MASTER

Risk-based valuation of early stage innovation projects at Philips Research

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Risk-based valuation of early stage innovation projects at Philips Research

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Abstract

This study focuses on the valuation of early stage adjacency innovation projects. Companies undertake adjacency projects in order to create long-term sustainable growth. Receiving ROI on these early stage projects is far from certain due to their high risk of failure and high uncertainty in required levels of investment and resulting returns. Valuation can be used to gain insight whether a project will deliver ROI. But, standard NPV valuation is not suitable for this task, as it has a simplistic view on risk and does not take into account the flexibility to stop a project. In this study, a new risk-based valuation model is presented which improves conceptually NPV valuation by taking into account the time-varying characteristics of innovation risk and flexibility to early stop projects as a response to this risk. It improves practically by giving more insight in the link between innovation risk and value and enforcing risk-based innovation project management. Two venture spin-offs were valued to validate the model. Sensitivity analysis showed that key positive value drivers for adjacency innovation projects are profitability and market growth, Key negative value drivers are the and innovation risks. As sensitivity analysis showed a large impact of innovation risks on value, a risk-based approach makes sense to value early stage adjacency innovation projects.

Management Summary

A. Introduction

This study focuses on the valuation of early stage adjacency innovation projects. Conventional valuation methods (NPV) are not suitable to value these innovation projects. They don't properly take into account the innovation risks specific to an innovation project which can cause the project to fail or the stage-gated management of these risks. In this study, a new valuation model is presented that takes into account innovation risks and stage gating.

B. Risk-Based Valuation Model

The proposed valuation model is to be used in a corporate innovation environment and is essentially risk-based and stage-gated. Risk-based valuation is an improvement upon standard NPV valuation by combining risk analysis and valuation and directly linking risk to value. Within the model, it is recognized that an innovation project is subject to market risk and on top of that idiosyncratic innovation risks. Market risk implies a required rate of return (WACC) which each project should meet in order to be added to the Philips portfolio. Innovation risks are unique to an innovation and arise for example due to uncertainties in the feasibility of key technologies or the existence of a market and potential customer. Four different innovation risks were identified and defined: technology risk, value proposition risks, competitive risks and go-to-market risks (Figure 1).

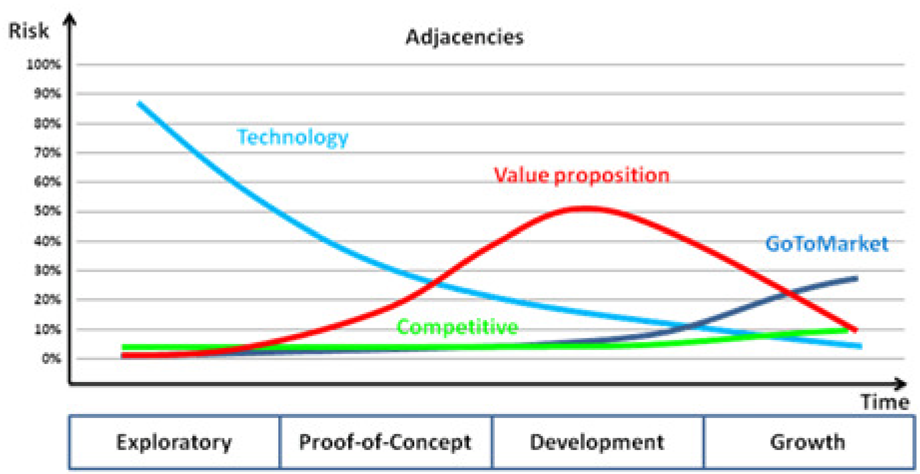

Figure 1: Risk is analyzed for 4 categories and 4 stages. The level of innovation risk determines the probability that an innovation project is stopped in a stage.

To cover innovation activities carried out in a typical corporate environment in a more or less structured way, stage gating is introduced in the calculations. This allows defining per stage the relevant variables e.g. levels of investment, stage time and risks. These risks are analyzed per stage and determine the probability that an innovation project is stopped in a certain stage, where a high risk implies a high probability that a project is stopped. Via this way, the effect of the stage-gated management of innovation projects is taken into account.

A distinction is made between R&D stages (exploratory, proof-of-concept and development),the growth stage and the mature stage of a business. The mature business stage is not explicitly taken into account but captured in a terminal value. Within this study, proof is given that this is a valid way to capture the value of the resulting business.

Value of a company is established via the rNPV method. The rNPV modifies the NPV calculation by adjusting each cash flow with the estimated probability that it occurs. These probabilities are estimated via the risk analysis described before. Apart from providing more clarity on the value build-up in the innovation chain, the introduction of Monte Carlo simulation allows to specifically indicate the main value drivers of an innovation project.

C. Main findings

Risk-Based Valuation

- Model validation (chapter 6) was performed via the valuation of two semi-recent spin-offs plus logical testing and stress-testing. The risk-based model gave an adequate valuation for the spin-offs.
- Risk-based valuation is a conceptual improvement on NPV valuation as it incorporates an improved way to capture innovation risks plus the flexibility created by stage gating to early stop projects.
- Risk-based valuation is a practical improvement over standard NPV valuation. The model makes the link between innovation risk and value more explicit. Next to this, it enforces risk-based innovation management by forcing R&D managers to think about and make explicit the risks underlying an innovation project.

Innovation Risk

- Sensitivity analysis showed a large impact of the total innovation risk on value. This supports a risk-based approach for early stage innovation project valuation.
- Management of the innovation portfolio faces projects with different risk profiles (see Chapter 5).

Uncertainty

- The fundamental issue underlying early stage valuation problems is the very high uncertainty in inputs. The usual high uncertainty in key value drivers implies that there is not much point in developing highly complex valuation models.
- What sensitivity analysis makes explicitly clear is what the real challenge is when valuing early stage innovation projects; reducing uncertainty with respect to the input variables and mapping out the uncertainty in value based on the perceived uncertainty in inputs. This seems to support the use of Monte-Carlo simulation to model this uncertainty.

Key value drivers

- Sensitivity analysis showed that the relative and absolute impact of different inputs differ from case to case.
- However, three key value drivers were identified that seem to have a standard large effect on value of an adjacency project. Value decreasing and value increasing value drivers can be identified.
- Key positive value drivers are (1) profitability and (2) market growth. Key negative value drivers are the (3) innovation risks.

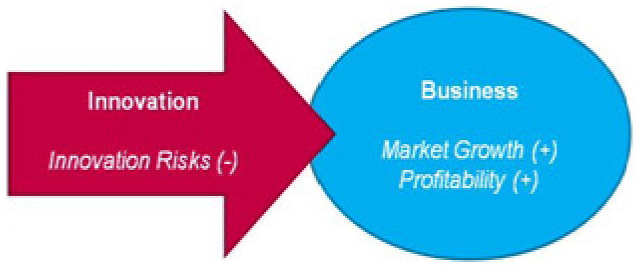

Figure 2: key value drivers for adjacency projects. Innovation risks have a large negative impact on value. Market growth and profitability have a large positive impact.

- From a theoretical point of view, these results seem logical; Growth and Return On Invested Capital (ROIC) are the two fundamental value drivers of a business (Copeland, Koller, & Murrin, 1990). The long-term growth of a business is likely to be highly correlated to the market growth. Profitability and has a large impact on the ROIC, as the profitability of a business is the return that is generated on the invested capital. Innovation risks will determine whether the business value will be captured at all, which supports its high impact on the valuation as well.

Managerial Implications

- The sensitivity analysis on the two venturing cases made explicit that projects management should focus on reduction of innovation risk and aim for fast growing and profitable markets in order to create value.

Future Work

- For future valuations it would be interesting to map the full uncertainty in output based on perceived uncertainty in all relevant inputs by using Monte-Carlo simulation.
- The application of the risk-based model could be extended to other projects. For example for roadmap innovations, the risk-based valuation model could be combined with real options. Risk-based valuation can be used to capture the specific innovation risk and flexibility to respond to innovation risk. Real options can be used to capture market risk and flexibility to respond to market risk. For such a model, uncertainty in the inputs can still be captured with Monte-Carlo simulation to model the uncertainty in output.

Preface

This study is the result of my final master thesis project conducted at Philips Research, Strategy & Business Development. The master thesis project is the final part of my master Innovation Management at the Eindhoven University of Technology. Completion of the master is my final step towards becoming an Industrial Engineer.

The path towards this study started during my bachelor Applied Physics. Within my bachelor, I had the opportunity to follow a one semester minor in the field of entrepreneurship & innovation. It was during this minor, that my interest in innovation management really started to take off and that I made the decision to start a master in the field of innovation management. During this master, my interest in the topic of valuation started and this topic was chosen as my specialization within the master. After numerous visits at venture capitalists and industrial corporations, Philips Research resulted as the site for the internship in the agreement that the research would contribute to innovation management practices via a study on the valuation of early stage innovation projects.

During my internship at Philips Research, I had the privilege of having Dr. Ronald Wolf as my company supervisor. His supervision, extensive experience in the field of business development & venturing, insights in early stage valuation and contributions to the research were essential for the successful completion of the project. Next to Ronald Wolf, I would like to thank all colleagues – especially from the Strategy & Business Development department – which made time and put energy and interest in my research.

Furthermore, I would like to thank prof. Ronald Mahieu who was my primary academic supervisor. He delivered key insights with respect to the topic of valuation and always made time to discuss problems and contribute to the academic foundations of the research and the resulting model. Also, I would like to thank Dr. Mathew Reindorp for his interest in my research and contributions as a second academic supervisor.

Finally, I thank my parents, brother and girlfriend. Their love and support helped me greatly not only during my execution of this research but also during the rest of my study and my live.

Jens Wolthuis, March 2013

List of Abbreviations

- DCF - Discounted Cash Flow
- NPV - Net Present Value
- rNPV - Risk-Adjusted Net Present Value
- ROV - Real Options Value
- ROIC - Return On Invested Capital
- ROI - Return On Investment
- EBITDA - Earnings Before Interest, Tax, Depreciation & Amortization
- NOC - Net Operating Capital
- CoC - Cost of Capital
- WACC - Weighted Average Cost of Capital
- CF - Cash Flow
- PCF - Probability Weighted Cash Flow

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1. Introduction

1.1 Introduction to the problem

Innovation can be defined as the application of knowledge to useful objectives. The importance of innovation for the general economy has been calculated by numerous sources e.g. (OECD, 2007).

Next to the importance of technology to the general economy, innovation is also highly important to individual companies. The viability of a company in the end depends on its ability to innovate (Nagji & Tuff, 2012). As the core markets of a corporation will eventually become mature and decline, sustained growth can only be found within new markets (Zook & Allen, 2003). Hence, companies undertake innovation projects for these new value spaces; often called adjacencies or breakthrough innovations e.g. (Nagji & Tuff, 2012).

Receiving return-on-investment (ROI) is not always guaranteed for these types of innovation projects. Most projects fail or are stopped at some point, for example due to technology related problems; research has shown that on average 3000 raw ideas are required to achieve 1 commercial success (Stevens & Burley, 1997). Thus, innovation is a high-risk endeavor (Cooper, 1990). Hence, innovation management essentially *is* risk management. A widely used method to systematically manage and reduce risk in innovation projects is Stage-Gating (Cooper, 1990), which structures innovation projects into a series of go/no-go decision points that exploits the option or flexibility to early stop the project (Boer, Risk-Adjusted Valuation of R&D Projects, 2003).

A financial assessment of innovation projects is important as it can give insight how likely it is that it will actually deliver ROI. Valuation is often used for this purpose. However, conventional valuation techniques (NPV) have two fundamental reasons for not being suitable in an early stage innovation context: (1) they don't take into account the time-varying risk profile for innovation projects or (2) the flexibility to early stop a project when specific innovation risk has been resolved (Steffens & Douglas, 2007).

Hence, the main topic of this study will be to develop a new valuation model that is better suited to value early stage adjacency innovation projects. Furthermore, we will identify key value drivers for these projects. This is valuable as uncertainty in the key value drivers will eventually determine the uncertainty in the value of a project.

In the remainder of this chapter will be a short literature review on some essential concepts for this study; adjacencies, risk, stage-gated management of risk and valuation.

1.2 Adjacency innovations

Adjacencies are markets that have to some extent links to the core markets of the corporation (Figure 3). Adjacency innovation projects are aimed at these adjacent markets and are often defined as: "innovations that involve leveraging something the corporation does well into a new space" (Nagji & Tuff, 2012). Related to adjacencies but even more radical, is breakthrough innovation. Breakthrough innovation is aimed at the creation of entirely new markets or value spaces outside the current scope of a company.

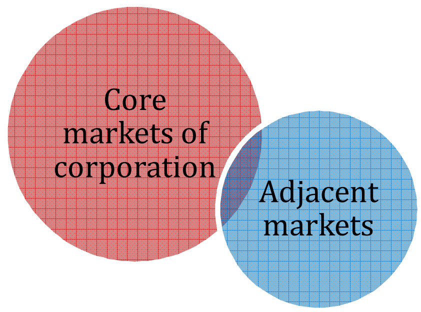

Figure 3: Adjacent markets are linked to the core markets of the corporation.

To further clarify what an adjacency project is, the innovation ambition (see Figure 4) matrix can be used (Nagji & Tuff, 2012). Adjacent innovations allow a company to draw on existing capabilities but require them to put to new use. Thus the reason for expansion into adjacency markets is that a competitive edge can be obtained in these markets.

