Project
The projects for which the company has undertaken to screen compounds against the assays developed for a collaborator.

(048) Collaborative Screening Project Completing = Collaborative Projects in Screening Phase/Time to Complete Screening Phase
Units: Project/year

(049) Collaborative Screening Project Undertaking = Collaborative Assay Development Project Completing*Fraction of Collaborations that Include Screening
Units: Project/year
The company does the screening phase for some fraction of its collaborative assay development projects, depending on how many of these collaborations included the screening phase. The screening phase for the rest of the assay development projects are done by the collaborator/competitor.

(050) Collaborator Analoging Project Completing = Collaborators' Projects in Analoging Phase/ Time To Complete Analoging Phase
Units: Project/year

(051) Collaborator Analoging Project Undertaking = Collaborator Screening Project Completing + (Collaborative Screening Project Completing*(1-Fraction of Collaborations that Include Analoging))
Units: Project/year
The company does the analoging phase for some fraction of its collaborative assay development & screening projects, depending on how many of these collaborations included the analoging phase. The analoging phase for the rest of the assay development, and assay development & screening projects are done by the collaborator/competitor.

(052) Collaborator Clinical Project Completing = Collaborators' Projects in Clinical Phase/ Time to Complete Clinical Phase
Units: Project/year

(053) Collaborator Clinical Project Undertaking = Collaborator Preclinical Project Completing* Preclinical Phase Success Rate
Units: Project/year

(054) Collaborator Preclinical Project Completing = Collaborators' Projects in Preclinical Phase/ Time to Complete Preclinical Phase
Units: Project/year

(055) Collaborator Preclinical Project Undertaking = (Collaborator Analoging Project Completing +

Collaborative Analoging Project Completing)*Discovery Phase Success Rate
Units: Project/year
The collaborator undertakes to develop all successful collaborative projects from the preclinical stage to the market. The fraction of projects that are successful in the discovery phase is determined by the Discovery Phase Success Rate.

(056) Collaborator Screening Project Completing = Collaborators' Projects in Screening Phase/ Time to Complete Screening Phase
Units: Project/year

(057) Collaborator Screening Project Undertaking = Collaborative Assay Development Project Completing*(1-Fraction of Collaborations that Include Screening)
Units: Project/year
The company does the screening phase for some fraction of its collaborative assay development projects, depending on how many of these collaborations included the screening phase. The screening phase for the rest of the assay development projects are done by the collaborator/competitor

(058) Collaborator Taking Drug to Market = Collaborator Clinical Project Completing*Clinical Phase Success Rate
Units: Project/year

(059) Collaborators' Drugs in Market = INTEG(Collaborator Taking Drug to Market - Drugs Leaving Market,0)
Units: Project

(060) Collaborators' Projects in Analoging Phase = INTEG(+Collaborator Analoging Project Undertaking - Collaborator Analoging Project Completing,0)
Units: Project
Projects for which the company either did the assay development or assay development & screening, but the analoging is done by the collaborator/competitor.

(061) Collaborators' Projects in Clinical Phase = INTEG(+Collaborator Clinical Project Undertaking + Proprietary Clinical Project Undertaking - Collaborator Clinical Project Completing,0)
Units: Project
The Clinical Phase is an aggregation of Phase I, Phase II, Phase III, Registration, and Launch. The collaborator undertakes not only its collaborative preclinical projects (which involved the company during the discovery phase), but also the company's proprietary projects which have been successfully brought through the preclinical phase.

(062) Collaborators' Projects in Preclinical Phase = INTEG(+Collaborator Preclinical Project Undertaking - Collaborator Preclinical Project Completing,0)
Units: Project
The collaborator undertakes to develop all collaborative projects from the preclinical stage to the market.

(063) Collaborators' Projects in Screening Phase = INTEG(+Collaborator Screening Project Undertaking - Collaborator Screening Project Completing,0)
Units: Project
Projects for which the company did the assay development, but the screening (and analoging) is done by the collaborator/competitor.

(064) Company's Initial Financial Resources = 3e+006
Units: $
The initial financial resources that the company started with.

(065) Company's Financial Resources = INTEG(Increasing Company's Financial Resources -Draining Company's Financial Resources,Comapany's Initial Financial Resources)
Units: $
The company's own financial resources are available for investment into its technology areas, proprietary projects, etc.

(066) Competitor Analoging Capacity =Competitor Initial Analoging Capacity + Competitor Initial Analoging Capacity*(Competitor Analoging Growth Switch*Competitor Analoging Growth Rate*(IF THEN ELSE(Time >Competitor Analoging Growth Start Time, (Time-Competitor Analoging Growth Start Time),0)))
Units: compound/year

(067) Competitor Analoging Growth Rate =1
Units: dimensionless

(068) Competitor Analoging Growth Start Time = 5
Units: year

(069) Competitor Analoging Growth Switch = 1
Units: dimensionless
When switch is off, the competitor's capability/capacity does not grow.

(070) Competitor Assay Development Capacity = Competitor Initial Assay Development Capacity + Competitor Initial Assay Development Capacity*(Competitor Assay Growth Switch*Competitor Assay Development Growth Rate*(IF THEN ELSE(Time >Competitor Assay Development Growth Start Time, (Time-Competitor Assay Development Growth Start Time),0)))
Units: assay/year

(071) Competitor Assay Development Growth Rate = 0.5
Units: dimensionless

(072) Competitor Assay Development Growth Start Time = 5
Units: year

(073) Competitor Assay Growth Switch = 0
Units: dimensionless
When switch is off, the competitor's capability/capacity does not grow.

