Structured Approach to R&D Valuation
Using Investment Science to Analyze New Ideas

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We present a Research & Development case study that illustrates how to model initial decisions vs. down-stream decisions and the uncertainty that characterizes long-term projects of this type. The model recognizes the value of postponing key decisions until their due time along a project's life. It also incorporates the uncertain outcomes of a Research stage, and the market fluctuations preceding the production and marketing stages.

Practitioners will recognize the features of the model as improvements to simply choosing a set of decision inputs and running a Net Present Value analysis to determine which set yields the most valuable cash flow. By incorporating the flexibility of making decisions in due time we provide a model that is closer to the actual thought process followed by Managers and people in charge of funding R&D projects.

Although the case study shows only two decisions and two uncertainty sources, the framework can be easily adapted to deal with much more complex cases. The solution process through which a value for the project with all its possible cash flows is computed can also be readily extended.

1 A simple product

The R&D group at a large electronics company is considering different funding alternatives for a new project. The project will have a duration of one year and can be funded at one of two different levels: An *Aggresive* funding level of $750K or a *Moderate* funding level at $350K. The functionality of the product resulting from the 1 year development stage is uncertain and is likely to be influenced by the amount of funding. The features of the finished product will determine, to a great extent, the degree of its market potential. After the development stage is completed, the company will follow one of three production-marketing (PM) strategies:

1. *In house* manufacturing and marketing
2. *Partnership* manufacturing and marketing
3. *Spin Off* the project as a separate company

Regardless of the PM strategy, the product's life horizon is 10 years with no residual values.

The R&D group would like to determine the best funding strategy to follow taking into consideration (i) the uncertainty with respect to the market potential obtained from the initial R&D or prototyping stage and (ii) the value obtained from the subsequent production and marketing choices.

1.1 Uncertainties

There are two key uncertainties in the framing of our example: The outcome of the initial (1 year) research stage, and the evolution of the market size for the product during that stage.

The initial research stage is modeled as having two possible outcomes based on the degree of success achieved: One is a "Breakthrough" outcome and the other one is a "Marginal" outcome. Each outcome represents a scenario under which production and marketing will take place, so the outcome influences the cash-flow forecast under each PM strategy. The chance of each outcome is influenced by the choice of funding level: larger funding leads to more research staff and better resources. It is therefore necessary to carry out a probability assesment excercise to determine (to the best of the experts' knowledge) what the direct influence of the funding level on the chances of the possible outcomes is. The experts are people from R&D who are extremely familiar with the way research unfolds. They are asked to provide the probability assessment along with some form of justification. A pier-review process validates the soundness of the assessment to help remove any biases. After a series of interviews with experts in the R&D department it has been determined that a *Low* funding level will result in a 30% chance of "Breakthrough" and 70% chance of "Marginal" from R&D, and *High* funding will turn the probabilities around: 80% for "Breakthrough" and 20% for "Marginal". Table 1 presents a hypothetical result of such assessment.

Funding Level	**Chance of** "Breakthrough"	**Chance of** "Marginal"
Aggresive	80%	20%
Moderate	30%	70%

Table 1: *Funding decision and its influence on the likelihood of the outcomes.*

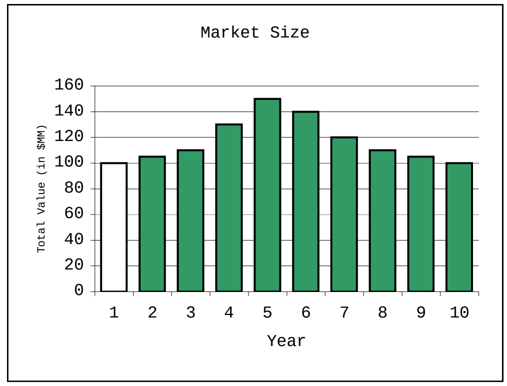

Figure 1: *Market size forecast. The first year is lost due to R&D.*

The second uncertainty is related to changes in the market size. Initially, at the time this analysis is conducted, a 10-year forecast is produced using all available data (see Figure 1). However, it is reasonable to believe that the current market conditions will not be the same one year into the future when the initial research stage will be completed. The market is modeled as having two possible directions: growing to a "Large" state of the world, or shrinking to a "Small" scenario. The likelihood of each outcome is independent of any variable in the analysis.