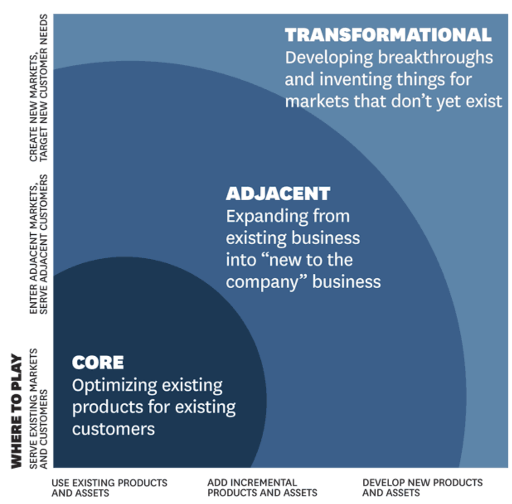

Figure 4: Innovation ambition matrix (Nagji & Tuff, 2012). In his matrix the novelty of products offered and markets addressed are shown in a continuum. Near the down-left corner are incremental efforts to change existing products and. In the top right corner are breakthrough/transformational efforts to create entirely new businesses and markets.

Attractive adjacencies are in areas where a growing demand can be expected and trends are present where innovation can bring value (Nijman, 2008). For example, Philips' current core markets are lighting, healthcare and lifestyle. Some examples of attractive adjacencies to Philips are shown in Table 1. One example is innovation aimed at chronic disease care at home which could reduce the frequency of hospital visits for chronic disease patients. Another example is patient centric care systems, for example instant bed-side molecular tests in a hospital.

	Lighting	Healthcare	Lifestyle
Adjacency 1	New uses of light	Patient centric care	Home comfort
Adjacency 2	Clean technology	Home healthcare	Social connectivity
Adjacency 3	Control systems	Chronic disease care	Dignified ageing

Table 1: Some examples of attractive adjacencies (Nijman, 2008).

Adjacency projects are in general more risky efforts to the company than aimed at the as moving further away from the core will imply more uncertainty whether key technologies are feasible, a true market exists and whether a real value proposition is created for the customer. To start a discussion about risk in adjacencies and breakthrough innovations projects, first a distinction has to be made between risk and uncertainty.

1.3 Risk and Uncertainty

Frank Knight made a very clear distinction between risk and uncertainty in his work *Risk, Uncertainty* and *Profit* (Knight, 1921). We acknowledge the distinction he made between risk and uncertainty; Knightian uncertainty is immeasurable and not possible to calculate, while Knightian risk can be measured and calculated. However, in our context we consider only risks that can be assessed either objectively or subjectively through management judgment. Often, this is referred as investment under uncertainty e.g. (Dixit & Pindyck, 1994). Critical for a discussion of risk for innovation projects is the distinction between market risk and innovation risk.

<u>Market risk</u>

Market risk is the part of risk correlated with the market (Steffens & Douglas, 2007). Also known as systematic risk or non-diversifiable risk, it can't be diversified away by a company via R&D portfolio management. Market risk will determine the return investors expect from this company. The required rate of return for a company is captured in the weighted average cost-of-capital (WACC). The WACC is derived from the simple fact that a company funding is composed of two components: debt and equity. Lenders (debt) and shareholders (equity) each require a return on the money they have invested in the company. The company cost of capital is often estimated as the weighted average of these returns and can be calculated relatively easily (see Appendix B). Any project within a corporation must earn this return in order to add economic value to the company. However, the WACC is only the right discount rate for investments with the same riskiness as the company's overall business (Brealey, Stewart, & Allen, 2011).

Innovation risk

When considering innovation projects at a company, innovation risks have to be taken into account as well. Innovation risks are unique to the innovation project and can cause a project to fail. Innovation risk is the part of risk uncorrelated with the market. Also known as unsystematic risk, specific, idiosyncratic or diversifiable risk, it can in principle be diversified away via R&D portfolio management. Innovation risk arises due to uncertainties for example in the feasibility of key technologies, the existence of a market and potential customer and the competitiveness of the innovation. From the viewpoint of a company, innovation risks are in principle partially diversifiable. This is exactly the reason why companies perform R&D portfolio management (Boer, 1999); in a portfolio of innovation projects there will always be some success cases that cancel out the failures.

1.4 Stage-Gating

A large part of stage-gated project management (Cooper, 1990) is aimed at systematically reducing innovation risks as fast as possible. As increasingly more resources are committed (investments in risk reduction are made) over time knowledge is increased and the innovation risk that the project can be stopped at some point in the future is reduced (Figure 5). A stage-gated process is divided in a number of stages. Between each stage there is a checkpoint or gate. For each gate, a set of deliverables is specified plus a set of quality criteria to which the deliverables will be assessed. When the deliverables are of sufficient quality, the project is passed to the next stage.

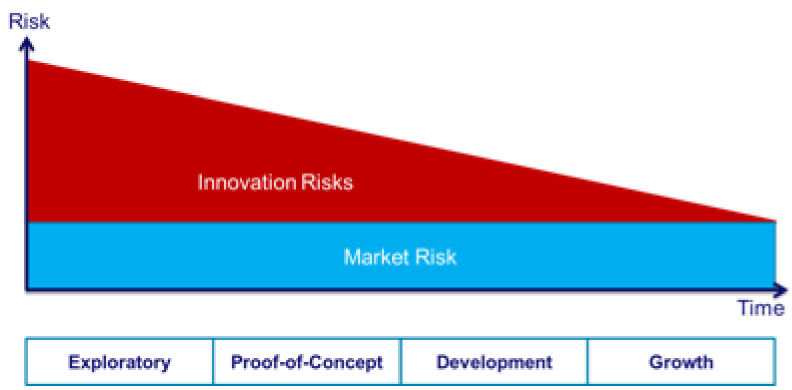

Figure 5: Innovation risks are reduced via stage-gated management (illustrative).

1.5 Valuation

Valuation is loosely defined as the determination of what something is potentially worth. More specifically, it can be seen as the estimated or determined market value of an investment. Thus valuation is about quantification (Boer, 1999). The value of innovations is quantifiable as well.

The main reason for performing a valuation is that managers need to maximize the expected return on investment (ROI) of their innovation project portfolio. A financial assessment of a project – including a valuation – gives more insight in the financial attractiveness of an innovation project.

A second reason is that valuation forces the people performing the evaluation to work on their input data quality. The valuation process requires making data relevant to the case explicit such that it can be shared and discussed. Doing so helps to avoid wild guesses about potential sales, margins etc. Building a consistent financial framework for valuation purposes forces one to make key assumptions and the effect on financial outcome explicit. These are for example assumptions with regard to expected market size, market penetration, time-to-market and profitability of the resulting business.

A third reason that is related to the former two is that building a financial model and performing a valuation gives the possibility of performing a sensitivity analysis. This last reason is probably the most compelling; as it gives managerial insight into the value drivers of a business case.

1.6 Contents of the study

In this chapter we introduced the fundamental problem to be addressed in this study and a short literature review op the topic was made. In chapter 2 the main research objectives will be formulated in more detail. In chapter 3 the research context will be discussed, focusing on the company site for the study. In chapter 4 multiple valuation techniques will be evaluated and the most suitable valuation technique to value early stage adjacency projects will be selected. In chapter 5 the proposed valuation model will be introduced. A valuation tool was built and tested to implement the valuation model. In chapter 6 the main outcomes of these tests will be discussed. Advanced analyses performed with the tool are discussed in chapter 7. The main conclusions from the study will be drawn in chapter 8.

2. Research Objectives

In this chapter the main research objectives will be formulated. The main research objectives are threefold. The first objective is to answer the main research questions. The second objective is to develop a valuation model that satisfies all valuation model requirements. The third objective is to develop a valuation tool that satisfies all valuation tool requirements.

2.1 Research Questions

The research project has three main research questions:

1. How to value early stage adjacency innovation projects?

This research question is aimed at finding out how the valuation model looks like and what the main elements are. It will be answered through five sub questions:

a. Which valuation technique is the most suitable to value early stage innovation projects?

This research question will be aimed at discovering which valuation technique is the most suitable in early stage innovation context. There are multiple valuation techniques like for example NPV, rNPV and real options.

b. Which are the required input parameters based on the type of adjacency, the availability of data and the selected methodology?

Related to question a., is the question which input parameters are necessary for the valuation tool. The required input parameters are of course specific to the valuation technique used.

c. How to represent the output? And what financial measures do we use for the output?

The valuation model will give some output and it is important to consider how this output should be represented in a tool. Should the output for example be a single number or rather a range of values? Of course the required output depends on the goal and skills of the user.

d. How should risk be handled?

Adjacency projects are subject to high innovation risk which can cause the project to fail. It will be important to consider explicitly how to incorporate risk when valuing these projects.

e. How to incorporate Stage-Gating into the model?

Adjacency projects are managed via a Stage-Gated methodology at Philips Research. Explicit incorporation of Stage-Gate will introduce managerial flexibility to continue or early stop a project, which can have a large effect on the value of the project.

2. *What are key value drivers for adjacency and breakaway innovation projects?*

A sensitivity analysis can give much information about the effect of key value drivers for a project. For example it would be interesting to know what the effect of the time-to-market is on the value of the project. Identifying these value drivers will give information how projects should be managed in order to maximize value and where resources should be committed to reduce uncertainty in value as fast as possible; uncertainty in the output will mainly be determined by uncertainty in the key value drivers.

2.2 Valuation model requirements

In chapter 1 two main flaws with respect to the use of the NPV method in an early stage innovation context were identified: (1) not taking into account the time-varying risk profile for innovation projects and (2) the flexibility to early stop a project. An improved valuation model would correct these flaws.

Another issue is the usual high uncertainty about the essential required inputs. Due to this issue, there isn't much point in developing highly detailed pro-forma models; for early stage valuation problems, the objective should not be precision but 'quick and dirty' models that identify the real drivers of value (Boer, 1999). The valuation model should be able to separate the clear winners from the clear losers, in order to minimize the probability of making an error.

2.3 Valuation tool requirements

Valuation tool requirements can be summarized in four keywords: credible, easy, practical, and compatible. Credibility implies that the valuation tool output should be arithmetically correct. Easy implies that the tool can be understood within a short timeframe (minutes rather than hours) by someone with a suitable background. Practical means that the valuation tool is not unwieldy in use. Compatible implies that the tool corresponds with the current stage-gate practice at Philips Research.

3. Research Context

In this chapter, the company setting of the research project will be discussed. The study was located at Philips Research. The company setting and the different types of innovation projects at Philips Research will be discussed. Next, the stage-gated management of these projects will shortly be touched upon.

3.1 Company Setting

Philips Electronics N.V.

Royal Philips Electronics N.V. is a diverse industrial company leading in health, lifestyle and lighting. Through innovations Philips is aiming to improve the quality of life and work towards a sustainable future. Founded in 1891 and currently headquartered in Amsterdam, The Netherlands, it employs 121.000+ people worldwide. In 2011, its sales amounted €22.6 billion. Being an innovative company it spends around 7% of sales in research and development (Philips, 2012). Philips is constituted by 3 main divisions: Healthcare, Lighting and Consumer Lifestyle. A fourth large element of the company is Philips Group Innovation, which is the place where most of its innovations are started. When innovating, Philips has an Open-Innovation Strategy which means that, where useful, it cooperates with external institutions, universities and companies in research & development to put innovations faster and more efficiently into the market. Philips Group Innovation, is composed by Philips Research, Innovation Services, IP&S (Intellectual Property & Standards), and the Healthcare Incubator[1].

Philips Research

Being a global organization by itself, Philips Research is responsible for the introduction of meaningful innovations to, as Philips aims, improve the lives of people. It provides technology options for innovations in the area of healthcare, lighting and well-being. It is positioned at the front-end of the R&D process. This means that Philips Research actually does the research part of Research & Development. Philips Research was founded in 1914. It is currently one of the world's largest research organizations and has multiple research centers in North America, Europe and Asia. Over 1500 people are currently being employed. The research project was centered at the High-Tech Campus in Eindhoven, where the largest location of Philips Research is located.

[1] http://www.philips.nl/about/company/businesses/corporatetechnologies/index.page

3.2 Innovation project types within Philips

Within Philips, R&D project types are categorized based on market lifecycle and the type of innovation. In essence this is the same approach/categorization as the innovation matrix. Three general categories in order of market lifecycle and innovativeness are roadmap innovations, adjacencies and breakaway innovations (Figure 6).

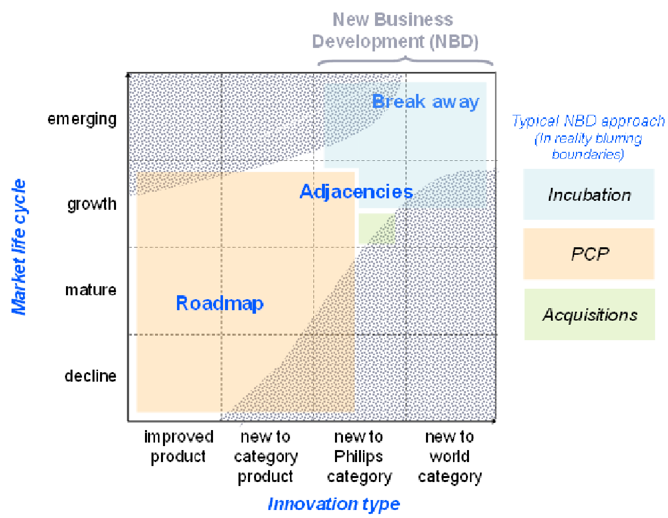

Figure 6: Innovation project types at Philips.

Roadmap

Roadmap innovations are aimed at the core of Philips current markets. There are two types of roadmap innovations: sustaining innovation projects and game changers. Sustaining innovation is defined as a type of innovation that will not disrupt the existing market and competitive landscape. It can be seen as 'the cost of staying competitive' in a market where Philips already is active. Mainly this type of innovation is about incremental product changes or incremental portfolio extensions to support current business. Game Changers addresses more radical innovation but still aimed at markets where Philips already is active. An innovation is a Game Changer, if it has the ability to radically disrupt the market and competitive landscape, with the intention to significantly increase market share or operating margins. It should give Philips competitive advantage in the sense that competitors won't be able to compete via traditional ways.