(074) Competitor Initial Analoging Capacity = 1e+006
Units: compound/year

(075) Competitor Initial Assay Development Capacity = 1
Units: assay/year

(076) Competitor Initial Screening Capacity = 1e+006
Units: compound/year

(077) Competitor Screening Capacity = Competitor Initial Screening Capacity + Competitor Initial Screening Capacity*(Competitor Screening Growth Switch*Competitor Screening Growth Rate*(IF THEN ELSE(Time >Competitor Screening Growth Start Time,(Time-Competitor Screening Growth Start Time),0)))
Units: compound/year

(078) Competitor Screening Growth Rate = 1

Units: dimensionless

(079) Competitor Screening Growth Start Time = 10
Units: year

(080) Competitor Screening Growth Switch = 1
Units: dimensionless
When switch is off, the competitor's capability/capacity does not grow.

(081) Confidence in Company's Ability to be Successful = INTEG(Changing of Confidence in Company, 0)
Units: dimensionless
Confidence in the company gradually changes over time based on how its projects fair relative to what was expected. A confidence level of 0 indicates that the company's projects are performing upto expectations, a level<0 indicates low confidence, and a level>0 indicates high confidence.

(082) Cost of Analoging Capacity = 1
Units: $/(compound/year)
The costs of capacity have been based on data from the company, but have been altered to make it so that an equal amount of resources are required to reach a given level of competence (attractiveness relative to the competitor) in each area.

(083) Cost of Assay Development Capacity = 1e+006
Units: $/(assay/year)
The costs of capacity have been based on data from the company, but have been altered to make it so that an equal amount of resources are required to reach a given level of competence (attractiveness relative to the competitor) in each area.

(084) Cost of Discovery Phase = 1.5e+007
Units: $/Project
Source: Estimated from figures used by Lehman Brothers (Lehman Brothers, 1996).

(085) Cost of Preclinical Phase = 5e+006
Units: $/Project
Source: Estimated from figures used by Lehman Brothers (Lehman Brothers, 1996).

(086) Cost of Screening Capacity = 1
Units: $/(compound/year)
The costs of capacity have been based on data from the company, but have been altered to make it so that an equal amount of resources are required to reach a given level of competence (attractiveness relative to the competitor) in each area.

(087) Cumulative Analoging Projects = INTEG(Collaborative Analoging Project Completing, 0)
Units: Project
The total number of analoging projects that the company has done.

(088) Cumulative Assay Development Projects = INTEG(Collaborative Assay Development Project Completing, 0)
Units: Project
The total number of assay development projects that the company has done.

(089) Cumulative Screening Projects = INTEG(Collaborative Screening Project Completing,0)
Units: Project
The total number of screening projects that the company has done.

(090) Desired Analoging Capacity =Investment in Analoging Switch*Begin Investing in Analoging* Initial Desired Analoging Capacity*
Effect of Attractiveness Gap on Desired Capacity f(Analoging Attractiveness Gap)
Units: compound/year
Desired capacity is equal to the initial desired capacity, adjusted according to the relative attractiveness "gap". A positive gap leads to a higher desired capacity, while a negative gap lowers desired capacity.

(091) Desired Assay Development Capacity =Initial Desired Assay Development Capacity*
Effect of Attractiveness Gap on Desired Capacity f(Assay Development Attractiveness Gap)
Units: assay/year
Desired capacity is equal to the initial desired capacity, adjusted according to the relative attractiveness "gap". A positive gap leads to a higher desired capacity, while a negative gap lowers desired capacity.

(092) Desired Attractiveness Level = 0.8
Units: dimensionless
The company's desired level of competency relative to the competitor.

(093) Desired Proprietary Projects Undertaking = 1
Units: Project/year
The company's desired stream of proprietary projects.

(094) Desired Screening Capacity =Investment in Screening Switch*Begin Investing in Screening* Initial Desired Screening Capacity*Effect of Attractiveness Gap on Desired Capacity f(Screening Attractiveness Gap)
Units: compound/year
Desired capacity is equal to the initial desired capacity, adjusted according to the relative attractiveness "gap". A positive gap leads to a higher desired capacity, while a negative gap lowers desired capacity.

(095) Discount Factor for Clinical Phase = EXP(-Risk Inclusive Discount Rate*Expected Time for Clinical Project to get to Market)
Units: dimensionless

(096) Discount Factor for Discovery Phase = EXP(-Risk Inclusive Discount Rate*Expected Time for Discovery Project to get to Market)
Units: dimensionless

(097) Discount Factor for Discovery Phase Costs = EXP(-Risk Free Discount Rate*Time to Complete Discovery Phase)
Units: dimensionless
The discount factor for the costs for a particular phase is calculated using the risk free discount rate, since these costs can be considered as being "fixed".

(098) Discount Factor for Preclinical Phase = EXP(-Risk Inclusive Discount Rate*Expected Time for Preclinical Project to get to Market)
Units: dimensionless

(099) Discount Factor for PreClinical Phase Costs = EXP(-Risk Free Discount Rate*(Time to Complete Discovery Phase+Time to Complete Preclinical Phase))
Units: dimensionless
The discount factor for the costs for a particular phase is calculated using the risk free discount rate, since these costs can be considered as being "fixed".