1.2 Value Model

Each PM strategy has a value based on the cashflow stream for the 9 years after R&D. The cashflow value for each year is computed using the market size (M) times a market share percentage forecast, times a margin-over-sales percentage. Therefore, each PM strategy has two sets of forecasts: market share (S) and margin (π):

$$v_{PM}(t) = M(t) \times S_{PM}(t) \times \pi_{PM}(t).$$

Also, there might be one-time extra costs (C) incurred after R&D but before production starts, and it is possible that additional value (I) to the company is created at the same time. Using a discount factor r_m[1], the net present value (NPV) of strategy *PM* over the full time horizon is equal to the discounted yearly cashflow down to year 2, plus additional value minus extra costs, and then discounted one more year (the R&D year).

There are two key questions we would like to address:

1. Which funding level and PM strategy combination maximizes the 10-year project value?

2. What is that maximum value?

1.3 Traditional analysis

We will use Discounted Cash-Flow analysis (DCF) as a base to compare results later. This is the most common approach to finding the value of projects. There are three possible PM strategies: *In House, Spin Off,* and *Partnership*, and each PM strategy has forecasts conditional on the outcome R&D[2]. We will use the (average) market forecast presented in Figure 1.

In order to compute the value, we proceed as follows:

1. Begin by focusing on funding level *Aggresive*.

2. For each PM strategy, compute the NPV given each possible R&D outcome.

[1]Using a risk preimum of 7.0% over a risk-free rate of 6.0% and a Beta of 1.55, the discount rate is 17.0%.

[2]The tables with the data can be found in the appendix at the end of this document.

3. Using the probabilities for the funding level, compute the expected NPV for each PM strategy.

4. The strategy with the highest expected NPV is the best choice for this funding level. Substract the funding quantity to obtain the actual value of the project.

5. Repeat these steps for the *Moderate* funding level.

6. Compare and select the funding level with the highest expected NPV. We now have an answer to the funding decision, the PM strategy decision, and the value of the project, as given by this analysis.

Applying these steps to our numeric data, we find the following expected NPV results per funding level:

Strategy	***Aggresive* Funding**	***Moderate* Funding**
In House	\$311	\$329
Partnership	-\$1,065	-\$239
Spin Off	\$163	-\$193

Table 2: *Expected NPV per DCF analysis (\$K).*

Given the probabilities of each R&D outcome and the cash flow data, the expected value for each funding level yields the following results: *In House* and a *Moderate* funding level is the combination with the highest expected NPV of \$329K. Management commits the funding and locks itself into one strategy one year ahead of the actual R&D outcome.

There are two key factors that the traditional DCF analysis fails to capture in this study case:

1. The uncertain market behavior during the first year (R&D time) is reduced to an average forecast that does not capture the amount of volatility that could force a change in the plans.

2. Although the decision to produce and market the prototype does not have to be evaluated until R&D has completed its project it is being decided now. Thus the fact that management most likely will revise its decision in the presence of new market data and fresh news from the lab has not been taken into account.

2 Structured Approach to R&D Funding

We developed a new, richer framework for this case:

- We model the first decision (funding) with its two possible values *Aggresive* and *Moderate* initially, as the only decision to be made.

- A year later, we model the state of the market size as "Large" or "Small". We carefully assess the likelihood of each one of this outcomes. This additional uncertainty captures the notion of volatility associated with evolving markets.

- The second decision (production-marketing strategy) will be made once R&D has concluded their 1-year work and the new market size data has been used to update the forecast.

- The value of a strategy will now depend on the state of the world as indicated by the choice of funding level, the outcome of R&D (RD) and the outcome of the market size (M_s): $v(PM|RD, M_s)$.

- All strategies will be considered in the final valuation. We seek to maximize the expected value of the project by choice of a funding level and production-marketing strategy.

Figure 2 shows a block diagram with a chronological representation of decisions and uncertainties. We begin by facing the funding decision. A year later, the R&D uncertainty is resolved in two possible outcomes. At that time the uncertainty about the state of the market is also resolved and the second decision can be confronted. We draw attention to the fact that the production-marketing decision is not made until a later date, hence the model is structured to accurately represent this management flexibility.