Adjacencies

Adjacencies and breakaway innovations should give Philips the opportunity to grow outside its core business thereby repositioning itself. Adjacencies can be seen as 'new to the company' innovation projects that leverage technologies or markets that currently belong to the core of Philips' activities in order to reduce risk. A new product-market combination is created, previously not yet known to Philips, but still falling within the current Philips scope: healthcare, lighting & consumer lifestyle.

Breakaway

Breakaway innovation is about the creation of new businesses outside Philips' current sector scope. Breakaway innovation is really about radical innovations new to Philips or even new the world (creation of new markets). Breakaway innovation is often done via corporate venturing.

3.3 Stage-Gating within Philips (ECD)

Philips currently has an ECD stage-gating R&D project management system in place, which essentially consists of 3 stages: exploratory, proof-of-concept and development. Each stage formally ends with a gate where a project is evaluated based on key criteria. Go/Kill decisions are made at these gates. The R&D stages consist of different phases checked for progress at milestones with key milestone success criteria. Each project must pass these milestones in order to progress to the next phase.

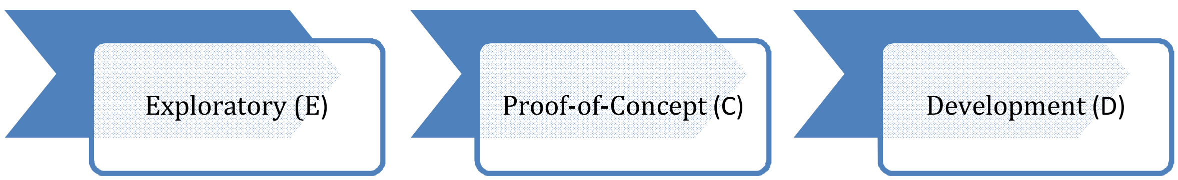

Figure 7: The stage-gated process at Philips consists of three different stages.

Exploratory (E)

The exploratory stage consists of just one phase: the landscaping & opportunity recognition phase. The exploratory stage is performed at Philips Research. In the exploratory stage the main task is the generation of a field of commercially promising ideas that can be transformed into research projects. Thus, the work done here is mainly explorative; it includes a scan of technological and market trends and of the competitive position is possible markets. The result of this stage is a research/business proposition which will be evaluated on whether there is an unmet end-user need, new technology potential, business potential and a strategic fit.

Proof-of-Concept (C)

The proof-of-concept stage has three phases. The first phase is technology creation. The main goal of this stage is to find out whether the independent key required technologies really are feasible. Technology creation is followed by principle creation, which in turn is followed by function creation. The proof-of-concept stage is still performed at Philips Research. This stage involves an effort to understand the full scope and limitations of new ideas through laboratory research and to find a potential (technological) project stopper. All key technological issues should be solved in this stage and the necessary performance data needs to be gathered for engineers and marketers to undertake development. At the end of the stage a validated business plan has been developed which will be assessed on whether there is a validated end-user insight, validated market and whether a product concept has been selected that demonstrates a new product function.

Development (D)

The development stage has three phases. The first phase is product concept. The main goal of the product concept stage is prototype development. However, other activities are formed as well for example the creation of a marketing plan. Product concept is followed by product design. The third phase is engineering. Development is performed at one of the three different business units of Philips: Healthcare, Lighting or Consumer Lifestyle, depending on the type of innovation. During development the first real product prototype is created and the product concept is worked out in more detail. Detailed market studies are made, including beta testing of the product in order to match product features with the customer. Furthermore a market plan and sales forecasts are developed. Pilot plants are built (if required) to test production. For healthcare products – if necessary – clinical trials are performed. At the end of development, in principle, the product is ready for formal launch.

After development, formal product launch takes place and the growth stage in the product lifecycle starts. Sales are ramped-up and full scale industrialization and commercialization starts. In the growth stage, large investments can be made in new plants and production lines if they are required. Expenditures for marketing and promotion are typically high shortly after formal launch.

4. Valuation Technique Selection

Multiple valuation techniques exist. Three main competing valuation techniques will be discussed in this chapter for their suitability in an innovation context: Net Present Value (NPV), Real Options Value (ROV) and Risk-Adjusted Net Present Value (rNPV). To illustrate and discuss the different valuation techniques in an innovation context we will consider a hypothetical venture project.

4.1 Early Stage venture example

A hypothetical venture project consists of two R&D stages: stage 0 and stage 1. After stage 1 has been completed formal product launch takes place. In both stages, investments in R&D are made and both innovation risk and market risk is resolved. We want to know what the value of the venture is at the start of stage 0 in order to see whether the venture is a clear winner or loser based on financial criteria. For the valuation problem details see Figure 8.

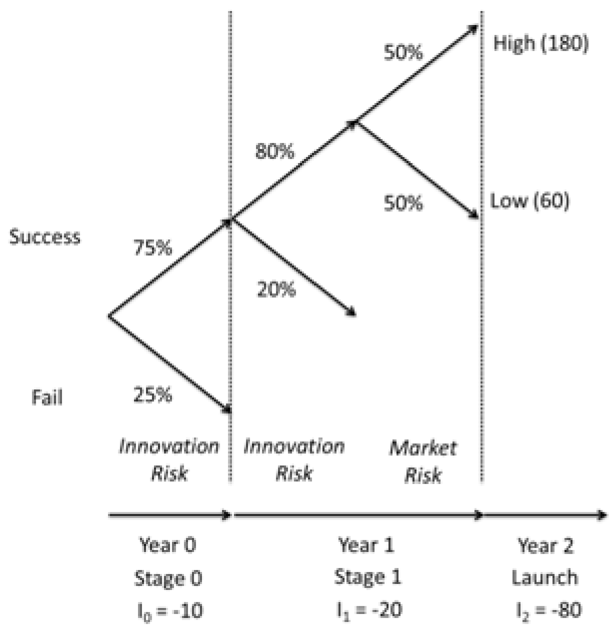

Figure 8: Venture project example. After the two R&D stages the decision is made to launch or not launch the venture commercially (start sales). The venture requires investment in stage 0 of I_1 = -10,investment in stage 1 of I_2 = -20 and investments related to launch of I_3 = -80. The venture is subject to considerable innovation risk (e.g. technical risk) and market risk. Innovation risk resolved in stage 0. There is a probability of 25% that project is stopped due to this risk in stage 0. Additional innovation risk resolved in stage 1. There is a probability of 20% that project is stopped due to this risk in stage 1. Market risk is resolved in stage 1. Suppose there are two possible market scenarios for the value of the business at the start of stage 2 both with a probability of 50%: 180 (high) or 60 (low). Expected value of business thus is $\mathrm{E(V)} = (180 + 60)/2 = 120$. The WACC for the venture is 10%. The risk-free rate is 5%.

4.2 NPV valuation

The NPV or Discounted Cash Flow (DCF) method for valuation is based on discounting of future expected free cash flows at a discount rate (cost-of-capital or CoC) that reflects the riskiness of these cash flows (Copeland, Koller, & Murrin, 1990). The NPV is calculated by discounting all cash flows of year *n* with at a rate $(1/CoC)^n$. The NPV approach is based on the simple concept that if the NPV > 0 then the investment is earning more than the cost of capital and the investment should be made. The investment should not be made when the NPV < 0. For the venture, the NPV is calculated by starting with the required investment in stage 1 and adding the expected value minus the investment in the second stage discounted at the WACC:

$$NPV = -10 + \frac{-20}{1.10} + \left(\frac{120 - 80}{1.10^2}\right) = 5$$

The venture is valued at 5 (M€). As the NPV is positive, the investment should be made according to the NPV decision rule. The NPV approach does not take into account innovation risk and the flexibility to early stop the venture when innovation risk is resolved (after stage 0). For example, the project could be stopped after stage 0 failed. Often innovation risk is taken into account by using a higher discount rate e.g. (Boer, 1999). However, this neglects the time-varying characteristics of the risk profile (risk is reduced after stage 0) and the value created by managerial flexibility (Steffens & Douglas, 2007).

Market risk is taken into account by discounting the expected value of the business at the corporate WACC. Flexibility to respond to market risk is also not taken into account; the expected market scenario is taken in the calculation of the value. Thus the option not to invest in the second stage when the low market scenario involves is neglected.

4.3 Real Options valuation

Real options valuation techniques have often been proposed as promising solutions to correct the deficiencies of the NPV approach e.g. (Copeland & Keenan, 1998). The underlying logic of real options is that a small investment leads to the future opportunity for making later investment commitments (Adner & Levinthal, 2004). The real options approach should exploit the flexibility in sequential investment decisions. The flexibility arises from the possibility of abandoning the investment (Adner & Levinthal, 2004). The basis of the whole approach is based on market price movements and the flexibility to respond to market risk (Steffens & Douglas, 2007). The Real Options Value (ROV) can be calculated by starting with the discounted required investment in stage 0 and stage 1 and adding the option value of the launch stage. The option value of the launch stage is calculated by making the optimal decision with respect to market risk. In the high business scenario the investment is made as 180-80 > 0. In the low business scenario the investment is not made as 60-80 < 0.

Thus the ROV can be calculated by multiplying the high business value scenario minus the required investment with the probability that this scenario occurs and discounting it at the WACC[2]:

$$ROV = -10 + \frac{-20}{1.10} + \left(\frac{0.5(180 - 80) + 0.5(0)}{1.10^2}\right) = 13$$

The value is 13 (M€). This is considerably higher than with the NPV approach. The reason for this is that the real options method does take into account market risk and the flexibility to respond to market risk; the investment in launch is only made in the high scenario. According to the real options decision rule the investment should be made.

4.4 Risk-Adjusted NPV

The Risk-Adjusted NPV (rNPV) method e.g. (Stewart, Allison, & Johnson, 2001) in principle uses the same approach as the NPV method, but it takes into account the innovation risks plus the flexibility to respond to this risk. It is assumed that the venture will be stopped in the case that R&D fails. Thus, the NPV approach can be adjusted by starting with the required investment in stage 0. Then, there is a 75% probability that the investment in stage 1 will be made and a ($75\% \times 80\% = 60\%$) probability that the investment in launch will be made. Discounting with the WACC gives the following rNPV:

$$rNPV = -10 + 0.75\left(\frac{-20}{1.10}\right) + 0.6\left(\frac{120 - 80}{1.10^2}\right) = -4$$

The venture is valued -4 (M€), which is much lower as innovation risks are accounted for plus the flexibility to respond to innovation risk. According to the rNPV decision rule, the investment in the next stage should not be made as the rNPV is smaller than 0. Market risk is taken into account by discounting the expected value of the business at the corporate WACC. Flexibility to respond to market risk is also not taken into account; the expected market scenario is taken in the calculation of the value.

4.5 Real Options + Risk-Adjusted NPV

In theory we can combine the real options technique and the rNPV technique. The rNPV technique can take into account flexibility with respect to innovation risk and real options can be used to take into account flexibility with respect to market risk. When combining the two approaches, we get the following valuation:

$$Value = -10 + 0.75\left(-\frac{20}{1.10}\right) + 0.6\left(\frac{0.5(180 - 80) + 0.5(0)}{1.10^2}\right) = 1$$

---

[2] Formal real options valuation works on basis of with risk-neutral probabilities and discounting at the risk-free rate. The logic behind risk-neutral valuation can be found in any modern valuation textbook e.g. (Copeland, Koller, & Murrin, 1990). Risk-neutral probabilities transform the actual probabilities so that future cash flows can be discounted at the risk-free rate. For sake of simplicity we will not make use of risk-neutral valuation here, however formally this is the appropriate way to approach such a problem.

The venture is valued 1 (M€). So the decision should be made to make the investment in the next stage. In this case both innovation risk and market risk plus the flexibility to respond to these two risk types is taken into account. Thus, from a theoretical point of view, combining the rNPV and real options approach is the most sound way to proceed.

4.6 Evaluation

In this chapter a short analysis was made of competing valuation techniques. The example shows two features why the NPV approach is not the correct approach in an innovation context. First of all, the approach does not take into account innovation risk and the flexibility to early stop the venture. Often innovation risk is taken into account by using a higher discount rate e.g. (Boer, 1999). However, this neglects the time-varying characteristics of the risk profile (risk is reduced after stage 0) and the value created by managerial flexibility (Steffens & Douglas, 2007), as the NPV approach assumes that all follow-up investments are always made.

The real options approach seems not to be appropriate in an early stage innovation context either as it doesn't take into account innovation risks. For most technology investments, risk is dominated by the innovation risks specific to the project and not market risks (Steffens & Douglas, 2007). As the rNPV takes into account innovation risk plus the flexibility to cope with this risk it seems to be the most appropriate. In principle, we could combine the real options and rNPV techniques like we did in the previous paragraph to take into account both risk types and flexibility to cope with these risks. However, ROV assumes that we can envision the different market scenarios plus the probability that these scenarios occur. This is reflected in our example via the specification of the different market scenarios plus their probabilities. Our argument is that such a prior specification is especially difficult in the case of early stage adjacency projects. Often it is not yet known what the exact target market is, let alone the different market scenarios that can develop for this market. Other authors also make the conclusion that such a prior specification may not be possible or even desirable (Adner & Levinthal, 2004).

Excluding flexibility to cope with market risk implies that we are making a conservative estimate of the value as inclusion of this flexibility by using real options analysis will always lead to a higher value. But as the required inputs e.g. the sales potential, profitability and time-to-market are highly uncertain, it follows that it is very likely that the error we are making by not applying the theoretically most sound approach – rNPV instead of real options + rNPV – is low compared to the error we are making by not knowing the 'correct' values of the inputs.

In the remainder of this study the rNPV technique will thus be used as the basis for our model. The main issue that remains is how to make a proper assessment of innovation risk assessment of innovation risk. The main contribution of this research is exactly with respect to this issue. In the following chapter a model will be presented how to improve assessment of innovation risk.

5. Risk-Based Valuation Model

In this chapter a risk-based valuation model will be presented. First the conceptual valuation model will be introduced, including the main building blocks of the model. Next the two key building blocks of the valuation model will be discussed separately; the risk model and the cash flow model. To conclude, the calculation of the rNPV from the cash flow model and risk model will be discussed.