(100) Discovery Phase Dropout Rate = (Collaborative Analoging Project Completing + Collaborator Analoging Project Completing)*(1 - Discovery Phase Success Rate)
Units: Project/year

(101) Discovery Phase Success Rate =Normal Discovery Phase Success Rate*Effect of Assay Development on Discovery Success Rate f(Relative Experience in Assay Development)
Units: dimensionless
The probability of a discovery project being successful depends to great extent on the assays. When the company has gained some experience in assay development, it is able to achieve a higher success rate for this phase.

(102) Draining Company's Financial Resources = MIN(Company's Financial Resources/Time to Invest Financial Resources, Need for Financial Resources)
Units: $/year
The company drains its resources according to its financial needs. If it needs more than it has, the company will attempt to raise capital to cover this difference.

(103) Drugs in Market =MAX((Collaborators' Drugs in Market) -
First X Drugs Fail in Market Switch, 0)
Units: Project
The Drugs in Market variable is used to test scenarios when drugs fail after getting to market.

(104) Drugs Leaving Market = Collaborators' Drugs in Market/Average Drug Lifetime
Units: Project/year

(105) Effect of Assay Development on Discovery Success Rate f ([(0,0)-(1,1)],(0,0),(1,1))
Units: dimensionless
The more experienced the company has in developing assays, the more successful its discovery projects will be.

(106) Effect of Attractiveness Gap on Desired Capacity f ([(-1,0)-(1,20)],(-1,0.6),(-0.5,0.65), (0,1), (0.25,3),(0.75,13),(1,20))
Units: dimensionless
A positive "gap" leads to a higher desired capacity, while a negative gap lowers desired capacity.

(107) Effect of Confidence in Company = Effect of Confidence in Company f(Confidence in Company's Ability to be Successful)
Units: dimensionless
Higher (based on its track record) confidence in the company, makes the company more attractive to both investors, as well as collaborators.

(108) Effect of Confidence in Company f ([(-2,0)-(2,2)],(-2,0.5),(2,1.5))
Units: dimensionless
Higher (based on its track record) confidence in the company, makes the company more attractive to both investors, as well as collaborators.

(109) Effect of Experience on Attractiveness f ([(0,0)-(1,1)], (0,0.5), (0.1,0.7), (0.25,0.85), (0.5,0.95), (1,1))
Units: dimensionless
As the company gains more experience, it is more attractive to collaborators.

(110) Effect of VCQ on Potential New Investment = Effect of VCQ on Potential New Investment f (Value Creation Quotient)
Units: dimensionless

A higher value creation quotient (VCQ) leads to higher potential investment in the company.

(111) Effect of VCQ on Potential New Investment f ([(0,0)-(3,1)], (0,0), (0.5,0.01), (1,0.03), (1.5,0.1), (2,0.2), (2.5,0.4), (2.75,0.6), (3,1))
Units: dimensionless
A higher value creation quotient (VCQ) leads to higher potential investment in the company.

(112) Expected Dropout Rate =DELAY FIXED(New Project Undertaking*(1-Expected Success Rate for Collaborations),Expected Time to get Drugs to Market,0)
Units: Project/year
The expectation of the company's projects getting to market (and also of some of them failing) depends on the projects undertaken in the past, the expected time for these projects to get to market, and the expected success rate.

(113) Expected Drugs in Market = INTEG(Expected Flow of Drugs to Market - Expected Drugs Leaving Market, 0)
Units: Project
The number of projects that should be in the market based on expectations.

(114) Expected Drugs Leaving Market = Expected Drugs in Market/Average Drug Lifetime
Units: Project/year

(115) Expected Flow of Drugs to Market =DELAY FIXED(New Project Undertaking* Expected Success Rate for Collaborations,Expected Time to get Drugs to Market,0)
Units: Project/year
The expectation of the company's projects getting to market depends on the projects undertaken in the past, the expected time for these projects to get to market, and the expected success rate.

(116) Expected Success Rate for Collaborations = Normal Discovery Phase Success Rate* Preclinical Phase Success Rate*Clinical Phase Success Rate
Units: dimensionless
The expected probability of a collaborative project resulting in a drug.

(117) Expected Success Rate for Projects in Clinical Phase = Clinical Phase Success Rate
Units: dimensionless

(118) Expected Success Rate for Projects in Discovery Phase = Discovery Phase Success Rate* Preclinical Phase Success Rate*Clinical Phase Success Rate
Units: dimensionless

(119) Expected Success Rate for Projects in Preclinical Phase = Preclinical Phase Success Rate* Clinical Phase Success Rate
Units: dimensionless

(120) Expected Time for Clinical Project to get to Market = Time to Complete Clinical Phase
Units: year

(121) Expected Time for Discovery Project to get to Market = Time to Complete Discovery Phase + Time to Complete Preclinical Phase + Time to Complete Clinical Phase
Units: year

(122) Expected Time for Preclinical Project to get to Market = Time to Complete Preclinical Phase + Time to Complete Clinical Phase
Units: year

(123) Expected Time to get Drugs to Market =Time to Complete Discovery Phase + Time to Complete Preclinical Phase + Time to Complete Clinical Phase
Units: year

(124) Expected Value of Successful Drug at Time of Launch = 2.5e+008
Units: $
The expected cumulative revenues of a drug in market, discounted to the year of launch. Source: Estimated from average drug lifecycle revenues used by Grabowski and Vernon (Grabowski, Vernon, 1990).

(125) FINAL TIME = 25
Units: year
The final time for the simulation.

(126) First X Drugs Fail in Market Switch = 1
Units: Project
The switch is used to set the (first x) number of drugs that fail after getting to market.