Each stage is defined as an individual entity in the model but the analysis combines them appropriately to match the actual structure of this case. We look first at the issues around choosing between two levels of funding.

2.1 Funding Decision

The first step consists of identifying the decisions and uncertainties directly related to research: The level of funding to be granted, the question about

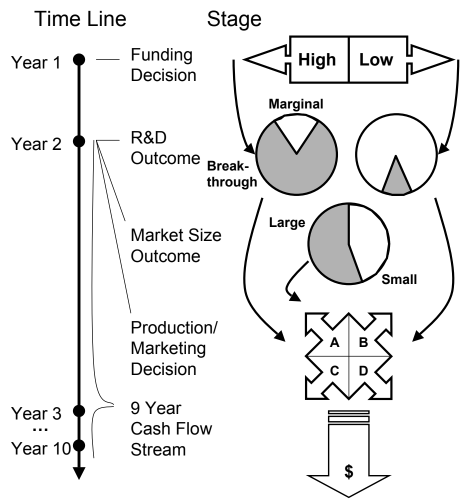

Figure 2: *The decision model*

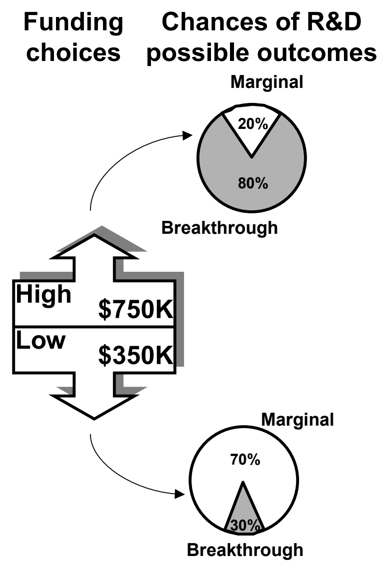

Figure 3: *A decision that directly affects the chances of success.*

the chances of success and the direct impact that the level of funding has on this uncertainty. We represent these key concepts in Figure 3.

There are two possible funding levels to choose from: *High*, and *Low*. After 1 year in the lab one of two possible outcomes will be revealed: a "Breakthrough", or just "Marginal" innovation. What changes from one funding level to the next is the *likelihood* of each outcome. Sensitivity analysis of the model can quickly determine how vulnerable the result is to changes in the probabilities: we recommend careful assessment if the model's recommendations change due to significant changes in the probabilities.

2.2 Revelation of outcomes

Once the first year has elapsed the two key uncertainties will reveal their outcomes. The R&D outcome will dictate which set of market share and margin forecasts to use for each PM strategy. The market size uncertainty is modeled as having two possible outcomes one year into the future: "Large" and "Small". Given a 10-year market forecast $M(t)$, a "Large" market size scales the forecast by some factor $u > 1$. Conversely, a "Small" market scales down the forecast by some factor d, $0 < d \leq 1$.

There is a probability associated with the likelihood of a "Large" market, q[3]. The NPV of each PM strategy will be computed using a market forecast scaled up or down depending on the "Large" or "Small" market size outcome.

2.3 Production-Marketing Decision

The second stage in the framework deals with the production-marketing choice at the time R&D has produced a prototype. The outcomes of the R&D and market size uncertainties impact the value of each of the strategies available to the company for production and marketing. Figure 4 shows a block diagram illustrating these relationships.

A cash-flow is prepared for each PM strategy that takes into account the R&D outcome and the market outcome: *In House*, *Partnership*, and *Spin Off*. We will add a fourth one: the option to *Abandon* after the first year. This strategy does not have any cash flow streams and simply generates an added value of $300K (perhaps in new patents) regardless of the combination of outcomes. Each strategy is valued under each possible scenario. The risk presented by the uncertainty in market size during the year of research before production and marketing

[3]A method to determine u, d, and q uses advanced Investment Science concepts to extract this information from a set of related stocks and their prices. Such method will be presented in an upcoming article.