5.1 Conceptual Valuation Model

As a general framework for the model we have used the product lifecycle e.g. (Boer, 1999). The product lifecycle consists of four stages: incubation (R&D), growth, mature and decline (Figure 9).

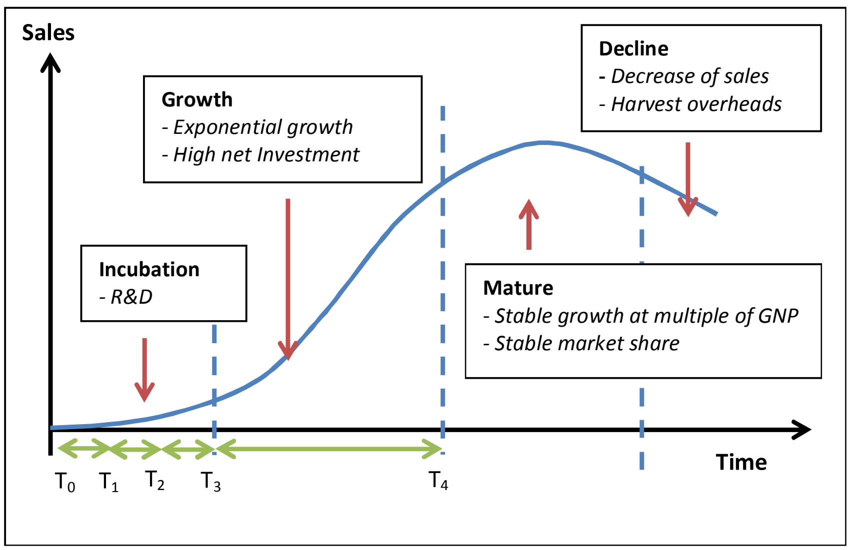

Figure 9: The Product Lifecyle. The first stage is incubation. In this stage upfront product development takes place. In the model, the incubation stage is split up into the three R&D stages identified previously. Exploratory starts at T_0 and ends at T_1. Proof-of-Concept starts at T_1 and ends at T_2. Development starts at T_2 and ends at T_3. After development, formal launch takes place at T_3 and the growth stage starts where sales increase at an exponential rate. High capital investments are required in this stage as well as initial high promotional expenditures in order to sustain this growth. The growth stage ends (T_4) when the market becomes mature. In the mature market a stable market share is obtained and sales grow at the market growth rate. After the mature market stage, decline starts. In the model, the choice was made to not explicitly model the mature and decline stage as they are hard to forecast (far into the future). As an alternative, used, the value of the mature business can be modeled via a terminal value (see below for an explanation).

The valuation technique used by the model is the rNPV method (see chapter 4). In order to determine the rNPV we need three key ingredients:

(1) Free cash flows
(2) Probability of these cash flows occurring
(3) The discount rate

The free cash flows are determined with a cash flow model and calculated on a monthly basis as innovation stages can sometimes only take only months and entering new stages often implies different cash flows.

The probability that cash flows occurs is determined with the risk model. This risk model is the main new contribution of this study and will be presented in the next paragraph. Risk is analyzed per stage. The risk in a stage will determine the probability that the stage fails and thus the probability that cash flows in that stage occur. The reason for this is that projects are only stopped at gates in the stage-gate process. Thus all cash flows that occur in a single stage have an equal probability of occurring.

By using the rNPV method innovation risk is taken into account by probability weighting the cash flows. Hence, we don't have to make an additional correction for risk and can use the company WACC as the correct discount rate that each project should meet in order to assess whether it is wise to add the project to the Philips innovation portfolio (see Appendix B).

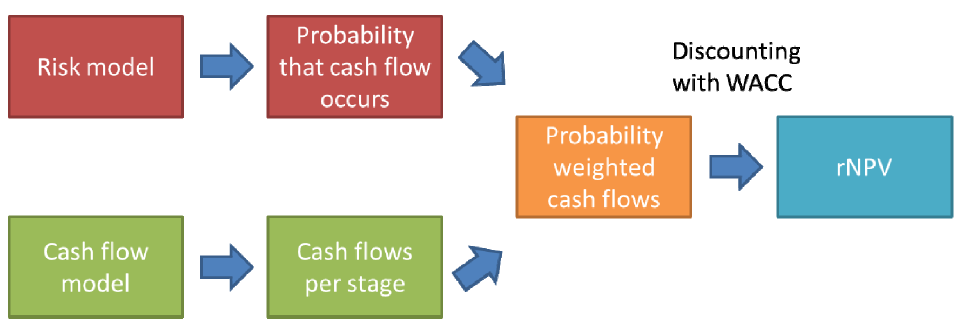

Figure 10: Conceptual representation of the valuation model. A risk model is used to assess innovation risk. From innovation risk probabilities that cash flows occur will be calculated per stage. The cash flow model will be used to calculate the cash flows that belong to each month and each stage. The cash flows and probabilities that cash flows occur will then be used to calculate probability weighted cash flows. They are then discounted with the WACC to obtain the rNPV.

5.2 Risk Model

Within our model we will define risk as the probability that an innovation project is stopped at a certain moment. As innovation projects are managed via a stage-gated process, the most practical way to implement this feature is to define innovation risk as the probability that a project is stopped in a specific stage. This can be in an R&D stage (exploratory, proof-of-concept or development) but also after R&D, when the product has formally been launched and sales are ramped up. Risk is estimated per stage as this is the most intuitive way for engineers, scientists and managers. Risk assessment on basis of a stage-gated system provides a framework to maximize the chance that a R&D project will succeed. Innovation risks adhere to four general properties:

1) Multiple risks can be identified
2) Risks occur in parallel rather than sequential
3) Risks change over time
4) Risk is cumulative

The first property of risk is that there is not just 'an innovation risk' for an innovation project. Rather, multiple risks can be identified that influence an innovation project. Based on literature and via discussions with new business development managers at Philips Research different risk categories were identified and defined (see next paragraph).

The second property for innovation risks is that they occur in parallel rather than sequentially. The common approach is to consider different risks as being sequential, for example (Whittington, 2010). Tools that take into account sequential risks also already exist; e.g. decision trees. However, a more realistic way to consider risk in an innovation project is to consider multiple risks in parallel; in each innovation stage a project can be killed for numerous reasons. For example, key required technologies may turn up not to be feasible, or a competitive product enters the market that renders the innovation useless.

The third property is that different risks become important at different points in the innovation timeline. The reason for this is that the nature of the activities required change going from idea to market. For example, usually in the early stages (research) the most of the work is done to resolve uncertainty in the field of technology (will it work?). Thus technology risk reduces quickly over time. But competitive risks can for example increase over time as more competitors enter the market after formal product launch has occurred.

The fourth property of risk is that it is increases as more risks are identified. The total innovation risk in a stage will be composed of the different risks. A low risk in one category and a high risk in the other category imply a high cumulative risk.

Based upon (1) internal discussions and (2) literature e.g. (Whittington, 2010) four different risks were identified as being the most important risk categories for a Philips relevant type of innovation. These risk categories were defined in such a way so that they are as orthogonally as possible. This implies that the risks are uncorrelated or independent. Hence, from now on we will also assume these risks to be orthogonal. So what is the effect of this assumption? We can find to risks that might be correlated: in theory value proposition risk could be negatively correlated with competitive risk; if there is a clear market/(end)customer it becomes more likely that competitors will identify this market. Hence, a low value proposition risk could automatically lead to a high competitive risk. This negative correlation has a reducing effect on the real innovation risk, which we would assess to be higher than in reality if we assume the risks to be independent. This implies that the valuation obtained with our methodology is a conservative estimate, which poses no problem as the goal is to separate the clear winners from the clear losers (financially).

The identified risk categories are technology risks, value proposition risks, competitive risks and go-to-market risks. We will now discuss all the categories and why they have an impact on project success or failure. For an overview see Table 2.

Technology Risk

This is the risk that all key essential technological and scientific issues for the proposition can't be solved in the framework of an innovation project.

Value Proposition Risk

This is the risk that no application for the technology can be found, that there is no market/(end)customer need, benefits are not understood by the market/(end)customer or that there is no fit with the market (product does not fully fit with customer needs).

Competitive Risk

This is the risk that competitors (can) claim a significant part of the market which typically results in a lower share of the market and margin pressure. The related competitive position is influenced by factors such as IP, brand, (exclusive) channel ownership, exclusive sourcing rights etc.

Go-to-Market Risk

This is the risk encompassing any element of the value chain that the product or service envisioned will not reach its potential customers. That includes factors as sales force capabilities, distribution channels, manufacturing capabilities and customer support. Additionally, this includes risks related to non-successful partnering strategies that relate to the above. Go-to-Market risks will be influenced by the company's current presence in the target market segment.

Innovation Risk	Nature of risk	Risk examples
Technology Risk	Will the product/service work?	• Basic technological and scientific issues that are theoretically or practically not solvable • Team or entire company does not have the competencies to solve the relevant scientific and technological issues • Pre-clinical and clinical testing failure
Value Proposition Risk	Is there a market?	• No market market/(end)customer need for the proposition • Benefits not properly understood by the market/(end)customer • No clear application for the technology can be found • Product does not fully fit with customer needs (wrong market fit with respect to performance, cost, ease, reliability, sustainability and experience) • Reimbursement is not obtained for the proposition
Competitive Risk	is the product/service competitive?	• Proposition can be copied by other companies (not protected by IPR or other means) • Strong existing position of competitors in the target market • Offering not competitive with existing other offerings (inferior on cost, ease, reliability, sustainability and experience)
Go-to-Market Risk	Can we bring it to the market and sell it?	• Lacking market knowledge or can't obtain partnership to effectively market or sell the product in the market • Required partnerships to manufacture the product can't be obtained • No access to the market, can't get distribution channels for product • Limited freedom-to-operate for any reason (political, financial, geographical)

Table 2: Innovation Risks. Four innovation risks can be identified. The nature of the risk is described plus and specific examples that contribute to this risk are given.

Obtaining input for risk estimation

The most basic way to obtain the risk estimates is just to use expert opinion from engineers, principal scientists, business developers and related project managers how they perceive risk in a particular stage. Another, more statistical, approach is to use a company database (if at hand) with data about which percentage of projects are killed at a specific stage and due to what reason (risk).

After the growth stage the innovation project specific risk is assumed to be reduced to zero and the risk of investing in this stage would only be the time value of money + normal business risk (captured by the WACC). When the risk values have been obtained for all risk categories and stages risk curves are fitted through the data points (Figure 11).

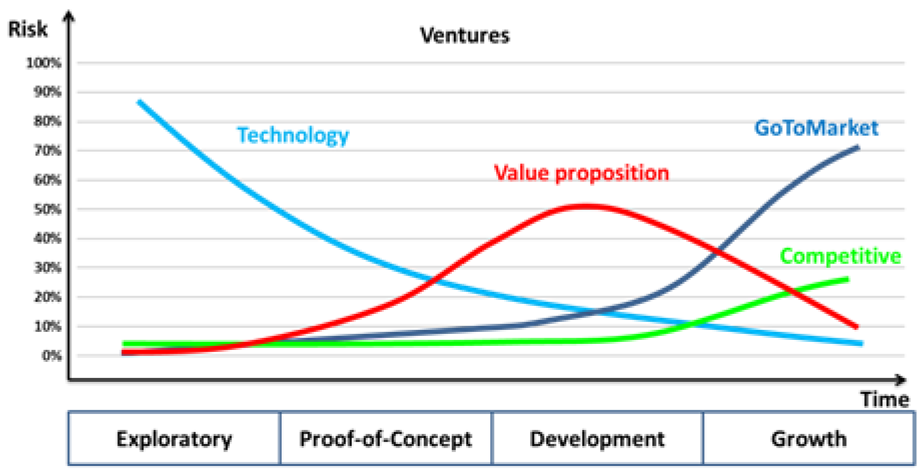

Figure 11: Illustrative example of project specific innovation risk curves. Risk for the different categories changes over time. Risk is estimated per risk type per stage and risk curves are plotted through these points; so there are 4 data points - one per stage per risk type - through which a risk curve can be fitted.

Risk Category	Source
Technology Risk	Principal Scientists, Project managers, Business Developers, Database
Value Proposition Risk	Project managers, Business Developers, Company Database
Competitive Risk	Project managers, Business Developers, Company Database
Go-To-Market Risk	Project managers, strategic marketeers, Business Developers, Company Database

Table 3: Sources to obtain estimates of risk per risk category.

Calculation of stage success probabilities

The important question is how to calculate the total innovation risk in a stage and ho to transform the risks to stage success probabilities in the rNPV equation. There are a few requirements for the calculation of the total innovation risk that can be logically deduced:

1) Maximum risk is 100%
2) Minimum risk is 0%
3) Total Innovation risk increases as more risks are added
4) Highest risk determines the lower boundary for the total innovation risk

The first and second requirement comes from the simple fact that the total innovation risk equals the probability that a project fails in a specific stage. Thus the probability of success for a specific stage can't be lower than 0% (100% risk) or higher than 100% (0% risk). The third requirement can be logically deduced from the fact that if an innovation project is subject to more risks then the probability that it is stopped in a certain stage should increase as the different risks were assumed to be orthogonal. The fourth requirement follows logically from the third requirement. In order to implement these requirements we can't simply add the different risks R_i to calculate the innovation risk R. For example, if for a specific stage technology risk = 60%, value proposition risk = 50%, competitive risk = 50% and go-to-market risk = 50% then innovation risk = 210%. Of course this is impossible. As the different risk categories were defined and assumed independent (orthogonal or uncorrelated), the separate probabilities of success per risk are also independent. Our proposed methodology is as follows. The probability of success with respect to a risk in a stage P_{kj} is one minus the risk R_{kj}:

$$P_{kj} = 1 - R_{kj} \qquad (1)$$

Probability theory states that if *n* success probabilities P_{kj} with respect to the different risks are independent then the probability of success of stage k P_k can be obtained via:

$$P_k = P_{k1} \times P_{k2} \times \ldots \times P_{kn} \qquad (2)$$

The probability P_i that cash flows of a stage *i* occur can be then calculated by multiplying the probabilities of success for the previous stages *k*:

$$P_i = \prod_{k=1}^{k-1} P_k \qquad (3)$$

Every innovation project will be unique with respect to the precise risks it faces. However, innovation projects can be categorized and each category will be subject to the same generalized risk profiles. On basis of discussions with business development experts at Philips Research standardized project risk profiles were deduced.