(127) Flow of Terms into Clinical Phase = (Average Terms of Collaborations in Preclinical Phase* Collaborator Clinical Project Undertaking) + (Average Terms of Proprietary Projects*Proprietary Clinical Project Undertaking)
Units: 1/year

(128) Flow of Terms into Discovery Phase = Collaborative Discovery Project Undertaking*Average Terms of New Collaborations
Units: 1/year

(129) Flow of Terms into Market = Average Terms of Collaborations in Clinical Phase*Collaborator Taking Drug to Market
Units: 1/year

(130) Flow of Terms into Preclinical Phase = Average Terms of Collaborations in Discovery Phase* Collaborator Preclinical Project Undertaking
Units: 1/year

(131) Flow of Terms out of Clinical Phase = Average Terms of Collaborations in Clinical Phase* Collaborator Clinical Project Completing
Units: 1/year

(132) Flow of Terms out of Discovery Phase = Collaborative Discovery Project Completing*Average Terms of Collaborations in Discovery Phase
Units: 1/year

(133) Flow of Terms out of Market = Drugs Leaving Market*Average Terms of Collaborations in Market
Units: 1/year

(134) Flow of Terms out of Preclinical Phase = Collaborator Preclinical Project Completing*Average Terms of Collaborations in Preclinical Phase
Units: 1/year

(135) Fraction of Collaborations that Include Analoging = Relative Attractiveness of Assay Development*Relative Attractiveness of Screening*Relative Attractiveness of Analoging
Units: dimensionless

The collaborations that include analoging depend on the joint attractiveness of assay development, screening and analoging.

(136) Fraction of Collaborations that Include Assay Development = 1
Units: dimensionless
All collaborations include assay development.

(137) Fraction of Collaborations that Include Screening =
Relative Attractiveness of Assay Development*Relative Attractiveness of Screening
Units: dimensionless
The collaborations that include screening depend on the joint attractiveness of screening and assay development.

(138) Increase in Collaboration Terms due to Analoging = 0.05
Units: 1/Project
The additional fraction of drug revenues that the company receives by doing the analoging phase of a given project.

(139) Increase in Collaboration Terms due to Screening = 0.05
Units: 1/Project
The additional fraction of drug revenues that the company receives by doing the screening phase of a given project.

(140) Increasing Company's Financial Resources =Royalties Switch*Royalties from Collaborators' Drugs
Units: $/year
The company's financial resources increase when it receives royalties.

(141) Initial Desired Analoging Capacity = 1e+006
Units: compound/year
Initial desired capacity reflects the capacity need to maintain the company's desired stream of drugs in development.

(142) Initial Desired Assay Development Capacity = 3
Units: assay/year
Initial desired capacity reflects the capacity need to maintain the company's desired stream of drugs in development.

(143) Initial Desired Screening Capacity = 1e+006
Units: compound/year
Initial desired capacity reflects the capacity need to maintain the company's desired stream of drugs in development.

(144) INITIAL TIME = 0
Units: year
The initial time for the simulation.

(145) Investment in Analoging =Investment of Financial Resources*Need for Investment in Analoging/Need for Financial Resources
Units: $/year
The amount of resources invested in analoging depends on the need for resources in analoging relative to the total need for resources.

(146) Investment in Analoging Switch = 0

Units: dimensionless
When switch is off, the company does not expand/invest in analoging.

(147) Investment in Assay Development =Investment of Financial Resources*Need for Investment in Assay Development/Need for Financial Resources
Units: $/year
The amount of resources invested in assay development depends on the need for resources in assay development relative to the total need for resources.

(148) Investment in Proprietary Projects =Investment of Financial Resources*Need For Investment in Proprietary Projects/Need for Financial Resources
Units: $/year
The amount of resources invested in proprietary projects depends on the need for resources in proprietary projects relative to the total need for resources.

(149) Investment in Proprietary Projects in Discovery Phase = Investment in Proprietary Projects Investment in Proprietary Projects in Preclinical Phase
Units: $/year
Projects further in the R&D pipeline receive a higher priority when resources are allocated for proprietary projects.

(150) Investment in Proprietary Projects in Preclinical Phase = MIN(Investment in Proprietary Projects, Need for Investment in Proprietary Preclinical Projects)
Units: $/year
Projects further in the R&D pipeline receive a higher priority when resources are allocated for proprietary projects.

(151) Investment in Proprietary Projects Switch = 1
Units: dimensionless
When switch is off, the company does not invest in proprietary projects.

(152) Investment in Screening =Investment of Financial Resources*
Need for Investment in Screening/Need for Financial Resources
Units: $/year
The amount of resources invested in screening depends on the need for resources in screening relative to the total need for resources.

(153) Investment in Screening Switch = 1
Units: dimensionless
When switch is off, the company does not expand/invest in screening.

(154) Investment of Financial Resources = New Investment in the Company + Draining Company's Financial Resources
Units: $/year
The company obtains financial resources by draining its own pool of resources, and by raising capital.

(155) Investment Shortfall = MAX(Need for New Investment - Potential New Investment in the Company,0)
Units: $/year
The amount of financial need not met by new investment in the company.

(156) Maximum Desired Projects in Discovery Phase = Desired Proprietary Projects Undertaking*Time to Complete Discovery Phase
Units: Project

The maximum number of projects that the company is willing to have in the discovery phase. This is to avoid a backlog of projects in the discovery phase.

(157) Need for Financial Resources = Need for Investment in Assay Development + Need for Investment in Screening + Need for Investment in Analoging + Need For Investment in Proprietary Projects
Units: $/year

(158) Need for Investment in Analoging = Cost of Analoging Capacity*((Analoging Capacity Shortfall/Time to Eliminate Capacity Shortfall) + Analoging Capacity Depreciation)
Units: $/year
The financial resources needed to eliminate the capacity shortfall and to compensate for depreciation.