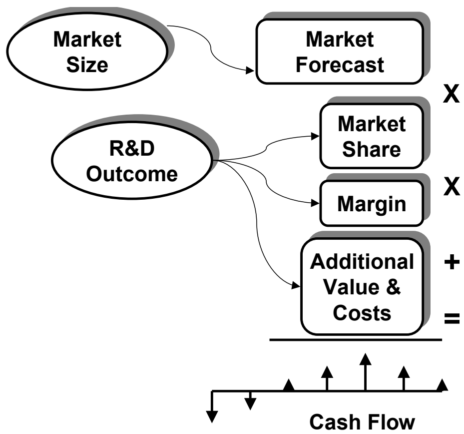

Figure 4: *Uncertain events could impact forecasts.*

must be considered in the cash flow valuation. In the definition of a strategy's NPV a discount rate r_m is defined for all periods. We use the appropriate discount rate related to the first year (r_f) as follows:

$$NPV_{PM} = \frac{1}{1+r_f} \cdot \sum_{t=2}^{10} \frac{1}{(1+r_m)^t} v_{PM}(t).$$

A last word about the option to *Abandon*: Given that we are modeling this decision to be made 1 year down the road, it is possible that conditions will change sufficiently to force to shutdown what looked like a valuable project. The key idea is that the decision is postponed until its proper place in time. Rather than commiting all resources at time 0, or canceling the project before it even starts, management can allow itself the benefit of exploring initially and deciding the fate of the project later with more data available.

2.4 Valuation

We now proceed to evaluate the model. Determining the value of the project starts at the end and runs backwards. The objective of this valuation is to find the set of choices that will maximize the expected value of the project.

Start by defining a state

$$S = \{FL, RD, M_s, PM\}.$$

A state is a particular combination of the possible values for the decisions and possible outcomes of the uncertainties. For example, one state is: funding (FL) is set to *Aggresive*; R&D (RD) produced a "Breakthrough"; the market size (M_s) grew to "Large"; and the production-marketing strategy (PM) is *Spin-off*. With this information it is possible to find a value $pv(S)$ using the cash-flow models available for the planning horizon:

$$pv(S) = NPV(PM|RD, M_s) - FL$$

We can now formulate our problem: Find FL^*, PM^*, such that

$$V(FL^*, PM^*) = \mathrm{E}[pv(S^*)]$$

is maximum. That is, choose the funding level FL and the production/marketing strategy PM that will maximize the expected value associated with such choices. To solve this problem we work backwards.

Notice that given a funding level, an R&D outcome and a market outcome, it is possible to determine which production-marketing strategy should be chosen: the one corresponding to the PM strategy with the largest valuation. This is consistent with our objective of value maximization. By finding the best strategy for all combinations of funding, R&D outcome and market size the model yields its first insight: a policy map for the second decision given a specific combination of outcomes.

Figure 5 shows a representation of the optimal choices along possible paths which represent the different states (minus the second decision variable which now has been optimized). There is also a symbolic representation of the probabilities associated to each outcome. Notice that there are some paths with a negative value. Given the objective of maximizing value across all production-marketing choices, this signals that larger losses are avoided by abandoning the project under certain circumstances. All these events will be factored in the final valuation.

The solution method for the rest of the model consists of using the probabilities and the value of each path to compute the expected value of each funding level. The one with the largest expected value is the optimal choice. Table 3 shows the expected value of each funding level in Figure 5. In this case it is more valuable to choose the higher funding level due to the improvement in the chances of R&D success and the gains associated to it. The risk-adjusted value is \$689K. Compare this value to the DCF result of \$329K.

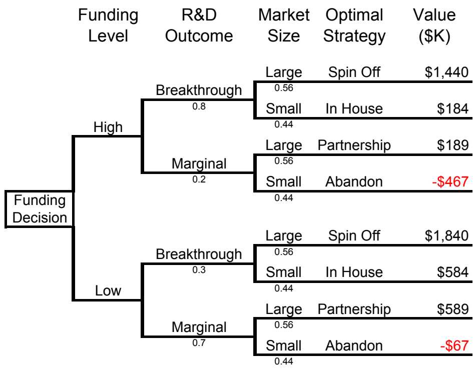

Figure 5: *Tree with all possible paths and their optimal value.*

Funding Level	**Expected Value**
High	689
Low	596

Table 3: *First decision result (in $K).*

Now, instead of choosing a production-marketing strategy at the same time the fudning decision is made, the model presents a matrix with the optimal choice based on each possible combination of outcomes (see Table 4). Notice that *In House* (the choice according to the traditional analysis) is only one of four different choices.