Risk curves for ventures (breakaway innovation)

(Corporate) ventures are high risk compared to adjacencies and roadmap innovations (Figure 12). For high tech ventures centered on a new technology or product technology risk is very high in the early stages. For service ventures this is not the case; in principle technology risk is zero for ventures that have a service as its core offering. Value proposition risk will be high as well and will be at the core when a decision for large scale funding needs to be made. After all, if no market/customer can be found for an offering then it will be worthless. Value proposition risk will be the highest during early development as at point large scale market studies will be made and key insights will be obtained whether there really is a need.

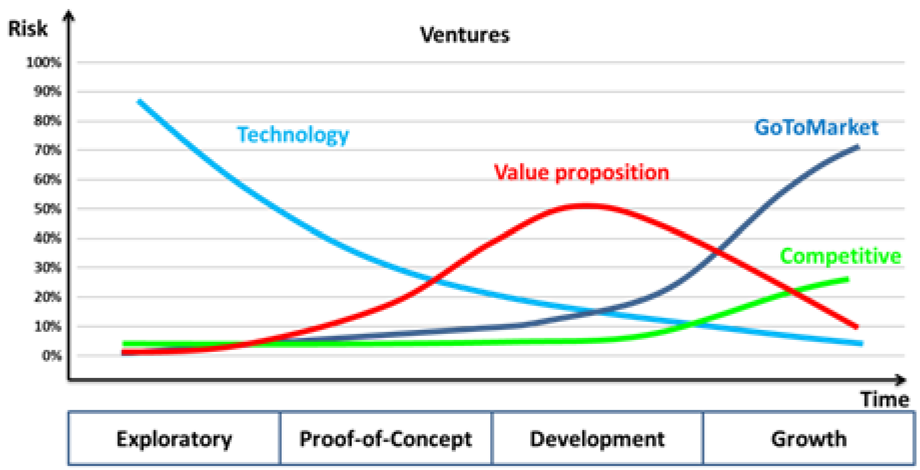

Figure 12: Standardized risk curves for ventures. Ventures are very risky with respect to each risk type. Curves were derived based upon internal discussions with business developers.

Competitive risks will stay low and increase when the growth stage commences and sales really ramps up. The reason for this only at this point it will become really clear whether the offering is competitive. Competitive risks will be high as the venture will be new to the market and highly dependent on IPR and to a lesser extent time-to-market. Go-to-market risk will only start to play a role late in the innovation process. This is because only at later stages it will become clear whether the venture is able to actually produce and sell and distribute the product in the market. A venture has no history with respect to its competencies in this field. Hence, go-to-market risks are high. Go-to-market risk for ventures will be highly dependent on the quality and experience of the venturing team. Having the right people in the right spot significantly reduces this risk.

Risk curves for adjacencies

Technology risks and value proposition profiles are similar for adjacencies and ventures as the same conditions apply. The main difference is in competitive and go-to-market risks, which could be significantly lower for an adjacency having some elements of strength already available in the company (Figure 13).

Competitive risks will be lower for adjacencies. The first reason for this is that a corporation will not enter a new adjacent market if it believes it cannot compete effectively in the market in the long term or if the market is highly competitive. For ventures, high competitive risks can be acceptable as an exit (acquisition by a larger company lowering competitive risks) can be a goal of the venture. The second reason for a lower competitive risk is that a corporation will be able to achieve a shorter time-to-market. A third reason is are established quality related processes in the last stages of the innovation chain.

Go-to-market risks will be lower compared to venture because a corporation will not enter an adjacency market if it believes it can't effectively develop and sell a product in the new market. In other words: its current market presence should give the corporation a right to play in the new market. It must be able to leverage exiting sales and distribution channels. Using these channels and the underlying marketing and sales strengths will reduce go-to-market risks significantly.

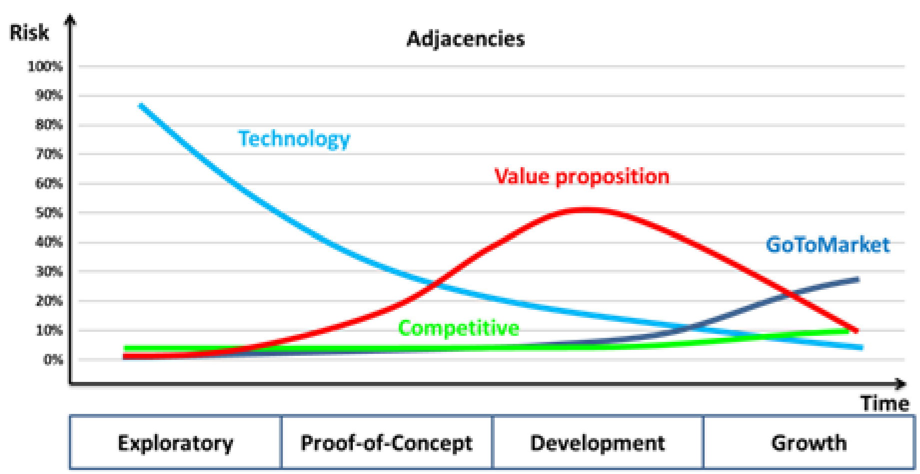

Figure 13: Standardized risk curves for adjacencies. Compared to ventures, adjacencies have a lower competitive risk and go-to-market risk as existing competencies and company resources are leveraged. Curves were derived based upon internal discussions with business developers.

Risk curves for roadmap innovation projects

For roadmap innovations, in general all risks are significantly lower (Figure 14). The reason for this is that roadmap innovations are aimed at core markets. The customer is well-known and a market has been proven to exist. Furthermore, a competitive risk is low because the corporation is likely to already have a strong brand, competitive cost-base, R&D and IP position in its core market. Furthermore, go-to-market risk is low because distribution and sales channels are in place and the corporation has shown to be capable to effectively produce and sell its products in its core markets.

For sustainable innovation, technology risks will be low as products will only have incremental changes. However, for game changers, technology risk can initially be high as the corporation attempts to gain a competitive advantage through superior technological solutions or processes.

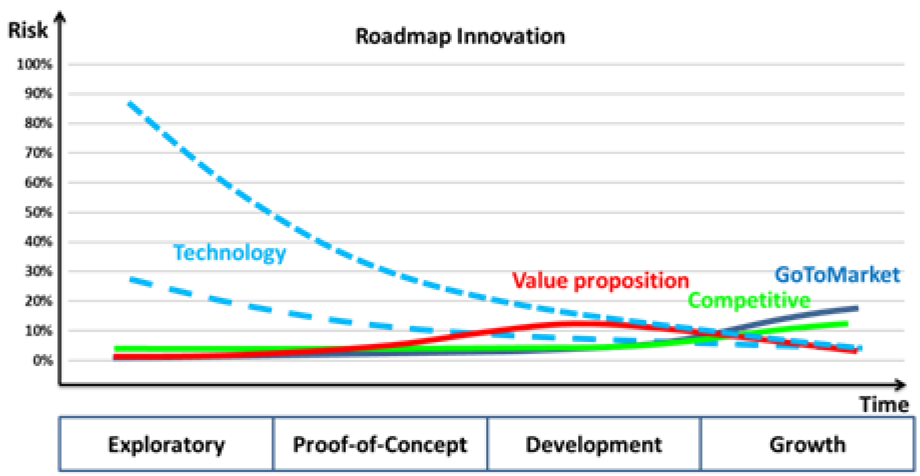

Figure 14: Standardized risk curves for roadmap innovation projects. For roadmap innovation projects all risks are considerably lower as the core is served. An exception is technology risk, which can be high Gamechangers as new technologies or processes are used. Curves were derived based upon internal discussions with business developers.

5.3 Cash Flow Model

R&D stages

In the R&D stages (exploratory, proof-of-concept & development), the free cash flows are composed by the R&D costs per month in these stages. Of course, these R&D costs differ depending on the stage of that month. The R&D costs are calculated by dividing the R&D costs per year for that stage by the number of months in one year:

$$CF_i = \frac{1}{12} \times (R\&D\ Costs\ per\ year)_i \quad (4)$$

Growth stage

After the R&D stages, the sales S-curve starts (see Appendix C). The S-sales curve is the starting point for the calculation of the sales. The sales S-curve follows logically from the product lifecycle described in paragraph 5.1. The free cash flows in a specific month CF_i are calculated by starting with the sales curve from the previous appendix, which calculates the monthly sales based on (1) the sales potential, (2) the duration of the growth phase (the sales potential is reached at the end of the growth phase) and (3) the market growth. The formula for the free cash flows in a specific month *i* is:

$$CF_i = (S_i \times EBITDA\%_i - D_i) \times (1 - t) - NI_i \quad (5)$$

Here, S_i are the monthly sales, $EBITDA\%_i$ the EBITDA margin in that month and D_i the depreciation for that month. Furthermore, t is the marginal tax rate and NI_i is the net investment in net operating capital for that month. This equals to total investment in fixed assets and working capital minus the depreciation for that month. After subtracting the depreciation and tax from the EBITDA we obtain the earnings, which are partly reinvested in net operating capital. We assume that the EBITDA margin can increase or decrease linearly during the growth stage via the following formula:

$$EBITDA\%_i = EBITDA\%_s + (EBITDA\%_m - EBITDA\%_s) \times \left(\frac{i-s}{m-s}\right) \quad (6)$$

Here, $EBITDA_s$ is the initial EBITDA margin at the start of sales, $EBITDA_m$ is the mature market EBITDA margin, i is the current month, s is the month when sales start (the growth stage starts) and m is the month when the mature stage starts. The choice for a linear increasing or decreasing EBITDA margin was made as it is the easiest way the incorporate the fact that early on the business operating expenses are likely to be higher due to high promotional and sales related expenditures. The depreciation for month i is calculated via:

$$D_i = \frac{1}{12}(D \times A_i) \quad (7)$$

Here, D is the depreciation as a % of total assets on a yearly basis and A_i are the assets (fixed capital, working capital) for month *i*. The total (net) operating capital in a month i is calculated via:

$$NOC_i = \frac{S_i}{NOC\ Turnover} \quad (8)$$

Here, $NOC\ Turnover$ is the ratio of sales to net operating capital. The NOC is assumed to be fixed over the lifetime for the business. The net investment for month i NI_ican then be calculated via:

$$NI_i = NOC_i - NOC_{i-1} \quad (9)$$

Mature stage

During the mature stage it is assumed that the business reaches stable growth and reaches a certain fixed market share of the total market. The annual sales growth rate for the business then equals the market growth rate. A stable growth situation can be modeled via a perpetuity growth formula (see next paragraph).

5.4 Calculation of Risk-Adjusted NPV

The rNPV is calculated via the following technique. The essential (and unique) step compared to a normal NPV equation is the following: all monthly cash flows are multiplied probability that they occur. This probability depends on the stage in which they take place and is calculated with equation (3). Then the probability weighted cash flows in a specific year y PCF_ycan be calculated via:

$$PCF_y = \sum_{j=1}^{12} P_j \times CF_j \qquad (10)$$

The reason for calculating the probability weighted cash flows per year is that discounting of these cash flows will be done on a yearly basis which is the usual practice in capital investment. These probability weighted cash flows can then be used directly in a standard NPV equation. The NPV equation consists of two parts. In the first part all probability weighted cash flows from the exploratory, proof-of-concept, development and growth stages are considered explicitly and discounted to the current year. In the second part of the formula the terminal value TV of the mature business is discounted to the current year and multiplied with the probability that the mature business stage is reached $\mathrm{P_Z}$:

$$rNPV = \left[\sum_{y=0}^{T} \frac{PCF_y}{(1+WACC)^y}\right] + \left[\frac{P_T \times TV}{(1+WACC)^T}\right] \qquad (11)$$

The terminal value is calculated with a perpetuity growth formula e.g. (Copeland, Koller, & Murrin, 1990):

$$TV = \frac{E_{M+1} \times \left(1 - \frac{g}{ROIC}\right)}{WACC - g} \qquad (12)$$

Here g is the perpetuity growth rate which equals the market growth rate and E_{M+1} the earnings in the first year of the mature stage and $ROIC$ the return on invested capital during the mature stage. The reason for using the perpetuity growth formula For the perpetuity growth rate the market growth is used as it is assumed that the resulting business will have reached its final market share and that this market share will stay constant. The perpetuity growth formula has become the gold standard for most financial analysts (Boer, 1999). What the perpetuity growth formula does is that it assumes that the business will keep growing with the perpetuity growth rate until infinity. This may seem unrealistic for an innovation project as the business will decline at some point. However, the following analysis shows that this is a reasonable assumption.

Valuation of mature companies is often performed with EBITDA, EBIT or PE (price/earnings) multipliers. The value of a company is then determined by multiplying its EBITDA, EBIT or earnings with a certain factor (the multiplier). This factor can be obtained by looking at companies in comparable industries (Boer, 1999). When we look at price/earnings (PE) ratios from different types of industries we can conclude that values between 10 and 30 are quite reasonable (Table 4).

Industry	PE ratio
Automotive	9,99
Diversified Company (e.g. Philips)	14,72
Semiconductor	30,16
Total Market Average	*23,78*

Table 4: PE ratios for different industry types[3]. The PE ratio is an equity valuation measure. It can be used to calculate the value of equity based upon the earnings a company is generating.