(159) Need for Investment in Assay Development = Cost of Assay Development Capacity*((Assay Development Capacity Shortfall/Time to Eliminate Capacity Shortfall) + Assay Development Capacity Depreciation)
Units: $/year
The financial resources needed to eliminate the capacity shortfall and to compensate for depreciation.

(160) Need for Investment in Proprietary Discovery Projects = Cost of Discovery Phase*Proprietary Projects in Discovery Phase/Time to Complete Discovery Phase
Units: $/year
The resources needed to continue the proprietary projects in the discovery phase.

(161) Need for Investment in Proprietary Preclinical Projects = Cost of Preclinical Phase*Proprietary Projects in Preclinical Phase/Time to Complete Preclinical Phase
Units: $/year
The resources needed to continue the proprietary projects in the preclinical phase.

(162) Need For Investment in Proprietary Projects =Investment in Proprietary Projects Switch* Begin Investing in Proprietary Projects*(Need for Investment in Proprietary Discovery Projects + Need for Investment in Proprietary Preclinical Projects)
Units: $/year
The financial resources needed to further the company's proprietary projects.

(163) Need for Investment in Screening = Cost of Screening Capacity*((Screening Capacity Shortfall/Time to Eliminate Capacity Shortfall) +Screening Capacity Depreciation)
Units: $/year
The financial resources needed to eliminate the capacity shortfall and to compensate for depreciation.

(164) Need for New Investment = Need for Financial Resources - Draining Company's Financial Resources
Units: $/year
Need for New Investment is the amount of capital the company would like to be able to raise. This is equal to the portion of the company's financial need that cannot be met by using its own resources.

(165) New Collaborations = Potential New Collaborations*Total Attractiveness to Collaborators
Units: collaboration/year

(166) New Investment in the Company = MIN(Need for New Investment, Potential New Investment in the Company)
Units: $/year
The company will take the lesser of the amount of capital it needs, and the amount it is able to raise.

(167) New Project Undertaking = Collaborative Discovery Project Undertaking + Proprietary Discovery Project Undertaking
Units: Project/year

(168) Normal Discovery Phase Success Rate = 1
Units: dimensionless
The transition probability from the discovery phase to the preclinical phase. Source: Estimated from figures used by OTA (OTA, 1993).

(169) Perceived Value of the Company = SMOOTH(Present Value of Company,Perception Delay)* Effect of Confidence in Company
Units: $
The perceived value of the company corresponds to the company's market value. This depends not only on the company's "actual" value, but also on the market's confidence in its capabilities (based on its track record).

(170) Perception Delay = 1
Units: year
The delay associated with the market becoming aware of the company's actual value.

(171) Potential New Collaborations = 3
Units: collaboration/year
The potential for new collaborations has been simplified to be 1 of each of the three types of collaborations that the company undertakes -- Assay development, Assay Development & Screening, and Assay Development, Screening, & Analoging. The company agrees to complete whichever combination of the above phases that the collaborator wishes, and in return, it is re-imbursed for any costs incurred during the project, and receives some fraction of drug revenues (determined by the terms of collaboration) should the project lead to a successful drug.

(172) Potential New Investment in the Company = Perceived Value of the Company*Effect of VCQ on Potential New Investment/Time to Raise Capital
Units: $/year
The maximum amount of capital the company can raise depends on the company's value creation quotient (VCQ), and its perceived value.

(173) Preclinical Phase Dropout Rate = Collaborator Preclinical Project Completing*(1-Preclinical Phase Success Rate)
Units: Project/year

(174) Preclinical Phase Success Rate = 0.3
Units: dimensionless
The transition probability from the preclinical phase to clinical PhaseI. Source: Estimated from figures used by OTA (OTA, 1993).

(175) Present Value of Collaborative Projects in Clinical Phase = Collaborators' Projects in Clinical Phase*Average Terms of Collaborations in Clinical Phase*Expected Success Rate for Projects in Clinical Phase*Discount Factor for Clinical Phase*Expected Value of Successful Drug at Time of Launch
Units: $
The value of projects in a particular phase depends on the number of projects in that phase, their average terms of collaboration, the expected $ value of a successful drug(note that the costs of these projects are not taken into account, since any costs incurred are re-imbursed by the collaborator), the expected success rate to market (which is higher later phases), and the discount rate (which is higher for later phases). This formulation was derived from the methodology used by Myers and Shyam-Sunder (Myers and Shyam-Sunder, 1991) in calculating NPV under uncertainty.

(176) Present Value of Collaborative Projects in Discovery Phase = Projects in Discovery Phase* Average Terms of Collaborations in Discovery Phase*Expected Success Rate for Projects in Discovery Phase*Discount Factor for Discovery Phase*Expected Value of Successful Drug at Time of Launch
Units: $
The value of projects in a particular phase depends on the number of projects in that phase, their average terms of collaboration, the expected $ value of a successful drug (note that the costs of these projects are not taken into account, since any costs incurred are re-imbursed by the collaborator), the expected success rate to market (which is higher later phases), and the discount rate (which is also higher for later phases). This formulation was derived from the methodology used by Myers and Shyam-Sunder (Myers and Shyam-Sunder, 1991) in calculating NPV under uncertainty.