After completing this numerical excercise the model yields clear insights. First of all, the optimal decisions are now clear: An optimal funding level, and the set of downstream decisions for each possible combination of outcomes (a policy map to guide decisions). Second, the value of the overall project has been computed combining two key elements: the value added by the uncertainty faced at present, and the value added by the flexibility of delaying the second decision and resolving the uncertainties.

3 Summary

A simplified R&D funding case has been presented to illustrate the complexity of making decisions given the uncertainties and long term planning horizon. We have described a framework that largely

	"Large" Market	**"Small" Market**
"Breakthrough"	Spin-off	In House
"Marginal"	Partnership	Abandon

Table 4: *Policy map given* High *funding level.*

matches the intuition of good managers who account for uncertainty and exercise flexibility in their decisions. It also focuses discussions on the critical assumptions, such as the chances of success in R&D given a particular funding level.

Key aspects of the model:

- Uncertainty is factored into the value equations using a sound model (outcomes and likelihoods).
- It correctly models each decision in time (value is added when downstream decisions are made in due time).
- Outputs yield powerful insights: value, sensitivity analysis and optimal strategy.

A Additional Tables

The following tables contain the data used for the numeric analysis.

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Market	100	105	110	130	150	140	120	110	105	110

Table 5: *Market size forecast (in $M).*

Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
M.Share	0.9%	1.9%	5.8%	10.1%	14.4%	16.9%	17.6%	17.9%	18.3%
Margin	-5.0%	-2.0%	1.8%	2.0%	2.8%	2.7%	3.1%	3.7%	4.5%

Table 6: *"Breakthrough" cash flow data for* In House*.*

Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
M.Share	8.1%	8.5%	8.9%	9.4%	9.8%	10.3%	10.9%	11.4%	12.0%
Margin	-5.0%	-1.0%	3.5%	3.0%	3.9%	5.2%	7.1%	9.0%	10.8%

Table 7: *"Breakthrough" cash flow data for* Spin Off*.*

Year	2	3	4	5	6	7	8	9	10
M.Share	4.5%	4.7%	5.0%	5.2%	5.5%	5.2%	4.9%	4.7%	4.5%
Margin	-40.0%	-5.0%	2.4%	2.3%	4.2%	9.9%	14.8%	17.1%	20.7%

Table 8: *"Breakthrough" cash flow data for* Partnership.

M.Share	2.3%	2.6%	5.2%	9.1%	13.0%	15.2%	15.8%	16.1%	16.5%
Margin	-10.0%	-4.0%	0.0%	1.8%	2.5%	2.5%	2.8%	3.3%	4.0%

Table 9: *"Marginal" cash flow data for* In House.

Year	2	3	4	5	6	7	8	9	10
M.Share	6.0%	6.4%	6.7%	7.0%	7.4%	7.8%	8.1%	8.5%	9.0%
Margin	-10.0%	-8.0%	-5.0%	-1.0%	3.0%	3.8%	5.0%	10.0%	13.8%

Table 10: *"Marginal" cash flow data for* Spin Off.

Year	2	3	4	5	6	7	8	9	10
M.Share	4.1%	4.3%	4.5%	4.7%	4.9%	4.7%	4.4%	4.2%	4.0%
Margin	-3.0%	-1.0%	2.2%	2.1%	3.8%	8.9%	13.3%	15.4%	18.6%

Table 11: *"Marginal" cash flow data for* Partnership.

Strategy	Completion Cost ($K)	Additional Value ($K)
In House	0	300
Spin Off	0	130
Partnership	0	0
Abandon	0	300

Strategy	Completion Cost ($K)	Additional Value ($K)
In House	100	0
Spin Off	0	0
Partnership	400	0
Abandon	0	300

Table 12: *"Breakthrough" and "Marginal" completion costs and additional value per strategy.*