We can calculate an implied PE ratio M from the perpetuity growth formula by leaving out the E_{M+1} factor:

$$CV = E_{M+1} \times M \quad \rightarrow \quad M = \frac{CV}{E_{M+1}} = \frac{\left(1 - \frac{g}{ROIC}\right)}{WACC - g} \tag{13}$$

The implied PE ratio *M* can then be calculated as a function of the g, ROIC and the WACC (Table 5). This table shows that the perpetuity growth formula gives a reasonable estimate of the value of the business in the mature stage compared to the industry average PE ratios.

	ROIC				
g	**10%**	**20%**	**30%**	**40%**	**50%**
2%	11	13	13	13	13
3%	13	15	15	15	15
4%	15	17	18	18	18
5%	19	21	22	23	23
6%	25	28	29	30	30

Table 5: Implied PE ratios calculated with equation (13). In the table the implied PE ratio can be found for different values of g and ROIC, while keeping the WACC fixed at the Philips WACC of 9%. The table shows that the values obtained with the perpetuity growth formula are in the same range as industry average PE ratios.

[3] http://pages.stern.nyu.edu/~adamodar/

6. Model Testing

In this section a discussion is made about the testing results from the risk-based model presented in the previous section.

6.1 Model Tests

Three different steps were taken to test the model:

1) Logical Testing
2) Stress Testing
3) Model Validation

<u>Logical Testing</u>

Logical testing consisted of checking whether the model gave correct output when tested for simple hypothetical cases. For example, for a 0% risk case the model should always give the same valuation as the NPV approach, when all other inputs are equal. The reason for this is that is that if the probabilities in the rNPV formula are all 100% the formula equals the standard NPV formula. For the results see Appendix G.

<u>Stress Testing</u>

Stress testing consisted of checking whether the model still gave sensible outputs in the case that extreme input values were entered into the model. For the results see Appendix H. For example, the test assesses the boundaries for the perpetuity growth rate. If this growth rate is too large, the model won't give sensible output anymore.

<u>Model Validation</u>

Model validation consisted of a valuation of two semi-recent spin-off ventures from Philips. These ventures will be called Venture1 and Venture2. The main reason for using ventures instead of adjacency projects is that both ventures had pre-money valuations which could be used as a benchmark. These pre-money valuations were derived via negotiations between the different stakeholders in the ventures (what share of the venture would they get for what price?). Pre-money valuation of Venture1 was 8 m€. Pre-money valuation of Venture2 was 6 m€. Input data for the ventures was obtained from the business cases for these ventures. Both ventures were generating no sales and they were still in the development stage. Input parameters for the ventures can be found in Appendix D and Appendix E.

Monte-Carlo simulation

For both ventures the required input data had a fairly high level of uncertainty. This uncertainty can in theory been taken into account via Monte-Carlo simulation (Appendix J). However, in order to do this effectively one should have knowledge about the distributions for the input variables. As the distributions for the input variables were not known – only written business cases were available without any information about uncertainty in data – assumptions had to be made.

This has an important implication: no conclusions can be drawn with respect to the absolute dispersion of the probability distribution for the rNPV as it is mainly determined by the dispersion in the input variables. We can only draw conclusions about the relative impact of the different input variables on the output variable. But this is exactly what sensitivity analysis does (Appendix J).

In order to make a sound comparison of the relative impact of the input variables, all variables were assigned the same small dispersion of (-10%, +10%) of their original value as the dispersion of the input variable will affect its impact on the output variable. A small dispersion of ±10% is taken to approximate a derivate of the output with respect to the respective input variable. Most input variables are defined per stage (see Appendix D and Appendix E). In order to limit the number of simulation variables and really be able to compare the effect sizes of different input parameters, instead of defining distributions for all different input variables we assumed that inputs of the same type (e.g. Technology Risk) were fully correlated. Thus input parameters of the same type (e.g. Technology Risk) were multiplied with the same parameter with the following distribution: $PERT(Min\,;Most\ Likely\,;Max) = PERT(0{,}9\ ;1\ ;1{,}1)$. A PERT distribution transforms the minimum most likely and maximum values into a distribution that approximates the normal distribution (see Appendix J). We will now discuss the different parameters.

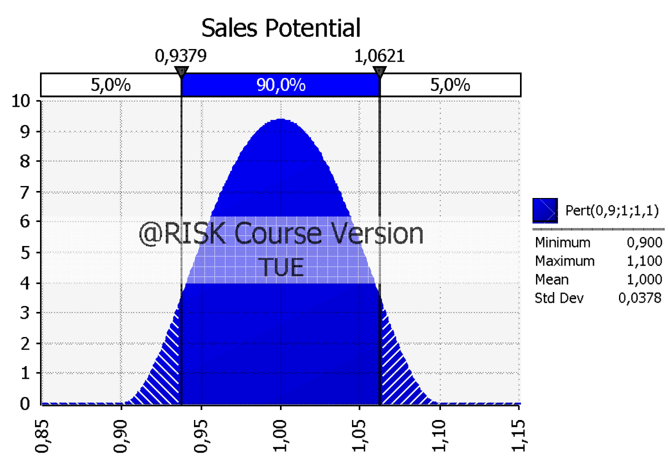

Figure 15: Pert distribution for the sales potential.

The first parameter α_1 is the Time-To-Market parameter. The base case stage durations of the exploratory stage ($Time_E$), proof-of-concept stage ($Time_C$) and development stage ($Time_D$) are multiplied with this factor:

$$\alpha_1 = TimeToMarket \rightarrow \alpha_1 Time_E, \quad \alpha_1 Time_C, \quad \alpha_1 Time_D \tag{14}$$

The second parameter α_2 is the Ramp-Up time parameter. The base case duration for the growth phase (when sales is ramped up until the sales potential is reached) is multiplied with this factor:

$$\alpha_2 = Ramp\ Up = Time_G \tag{15}$$

The third parameter α_3 is the profitability parameter. The initial EBITDA margin in the growth stage $EBITDA_G$ and mature stage EBITDA margin $EBITDA_M$ are used as a proxy for the profitability:

$$\alpha_3 = Profitability \rightarrow \alpha_3 EBITDA_G, \quad \alpha_3 EBITDA_M \tag{16}$$

The fourth parameter α_4 is the R&D costs/year parameter. The different estimations of R&D costs/year per stage are multiplied with this factor. The R&D costs/year in the exploratory stage (T_E), R&D costs/year in the proof-of-concept stage (T_C), R&D costs/year in the development stage (T_D) and R&D costs/year in the growth stage (T_G) are all multiplied with the same parameter α_4:

$$\alpha_4 = R\&D\ C/y \rightarrow \alpha_4 (R\&D\ C/y)_E,\ \alpha_4 (R\&D\ C/y)_C,\ \alpha_4 (R\&D\ C/y)_D \tag{17}$$

Parameter α_5 until α_8 are the risk parameters. The different estimations of risk per stage are multiplied with this factor. For example the technology risk in the exploratory stage (T_E), technology risk in the proof-of-concept stage (T_C), technology risk in the development stage (T_D) and technology risk in the growth stage (T_G) are all multiplied with the same parameter α_4. The same procedure is followed with the other variables:

$$\alpha_5 = Technology\ Risk \rightarrow \alpha_5 T_E, \quad \alpha_5 T_C, \quad \alpha_5 T_D, \quad \alpha_5 T_G \tag{18}$$

$$\alpha_6 = Value\ Proposition\ Risk \rightarrow \alpha_6 V_E,\ \alpha_6 V_C,\ \alpha_6 V_D,\ \alpha_6 V_G \tag{19}$$

$$\alpha_7 = Competitive\ Risk \rightarrow \alpha_7 C_E,\ \alpha_7 C_C,\ \alpha_7 C_D,\ \alpha_7 C_G \tag{20}$$

$$\alpha_8 = GoToMarket\ Risk \rightarrow \alpha_8 G_E, \quad \alpha_8 G_C, \quad \alpha_8 G_D, \quad \alpha_8 G_G \tag{21}$$

Market Growth, the NOC Turnover and Sales Potential were already defined to be equal for all stages:

$$\alpha_9 = Market\ Growth \tag{22}$$

$$\alpha_{10} = NOC\ Turnover \tag{23}$$

$$\alpha_{11} = Sales\ Potential \tag{24}$$

Variables like the WACC, marginal tax rate and depreciation were not assigned a distribution, as they can be estimated without a too high error. To conclude, we now have 11 different input parameters which are assigned a distribution function and assumed a full correlation of the same type of variables over the stages.

6.2 Valuation Venture1

The input values for venture1 can be found in Appendix D. In Figure 16 the primary valuation results from the valuation of venture1 can be found. This distribution is a probability density function, which shows the probability (y-axis) for a specific valuation (x-axis). The surface under the graph is 1 (a key property of probability density functions).

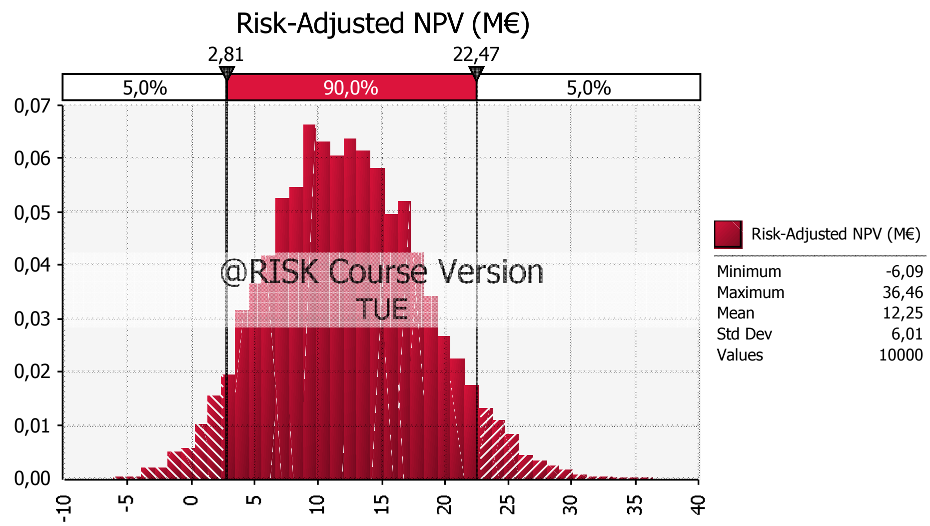

Figure 16: Risk-Adjusted NPV for venture 1. The output distribution for the rNPV has a mean of 12M€ and a standard deviation of 6 M€.

The output distribution for the rNPV has a (mean; standard deviation) of (12 M€; 6 M€). This implies that the valuation obtained with the model is close to the pre-money valuation made at Philips research, which was 8 M€. Thus the valuation is accurate, but not precise due to the large standard deviation. Even with the low dispersion in the input variables a high dispersion in the valuation is the result. As the mean value of the valuation is close to the pre-money valuation by Philips Research, we conclude that the model gave an adequate output.

6.3 Valuation Venture2

The input values for venture 2 can be found in Appendix E. In Figure 17 the primary valuation results from the valuation of venture2 can be found.

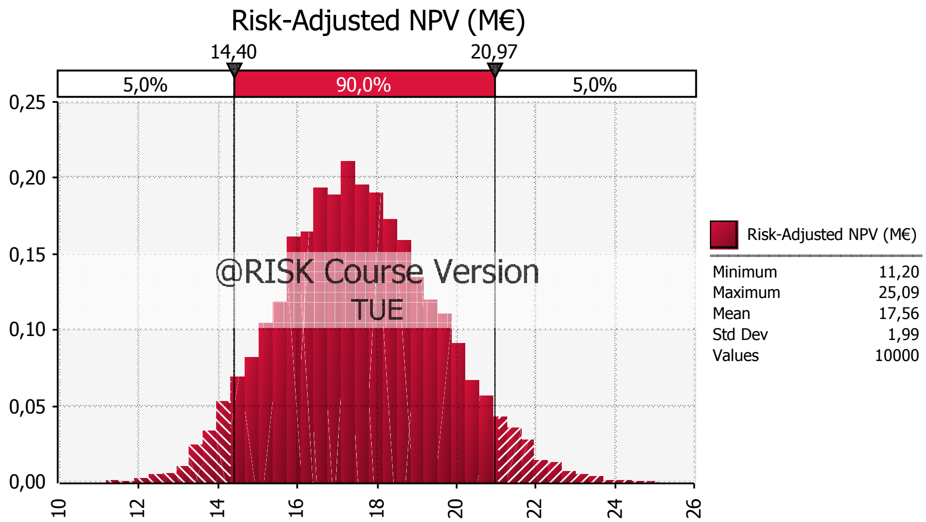

Figure 17: Risk-Adjusted NPV for Venture 2. The output distribution for the rNPV has a mean of 18M€ and a standard deviation of 2M€.

The output distribution for the rNPV has a (mean; standard deviation) of (18 M€; 2 M€) M€. The pre-money valuation of 6 M€ made by Philips Research does not fall within the range of outcomes generated with the simulation. There can be multiple causes for this. The perceived risk by the stakeholders at the time of the sale could have been higher than the perceived risk in the venture by business developers at the current time, which would have lead to a lower valuation result. Secondly, it is not known what valuation approach was used by the stakeholders. Use of a standard NPV approach to value the venture with a high discount rate to adjust for the high innovation risk in the venture would probably also have resulted in a lower valuation, as the flexibility to early stop the venture is not taken into account. We can test this with the model by setting al risks to zero – which transforms it to a standard NPV model – and increasing the discount rate.

Discount rate	Valuation
30%	11 M€
35%	7 M€
40%	4 M€

Table 6: Valuations obtained via the NPV approach for different high risk-adjusted discount rates shows that the NPV approach would lead to the low valuation in the range of the pre-money valuation of venture2.

7. Analysis

In this chapter the valuation results for venture1 and venture2 will be analyzed in more detail. The results from the sensitivity analysis can be represented in a tornado diagram (see Appendix J for an explanation on tornado diagrams). Main goal will be to identify key value drivers. We will make a distinction between positive and negative value drivers. Positive value drivers will have a value increasing effect when their value increases. For negative value drivers the opposite will apply.