(177) Present Value of Collaborative Projects in Preclinical Phase = Collaborators' Projects in Preclinical Phase*Average Terms of Collaborations in Preclinical Phase*Expected Success Rate for Projects in Preclinical Phase*Discount Factor for Preclinical Phase*Expected Value of Successful Drug at Time of Launch
Units: $
The value of projects in a particular phase depends on the number of projects in that phase, their average terms of collaboration, the expected $ value of a successful drug(note that the costs of these projects are not taken into account, since any costs incurred are re-imbursed by the collaborator), the expected success rate to market (which is higher later phases), and the discount rate (which is higher for later phases). This formulation was derived from the methodology used by Myers and Shyam-Sunder (Myers and Shyam-Sunder, 1991) in calculating NPV under uncertainty.

(178) Present Value of Company =Present Value of Collaborative Projects in Discovery Phase + Present Value of Collaborative Projects in Preclinical Phase + Present Value of Collaborative Projects in Clinical Phase + Present Value of Proprietary Projects in Discovery Phase + Present Value of Proprietary Projects in Preclinical Phase + Present Value of Drugs in the Market
Units: $
The actual present value of the company is the sum of the values of all projects in the pipeline (proprietary and collaborative) and any revenues the company is receiving in the form of royalties.

(179) Present Value of Drugs in the Market = Royalties Switch*Drugs in Market*Expected Value of Successful Drug at Time of Launch*Average Terms of Collaborations in Market
Units: $

(180) Present Value of Proprietary Projects in Discovery Phase = ((Expected Value of Successful Drug at Time of Launch*Discount Factor for Discovery Phase) - (Cost of Discovery Phase*Discount Factor for Discovery Phase Costs) - (Cost of Preclinical Phase*Discount Factor for PreClinical Phase Costs))* Proprietary Projects in Discovery Phase*Average Terms of Proprietary Projects*Expected Success Rate for Projects in Discovery Phase
Units: $
The value of proprietary projects in a particular phase depends on the discounted expected future $ value of a successful drug less the discounted future costs incurred by the company prior to collaboration, the number of projects in that phase, the average terms of collaboration they will secure, and the expected success rate to market (which is higher later phases). This formulation was derived from the methodology used by Myers and Shyam-Sunder (Myers and Shyam-Sunder, 1991) in calculating NPV under uncertainty.

(181) Present Value of Proprietary Projects in Preclinical Phase = ((Expected Value of Successful Drug at Time of Launch*Discount Factor for Preclinical Phase) - (Discount Factor for PreClinical Phase Costs *Cost of Preclinical Phase))*Proprietary Projects in Preclinical Phase*Average Terms of Proprietary Projects*Expected Success Rate for Projects in Preclinical Phase
Units: $

The value of proprietary projects in a particular phase depends on the discounted expected future $ value of a successful drug less the discounted future costs incurred by the company prior to collaboration, the number of projects in that phase, the average terms of collaboration they will secure, and the expected success rate to market (which is higher later phases). This formulation was derived from the methodology used by Myers and Shyam-Sunder (Myers and Shyam-Sunder, 1991) in calculating NPV under uncertainty.

(182) Project Experience Needed to Reach Proficient Level = 10
Units: Project
The level of experience (number of projects completed) to become proficient.

(183) Projects in Discovery Phase = INTEG(+Collaborative Discovery Project Undertaking - Collaborative Discovery Project Completing,0)
Units: Project
All projects in discovery phase which are partly or fully being done by the company.

(184) Projects per Collaboration = 3
Units: Project/collaboration
A project is focused on a particular gene target. First, an assay for this gene target must be developed. Then, if the collaboration includes the screening phase, compounds from the collaborator's Library must be screened against the assay, and "hit" compounds identified. If the collaboration includes the analoging phase, the hits/leads must be analoged and optimized Lead compounds must be identified.

(185) Proprietary Clinical Project Undertaking = Preclinical Phase Success Rate*Proprietary Preclinical Project Completing
Units: Project/year

(186) Proprietary Discovery Phase Dropout Rate = (1-Discovery Phase Success Rate)*Proprietary Discovery Project Completing
Units: Project/year

(187) Proprietary Discovery Project Completing = ZIDZ(Proprietary Projects in Discovery Phase,(Time to Complete Discovery Phase*(Need for Investment in Proprietary Discovery Projects/Investment in Proprietary Projects in Discovery Phase)))
Units: Project/year
If the company is able to invest the resources needed into proprietary projects in any particular stage of the pipeline, it will be able to move them along in the "normal" time needed for that particular phase (the Time to Complete Phase). Otherwise, these projects will take relatively longer, based on how much the company is able to invest in the projects in that phase.

(188) Proprietary Discovery Project Undertaking =Investment in Proprietary Projects Switch* Begin Investing in Proprietary Projects*MIN(Desired Proprietary Projects Undertaking, MAX((Maximum Desired Projects in Discovery Phase - Proprietary Projects in Discovery Phase)/TIME STEP,0))
Units: Project/year
The company will maintain its desired stream of proprietary project undertaking, unless a backlog of projects is building up in the discovery phase, in which case the number of new proprietary project undertakings will be reduced accordingly.

(189) Proprietary Preclinical Phase Dropout Rate = (1-Preclinical Phase Success Rate)*Proprietary Preclinical Project Completing
Units: Project/year

(190) Proprietary Preclinical Project Completing = ZIDZ(Proprietary Projects in Preclinical Phase, (Time to Complete Preclinical Phase*ZIDZ(Need for Investment in Proprietary Preclinical Projects, Investment in Proprietary Projects in Preclinical Phase)))
Units: Project/year
If the company is able to invest the resources needed into proprietary projects in any particular stage of the pipeline, it will be able to move them along in the "normal" time needed for that particular phase (the Time to Complete Phase). Otherwise these projects will take relatively longer, based on how much the company is able to invest in the projects in that phase.

(191) Proprietary Preclinical Project Undertaking = Discovery Phase Success Rate*Proprietary Discovery Project Completing
Units: Project/year

(192) Proprietary Projects in Discovery Phase = INTEG(Proprietary Discovery Project Undertaking - Proprietary Discovery Project Completing,0)
Units: Project
The company does the discovery and preclinical phases of its proprietary projects, and then finds a collaborator to take it through to market.

(193) Proprietary Projects in Preclinical Phase = INTEG(Proprietary Preclinical Project Undertaking - Proprietary Preclinical Project Completing,0)
Units: Project
The company does the discovery and preclinical phases of its proprietary projects, and then finds a collaborator to take it through to market.

(194) Relative Attractiveness of Analoging = Analoging Capacity*Effect of Experience on Attractiveness f(Relative Experience in Analoging)/((Analoging Capacity*Effect of Experience on Attractiveness f(Relative Experience in Analoging)) + Competitor Analoging Capacity)
Units: dimensionless
Relative attractiveness of analoging depends on both the company's capacity, as well as its experience in this area, relative to its competitor (the competitor is assumed to have the "normal" amount of experience -- i.e. a relative experience of 1).

(195) Relative Attractiveness of Assay Development = Effect of Experience on Attractiveness f(Relative Experience in Assay Development)*Assay Development Capacity/((Effect of Experience on Attractiveness f(Relative Experience in Assay Development)*Assay Development Capacity) + Competitor Assay Development Capacity)
Units: dimensionless
Relative attractiveness of assay development depends on both the company's capacity, as well as its experience in this area, relative to its competitor (the competitor is assumed to have the "normal" amount of experience -- i.e. a relative experience of 1).

(196) Relative Attractiveness of Screening = Screening Capacity*Effect of Experience on Attractiveness f(Relative Experience in Screening)/((Screening Capacity*Effect of Experience on Attractiveness f(Relative Experience in Screening)) + Competitor Screening Capacity)
Units: dimensionless
Relative attractiveness of screening depends on both the company's capacity, as well as its experience in this area, relative to its competitor (the competitor is assumed to have the "normal" amount of experience -- i.e. a relative experience of 1).

(197) Relative Experience in Analoging = Cumulative Analoging Projects/Project Experience Needed to Reach Proficient Level
Units: dimensionless
The company's level of experience relative to the "proficiency" level.

(198) Relative Experience in Assay Development = Cumulative Assay Development Projects/Project Experience Needed to Reach Proficient Level
Units: dimensionless
The company's level of experience relative to the "proficiency" level.

(199) Relative Experience in Screening = Cumulative Screening Projects/Project Experience Needed to Reach Proficient Level
Units: dimensionless
The company's level of experience relative to the "proficiency" level.

(200) Revenue per Drug = 4e+007
Units: $/year
Average annual revenues from a drug in market. Source: Estimated from average drug lifecycle revenues used by Grabowski and Vernon (Grabowski, Vernon, 1990).

(201) Risk Free Discount Rate = 0.06
Units: dimensionless
The risk free discount rate represents a forecasted long term treasury bond rate. Source: Estimated from figures used by Myers and Shyam-Sundar (Myers, and Shyam-Sundar, 1991).

(202) Risk Inclusive Discount Rate =Risk Free Discount Rate + Risk Premium
Units: 1/year
The discount rate is the risk-free rate plus a risk premium, and represents the cost of capital of future cash flows (i.e. expected drug revenues), appropriate to the cash flows' risks. Source: Estimated from the discount rate calculated (in real terms) for "small" pharmaceutical firms by Myers and Shyam-Sundar (Myers, and Shyam-Sundar, 1991).

(203) Risk Premium = 0.1
Units: dimensionless
The risk premium is added to the risk-free rate to calculate the cost of capital of future cash flows (i.e. expected drug revenues). Source: Estimated from figures used by Myers and Shyam-Sundar (Myers, and Shyam-Sundar, 1991).

(204) Royalties from Collaborators' Drugs =Drugs in Market*Revenue per Drug*Average Terms of Collaborations in Market
Units: $/year
Royalties depend on the number of drugs in the market, the revenues for each drug, and the (average) fraction of those revenues that the company receives(average terms of collaboration).

(205) Royalties Switch = 1
Units: dimensionless
When switch is on the company receives royalties - used to test various scenarios.

(206) SAVEPER = 0.25
Units: year
The frequency with which output is stored.

(207) Screening Attractiveness Gap = Desired Attractiveness Level-Relative Attractiveness of Screening
Units: dimensionless
The Gap is the difference between desired and actual attractiveness. This gap can be negative, which represents the case where the company exceeds its own expectations.

(208) Screening Capacity = INTEG(Acquiring Screening Capacity-Screening Capacity Depreciation, 0)

Units: compound/year
Screening Capacity represents the company's ability to screen compounds against target assays. This "capacity" is in the form of screening robots (HTS systems) and scientists/researchers.

(209) Screening Capacity Depreciation = Screening Capacity/Average Lifetime of Capacity
Units: compound/(year*year)
Depreciation represents both the depreciation of equipment, as well as the "depreciation" of the technology (i.e. the technology used becoming obsolete).