7.1 Sensitivity Analysis Venture1

Results from the sensitivity analysis on venture1 are shown in Figure 18. Base case input values can be found in Appendix D. The input variables are sorted exactly in the same order with respect to their effect size on value. By far the most important business related value driver for venture1 is the profitability of the business. The coefficient value is 0,68 which implies that when the input value for the profitability increases with 10%, the rNPV increases by 6,8%. This is seems to be intuitively correct as the profitability of a business has a large impact on the free-cash flows. The second most important business related value driver is the NOC turnover. It is a positive value driver. This makes sense as the relatively low value of the NOC turnover (Appendix D), suggests a need for high capital investments to sustain the business, which has a decreasing effect on the free-cash flows.

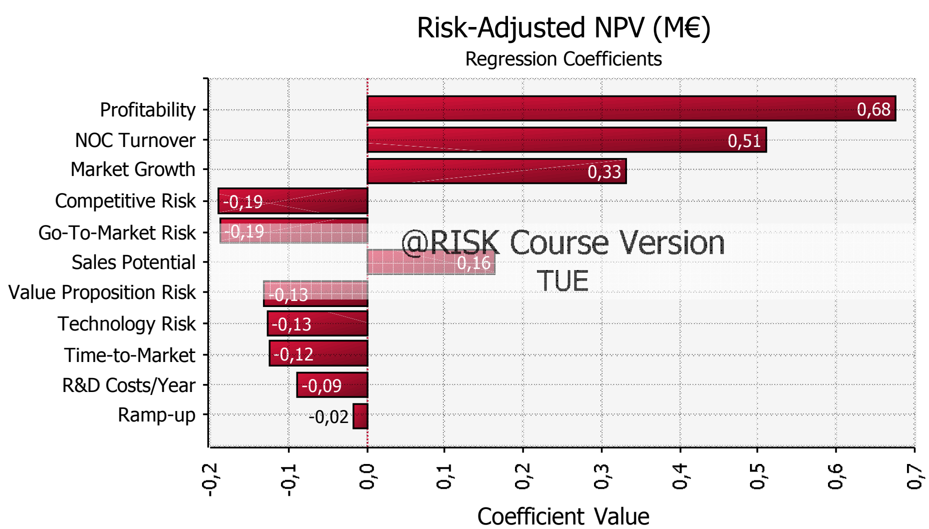

Figure 18: Sensitivity Analysis of the venture1 valuation. Profitability, NOC turnover and market growth have by far the largest (positive) effect. The total effect of all innovation risks is large as well.

Market growth is the third most important input. The different types of innovation risks have a mediocre (negative) impact on value However; the when considering all these risks together, impact of the total innovation risk is large. Striking is that the market growth has a larger impact on value than the initial sales potential for the venture. Intuitively this feels right; the value of a very fast growing business that starts with a low sales potential will eventually have larger sales then a slow growing business that starts with a larger sales potential. Time-to-market had a mediocre negative impact on value. This is lower than what R&D Costs/year and ramp-up time had a relatively low negative impact on the value.

7.2 Sensitivity Analysis Venture2

The results from the sensitivity analysis of venture 2 are represented in Figure 19. Base case input values can be found in Appendix E. The sensitivity analysis shows again that the profitability is the largest positive value driver. The largest negative value driver is value proposition risk. This is due to the relatively high value proposition risk for venture 2 in the development stage compared to venture 1. Again the market growth was the third most important factor. Sales potential had a larger positive effect compared to the venture 1 case. In this case also most risk types (except for value proposition risk) have a mediocre impact on the rNPV. The impact of NOC turnover rate is much lower due to the exceptionally high base case value of 4.0 (see Appendix E). Again ramp-up and R&D costs/year were the variables with the lowest impact on the rNPV.

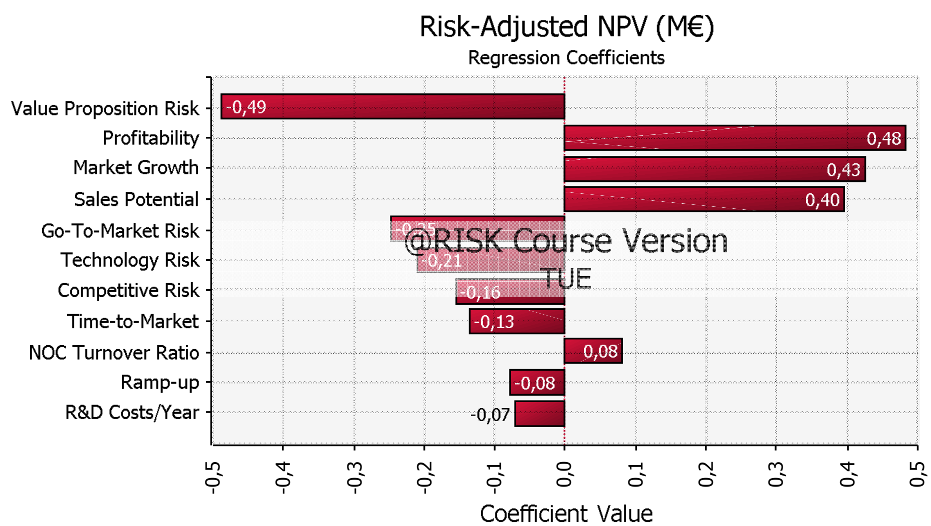

Figure 19: Sensitivity Analysis for the venture2 valuation. Value proposition risk has the largest negative effect. The total effect of all innovations risks is very large. Profitability, market growth and sales potential have a large positive effect.

7.3 General Conclusions from Analysis

First of all, the relative and absolute impact of different inputs seems to be case specific to a large extent. For example, for the first venture, profitability, NOC turnover, market growth and the innovation risk (considering all risks together) had the largest impact on the rNPV. For the second venture, innovation risk (especially value proposition risk), profitability, market growth and sales potential were the most important inputs.

However we can draw the conclusion that profitability (1) and market growth (2) are important positive value drivers for an adjacency as for both ventures these two variables emerged as important inputs. For both cases profitability was more important than market growth. From a theoretical point of view, these results seem logical; Growth and Return On Invested Capital (ROIC) are the two fundamental value drivers of a business (Copeland, Koller, & Murrin, 1990). The long-term growth of a business is likely to be highly correlated to the market growth. Profitability and has a large impact on the ROIC, as the profitability of a business is the return that is generated on the invested capital. Next to the large impact of profitability and market growth the total innovation risk (3) seems to have a large impact on value and thus is a key negative value driver. The relative and absolute impact of the different risks is seems to be case specific. This is caused by the specific investment requirements in R&D per stage and specific levels of risk in these stages.

The high impact of innovation risk supports a risk-based approach for adjacency project valuation. The key business related value drivers will determine the value of a business that results from an innovation project. Innovation risk will determine the probability that the business value is actually captured. Hence, the results obtained in this study make sense.

The tornado graphs in Figure 19 and Figure 19 show that the valuation is highly sensitive with respect to a number of input variables. The valuation results in Figure 17 and Figure 18 make this explicit as well; the small dispersion in input variables (±10%) leads to a relatively large dispersion in the valuation. It thus not makes sense to build complex valuation models requiring a large amount of inputs. What sensitivity analysis makes explicitly clear is what the real challenge is when valuing early stage innovation projects; reducing uncertainty with respect to the input variables and mapping out the uncertainty in value based on the perceived uncertainty in inputs. This seems to support the use of Monte-Carlo simulation to model this uncertainty.

8. Conclusions

In the previous chapters, a risk-based valuation model was presented and tested via the valuation of two ventures. Furthermore, sensitivity analysis was performed to identify key value drivers. In this chapter, the main findings from the study will be summarized and the research questions will be answered. Next to this, the limitations and relevance of the will be discussed. This chapter will end with a short reflection.

8.1 Main Findings

Risk-Based Valuation

Model validation (chapter 6) was performed via the valuation of two semi-recent spin-offs plus logical testing and stress-testing. The risk-based model gave an adequate valuation for the two spin-offs. Risk-based valuation is a conceptual improvement on NPV valuation as it incorporates an improved way to capture innovation risks plus the flexibility created by stage gating to early stop projects. Furthermore, the model is a practical improvement over standard NPV valuation. The model makes the link between innovation risk and value more explicit. In this way it helps managers to better assess the financial attractiveness of innovation projects. Next to this, it enforces risk-based innovation management by forcing R&D managers to think about and make explicit the risks underlying an innovation project.

Key value drivers

Sensitivity analysis showed that the relative and absolute impact of different inputs differ from case to case. However, three key value drivers were identified that seem to have a standard large effect on value of an adjacency project. Value decreasing and value increasing value drivers can be identified. Key positive value drivers are (1) profitability and (2) market growth. Key negative value drivers are the (3) innovation risks.

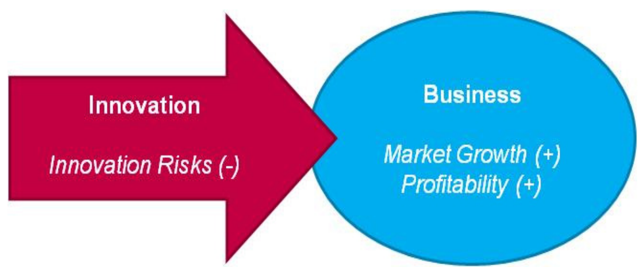

Figure 20: key value drivers for adjacency projects. Innovation risks have a large negative impact on value. Market growth and profitability have a large positive impact.

From a theoretical point of view, these results seem logical; Growth and Return On Invested Capital (ROIC) are the two fundamental value drivers of a business (Copeland, Koller, & Murrin, 1990). The long-term growth of a business is likely to be highly correlated to the market growth. Profitability and has a large impact on the ROIC, as the profitability of a business is the return that is generated on the invested capital. Innovation risks will determine whether the business value will be captured at all, which supports its high impact on the valuation as well.

Innovation Risk

Sensitivity analysis showed a large impact of the total innovation risk on value. This supports a risk-based approach for early stage innovation project valuation. Management of the innovation portfolio faces projects with different risk profiles (see Chapter 5).

Uncertainty

The fundamental issue underlying early stage valuation problems is the very high uncertainty in inputs. The usual high uncertainty in key value drivers implies that there is not much point in developing highly complex valuation models. What sensitivity analysis makes explicitly clear is what the real challenge is when valuing early stage innovation projects; reducing uncertainty with respect to the input variables and mapping out the uncertainty in value based on the perceived uncertainty in inputs. This seems to support the use of Monte-Carlo simulation to model this uncertainty.

Managerial Implications

The sensitivity analysis on the two venturing cases made explicit that projects management should focus on reduction of innovation risk and aim for fast growing and profitable markets in order to create value.

Future Work

For future valuations it would be interesting to map the full uncertainty in output based on perceived uncertainty in all relevant inputs by using Monte-Carlo simulation. Next to this application of the risk-based model could be extended to other projects. For example for roadmap innovations, the risk-based valuation model could be combined with real options. For these projects the use of real options is warranted, as generally more market knowledge is available. Risk-based valuation can be used to capture the specific innovation risk and flexibility to respond to innovation risk. Real options can be used to capture market risk and flexibility to respond to market risk. For such a model, uncertainty in the inputs can still be captured with Monte-Carlo simulation to model the uncertainty in output.

8.2 Research Questions

1. How to value early stage adjacency innovation projects?

This research question will be answered through five sub questions.

a. Which valuation technique is the most suitable to value early stage adjacency projects?

In chapter 4 it was concluded on theoretical and practical grounds that the Risk-Adjusted Net Present Value (rNPV) is the most suitable approach to value early stage adjacency projects as this approach takes into account both the time-varying aspects of innovation risk as well as the flexibility to early stop projects due to this risk.

b. Which are the required input parameters based on the type of adjacency, the availability of data and the selected methodology?

The main inputs for the risk-based valuation model are either related to the risk model or to the cash flow model. The risk model requires expert opinion on the risk curves for the different risk types. A risk assessment is made per risk type and per stage. The cash flow model requires input on the required R&D cost per year per stage, and the expected duration of the different stages. Next to this, business related variables are needed: market growth, sales potential, EBITDA margin, depreciation and the marginal tax rate.

c. How to represent the output? And what financial measures do we use for the output?

The primary output is represented in a single number: the risk-adjusted net present value (rNPV). By using Monte-Carlo simulation, a distribution can be plotted for the rNPV. Furthermore, this technique allows for a quick assessment of the sensitivity of the rNPV for various input parameters.

d. How should risk be handled?

Risk in an innovation project consists of the market risk and on top of that, additional innovation risks. Innovation risks are assessed for each of the R&D stages and the growth stage of the business lifecycle. Four types of project specific risks were identified: technology risks, value proposition risks, competitive risks and go-to-market risks. Innovation risks determine the probability of success for the different stages and thus the expected cash flows. The remaining market risk is captured by discounting all future cash flows with the company WACC.

e. How to incorporate Stage-Gating into the model?

In the valuation mode stage-gating is explicitly taken into account. Risk is assessed per stage and the risk in a specific stage determines the probability of success of that stage. This approach assumes that a project can be stopeed at a gate. This is also reflected in the calculation of the rNPV as cash flows are weighted with the probability of their occurrence. Also, the durations and cost/time of each of the different stages are required as direct input. In this way a longer duration of a specific stage is penalized.

2. *What are key value drivers for adjacency innovation projects?*

Sensitivity analysis showed that the relative and absolute impact of different inputs differ from case to case. However, key value drivers were identified that seem to always have a large effect on value of an adjacency project. Value decreasing and value increasing value drivers can be identified. Key positive value drivers are (1) profitability and (2) market growth. Key negative value drivers are the (3) innovation risks.

8.3 Limitations

Venturing case studies

Within the study only two venturing cases were considered, as for these two ventures two pre-money valuations were available for comparison. Probably more support could be built for the model when cases were valued.