(210) Screening Capacity Shortfall = MAX(Desired Screening Capacity-Screening Capacity,0)
Units: compound/year

(211) Screening Capacity to be Acquired = INTEG(+Additional Screening Capacity to be Acquired - Acquiring Screening Capacity,0)
Units: compound/year

(212) Setting Begin Investing in Analoging = Begin Investing in Analoging when Competent in Screening Switch*IF THEN ELSE(Relative Attractiveness of Screening > Attractiveness Threshold for Expansion :AND:Begin Investing in Analoging = 0,1/TIME STEP,0) + Begin Investing in Analoging when Drugs in Market Switch*IF THEN ELSE(Drugs in Market > 1 :AND: Begin Investing in Analoging = 0, 1/TIME STEP,0)
Units: 1/year
Depending on company strategy, investment in analoging begins either when the attractiveness threshold for expansion is reached in screening, or when the company gets its first successful drug to market.

(213) Setting Begin Investing in Proprietary Projects = Begin Investing in Proprietary Projects when Competent in Screening Switch*IF THEN ELSE(Relative Attractiveness of Screening > Attractiveness Threshold for Expansion :AND: Begin Investing in Proprietary Projects = 0,1/TIME STEP,0) + Begin Investing in Proprietary Projects when Drugs in Market Switch*IF THEN ELSE(Drugs in Market > 1 :AND: Begin Investing in Proprietary Projects=0,1/TIME STEP,0)
Units: 1/year
Depending on company strategy, investment in proprietary projects begins either when the attractiveness threshold for expansion is reached in screening, or when the company gets its first successful drug to market.

(214) Setting Begin Investment in Screening = IF THEN ELSE (Relative Attractiveness of Assay Development>=Attractiveness Threshold for Expansion :AND: Begin Investing in Screening = 0,1/TIME STEP,0)
Units: 1/year

(215) Terms of Collaborations for Drugs in Market = INTEG(Flow of Terms into Market- Flow of Terms out of Market,0)
Units: dimensionless

(216) Terms of Collaborations in Clinical Phase = INTEG(Flow of Terms into Clinical Phase - Flow of Terms out of Clinical Phase,0)
Units: dimensionless

(217) Terms of Collaborations in Discovery Phase = INTEG(Flow of Terms into Discovery Phase - Flow of Terms out of Discovery Phase,0)
Units: dimensionless

(218) Terms of Collaborations in Preclinical Phase = INTEG(+Flow of Terms into Preclinical Phase - Flow of Terms out of Preclinical Phase,0)

Units: dimensionless

(219) TIME STEP = 0.125
Units: year
The time step for the simulation.

(220) Time to Change Confidence in Company = 2
Units: year
The time needed for the market and collaborators to adjust their confidence in the company, based on how its projects fair relative to what was expected.

(221) Time To Complete Analoging Phase = 0.5
Units: year
The average time to complete an analoging project. Source: Estimated from Thayer (Thayer, 1995).

(222) Time to Complete Assay Development Phase = 0.5
Units: year
The average time to complete an assay development project. Source: Estimated from Thayer (Thayer, 1995).

(223) Time to Complete Clinical Phase = 7
Units: year
The average time required to complete Phase I, II, and III development, and FDA filing. Source: Estimated from figures used by Bienz-Tadmor (Bienz-Tadmor, 1993).

(224) Time to Complete Discovery Phase = Time to Complete Assay Development Phase + Time to Complete Screening Phase + Time To Complete Analoging Phase
Units: year

(225) Time to Complete Preclinical Phase = 1.5
Units: year
The average time required to complete the preclinical phase of a project. Source: Estimated from figures used by Bienz-Tadmor (Bienz-Tadmor, 1993).

(226) Time to Complete Screening Phase = 0.5
Units: year
The average time to complete a screening project. Source: Estimated from Thayer (Thayer, 1995).

(227) Time to Eliminate Capacity Shortfall = 2
Units: year
Given a capacity shortfall (i.e. a gap between desired and actual capacity), the time horizon over which the company plans to eliminate this gap.

(228) Time to Invest Financial Resources =1
Units: year
Resources are invested through an annual budget allocation.

(229) Time to Raise Capital = 1
Units: year
The time needed to raise capital.

(230) Total Attractiveness to Collaborators = Effect of Confidence in Company*(Relative Attractiveness of Assay Development + (Relative Attractiveness of Assay Development*Relative Attractiveness of

Screening) + (Relative Attractiveness of Assay Development*Relative Attractiveness of Screening* Relative Attractiveness of Analoging))/3
Units: dimensionless
The attractiveness of the company to collaborators depends on the confidence in the company (based on its track record in terms of successful R&D efforts), and on the attractiveness of its competencies relative to the competitor. Three types of collaborations are considered by the company - Assay development, Assay Development & Screening, and Assay Development, Screening, & Analoging. The number of assay development collaborations depends on the attractiveness of assay development; the number of assay development & screening collaborations depends on both the attractiveness of assay development as well as the attractiveness of screening; and so on.

(231) Total Investments Made in the Company = INTEG(New Investment in the Company, Company's Initial Financial Resources)
Units: $
The total amount of capital the company has raised.

(232) Value Creation Quotient = XIDZ(Perceived Value of the Company, Total Investments Made in the Company, 1)
Units: dimensionless
The ratio of a company's current market value (Perceived Value of the Company) to the amount of capital it has raised (Total Investments Made in the Company) is referred to as its value creation quotient (VCQ) by Coggan (Coggan, 1996). Coggan states that the VCQ can be indicative of how successful a company is, and it is used in the model as an indicator of how much capital the company will be able to raise.