Required data input quality

For the cases, all required data inputs were not easily available. Data had to be extracted from the available business plans. Financial data within these business plans of course was also mainly based on estimates. Thus uncertainty with regard to the input data was high.

Method is only suitable for high risk early stage projects

The ROI for roadmap opportunities cannot be judged by the risk based valuation method proposed. One should judge this more in terms of market extension rather than market creation potential. For this the terminal valuation must be defined differently than proposed in this study. The risk-based model is aimed at early stage adjacency projects that are still in the exploratory or proof-of-concept stage. Later stage projects might be better valuated with more rigid financial methods (rigorous NPV analysis) as innovation risk will be reduced to a great extent at this point and there will be less uncertainty in inputs.

8.4 Relevance

Academic Relevance

The academic relevance of this study is that it makes a unique link between the innovation risks, flexibility created by stage-gating and valuation. In this study, it is recognized that innovation risks are an important element that should be considered when valuing early stage adjacency projects. The risk-based model presented in this study is a conceptual improvement over standard NPV valuation. It incorporates an improved way to capture innovation risks plus the flexibility created by stage-gating to early stop projects.

Relevance to Philips

The risk-based model presented in this study is a practical improvement over standard NPV valuation. The model makes the link between innovation risk and value more explicit. In this way it helps managers to better assess the financial attractiveness of innovation projects. Furthermore, it enforces risk-based innovation management as R&D managers need to think about and make explicit the risks underlying an innovation project.

8.5 Reflection

Execution of this research resulted in numerous insights and learning moments for me as a person. Let's start with the process. I discovered that it takes a long time to really get to the core of a problem of a company. There is a huge gap between your own perception what the problem you are trying to solve actually is and how a company perceives a problem. Bridging this gap requires time and numerous conversations with people known to the issue at a company. Probably, more interaction early on had been useful for the speed and quality of the solution presented in this paper.

Process related was the development of the model. When modeling, an important issue to consider is the balance between complexity and simplification. For example, to make to model applicable to a broader range of innovation types, real options could have been included as an extension (see future work). This would have made the model more complex. On the other side, the model could have been simpler with respect to the cash flow model. For example, later analysis showed that by far the largest value of the business is encapsulated in the mature stage (terminal value). So value of the business could have for example been modeled by estimating the earnings and using a PE multiplier to translate this to a business value. The innovation trajectory could then have been modeled with just the R&D costs, time and risk analysis per stage. Possibly, such a simplified model would have been just as powerful as the current model.

The former point also relates to one of our conclusions that the real challenge when valuing early stage innovation projects is the uncertainty in the input variables. The largest effort should not go to the development of sophisticated models but to work on input data quality.

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Appendix A Valuation Model Inputs

Project

Here the name of the project can be entered.

Year

This is the reference year for the valuation.

Current Stage

Here the current stage of the project can be entered. Options: exploratory, proof-of-concept, development, growth and mature.

Sales Potential

This is the annual sales to be obtained by the product at the end of the growth stage. During the growth stage, sales will increase via an s-shaped curve towards the sales potential.

WACC

This is the weighted average cost of capital (WACC). The WACC will be used to discount future cash flows to their current value. The WACC is used because this is the minimal rate of return each project within a corporation should obtain. For Philips the current WACC is approximately 9%.

NOC Turnover Ratio

The NOC (Net Operating Capital) is the sum of the company's net working capital and long-term operating assets. Net working capital comprises all the current working assets of a company (cash, inventories, receivables) minus operating liabilities (payables, loans, outstanding bonds). Long-term operating assets are used to support the company operations in the long term (plant, property & equipment).

The NOC turnover ratio is the ratio of sales/NOC. The NOC turnover ratio says something about how efficiently a company generates sales with respect to its assets. NOC turnover ratios are industry specific. For example, the chemical industry has typically low NOC turnover ratios (<1) and retailers have high NOC turnover ratios (>3).

Marginal Tax Rate

This is the tax percentage on that has to be paid over the earnings (EBIT). Marginal tax rates vary from country to country (NL: 25%, GER: 29,48%, UK: 24%, France: 33,33% and USA: 40%).

Depreciation

Depreciation is the percentage of depreciation of the value of all assets per year. All assets include fixed assets and working capital. However, as working capital does not depreciate, a percentage of 10% depreciation of assets implies a higher effective depreciation of fixed assets. A conservative estimate of depreciation would be 10% per year.

Market growth

The long-term growth rate for the business will equal the market growth as in the mature market, market shares will stabilize and stay constant.

Technology Risk [Stage]

The technology risk in a particular stage is the probability that the project will fail due to technology related factors in this stage; for example that essential technological and scientific issues for the proposition can't be solved in the framework of the program. Additionally, for healthcare products, it concerns the risk that clinical trials fail.

Value Proposition Risk [Stage]

The value proposition risk in a particular stage is the probability that the project will fail due to value proposition related factors in this stage. For example, that no application for the technology can be found, that there is no market/(end)customer need, benefits are not understood by the market/(end)customer, that there is no fit with the market (product does not fully fit with customer needs).

Competitive Risk [Stage]

The competitive risk in a particular stage is the probability that the project will fail due to competitive factors in this stage. For example; competitors claim a significant part of the market or that the margins expected will be low because of market conditions foreseen.

Go-To-Market Risk [Stage]

The go-to-market risk in a particular stage is the probability that the project will fail due to go-to-market related factors in this stage. These factors encompass any element of the value chain required for any new product to reach its potential customers. This includes factors as sales force capabilities, distribution channels, manufacturing capabilities and customer support. Additionally, this includes risks related to non-successful partnering strategies that relate to the above. Go-to-Market risks will be influenced by the company's current presence in the target market segment.

Time [Stage]

The time for a particular stage is the total time this stage takes in months.

R&D cost/year [Stage]

The R&D cost/year is required investment per for upfront development of the product for a particular stage.

EBITDA Margin [Stage]

The EBITDA margin for a particular stage is the EBITDA margin that will be obtained at the start of this stage.

Appendix B The WACC for Philips

The capital funding of a company is composed of two components: debt and equity. Lenders (debt) and shareholders (equity) each require a return on the money they have invested in the company. The company cost of capital is often estimated as the weighted average of these returns, hence the name; Weighted Average Cost of Capital (WACC). Any project within a corporation must earn this return in order to add economic value to the company. The formula for the calculation of the WACC is:

$$WACC = (\%debt) \times (1 - t) \times (cost\ of\ debt) + (\%equity) \times (cost\ of\ equity)$$

The $\%debt$ is the percentage of debt to debt + equity, $\%equity$ is the percentage of equity to debt + equity, t is the tax the company pays. Debt is tax deductible; hence it is multiplied with 1 minus the tax percentage for the company. As the cost of capital is based on market considerations, market values should be used for equity and debt to establish these weights. Next, the definitions of the cost of debt and cost of equity will be discussed as well as how to obtain them.

The cost of equity

The level of return shareholders ask from a company depends on how risky an investment in the company is. If shares of other companies of comparable risk offer better returns, shares will be sold. The cost of equity is basically what it costs to a company to maintain a share price the satisfy investors. The most common way of determining the cost of equity is the Capital Asset Pricing Model (CAPM). It can be found in any regular financial or valuation textbook e.g. (Copeland, Koller, & Murrin, 1990):

$$Cost\ of\ Equity = Riskfree\ rate + beta \times market\ premium$$

Risk-free rate

This is the return obtained by investing into assets that are theoretically risk free. It is an accepted method to take the long-term interest rate received on AAA countries (e.g. Germany, The Netherlands) as a benchmark for the risk-free rate. The risk-free rate establishes a lower boundary for the required rate of return on any other investment.

Beta

The beta measures how strongly the company's share price is correlated to the market. A beta of one implies a perfectly in line with the market. If the beta>1 the company's stock price will exaggerate the (stock) markets movement, but it will move in the same direction. If the beta<1 the stock price will move in the opposite direction of the (stock)market.

Market premium

The market premium is the return investors expect to compensate them for taking the extra risk of investing in the entire stock market over and above the risk-free rate.

The cost of debt

The cost of debt is the rate of return that a company must offer to creditors to induce them to lend money to the corporation. Normally there is no single cost of debt for a corporation, as it will offer bonds with multiple maturities and yields to investors. However, a company has an average cost of debt. For example, for Philips the average cost of debt was 6,2% in 2011 (Philips, 2012).

Calculating the WACC for Philips

As a required rate of return for adjacency projects at Philips, we can make and updated calculation for the current (January 2013) WACC of Philips. The required parameters are drawn from various reliable data sources.

Parameter	Value	Source
Risk-free rate; Netherlands Government 10 Yr Bond	1,7%	http://www.bloomberg.com
Beta	1,32	http://finance.yahoo.com
Market Risk Premium	6%	http://pages.stern.nyu.edu/
Cost of Debt	6,2%	Philips Annual Report 2011
Tax Rate	25%	http://pages.stern.nyu.edu/
Debt	1,5B	Philips Q3 2012 Report
Equity (market values)	920M x €20 = 18,4B	http://www.beurs.nl/

Table 7: Input values for the determination of the Philips WACC.

Using these input parameters the Philips WACC is calculated below:

% Equity = 18,4/(1,5+18,4) = 92,4%
Cost of Equity = 1,7% + 1,32 x 6% = 9,6%

% Debt = 1-92,4% = 7,6%
(1-tax) x Cost of Debt = (1-25%) x 6,2% = 4,6%

WACC = (92,4% x 9,6%) + (7,6% x 4,6%) = 9%

Appendix C The S-Curve

For new innovations, sales in the first few years after formal launch will in general follow an S-shaped pattern. The formula for S-shaped growth is the following:

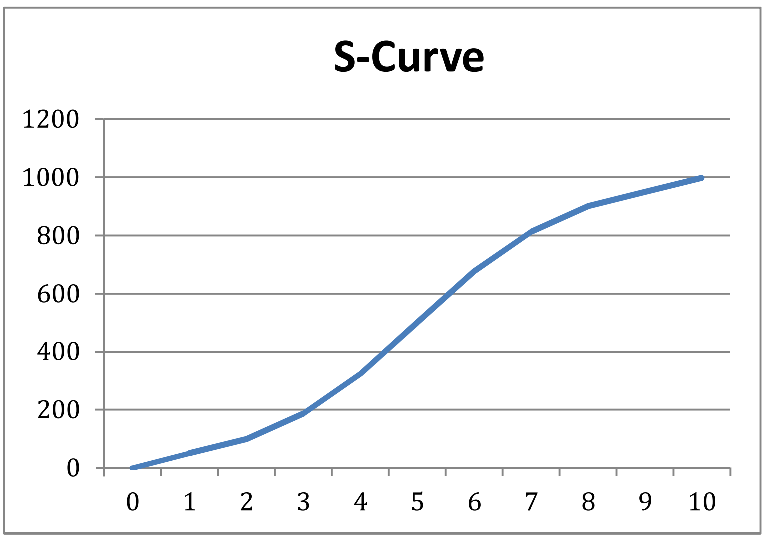
$$S_y = \frac{P}{1 + EXP[-\beta(t - T)]}$$

Here S_y are the sales in year y, P is the sales potential, β is the growth factor that determines how steep the S-curve is and T the time when 50% of the sales potential is reached. T is the middle between the year when sales starts T_3 and the year when the market becomes mature T_4. Thus, $T = (T_3 + T_4)/2$. Furthermore, if we want the sales curve to be at 95% of the sales potential in the first year of mature market, then we can solve the following equation for β:

$$0{,}95 \times P = \frac{P}{1 + EXP[-\beta(T_4 - T)]}$$

This gives $\beta = (2/T) \times LN\left(\frac{1}{0{,}95} - 1\right)$. Thus specifying, P, T_3 and T_4 completely determines the S-curve. In year $T_4 + 1$ normal linear growth starts with a fixed market growth rate.

T3 (= year of start sales)	1
T4 (= year market mature)	9
Sales Potential S (95% at year M)	1000
Beta	0,74
(T3+T4)/2	5
Market growth	5%



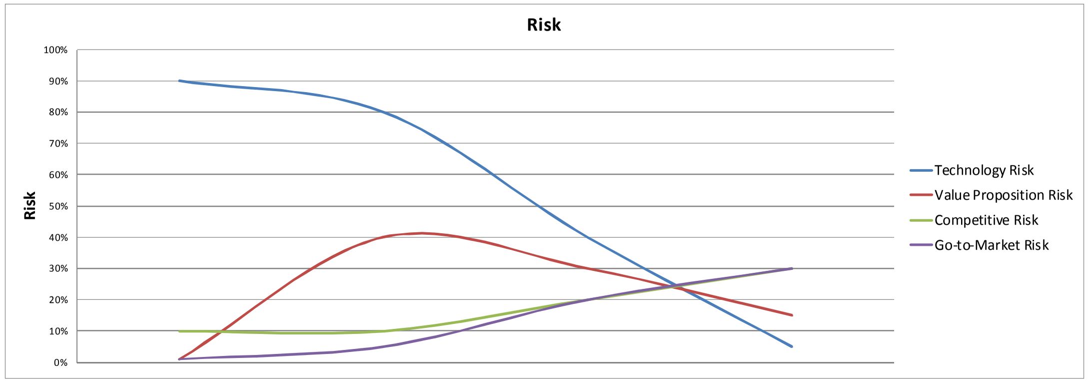
Year	0	1	2	3	4	5	6	7	8	9	10
Fraction of S	0,00	0,05	0,10	0,19	0,32	0,50	0,68	0,81	0,90	0,95	1,00
Sales	0	50	99	187	324	500	676	813	901	950	998
Sales Growth Rate			98%	88%	74%	54%	35%	20%	11%	5%	5%

Appendix D Data Venture1

Input Sheet

PHILIPS

Project	Venture1
Year	2011
Current Stage	Development
Sales Potential	€ 200.000.000
WACC	9%
NOC Turnover Ratio	0,9
Marginal Tax Rate	30%
Depreciation	10%
Terminal Growth Rate	5%



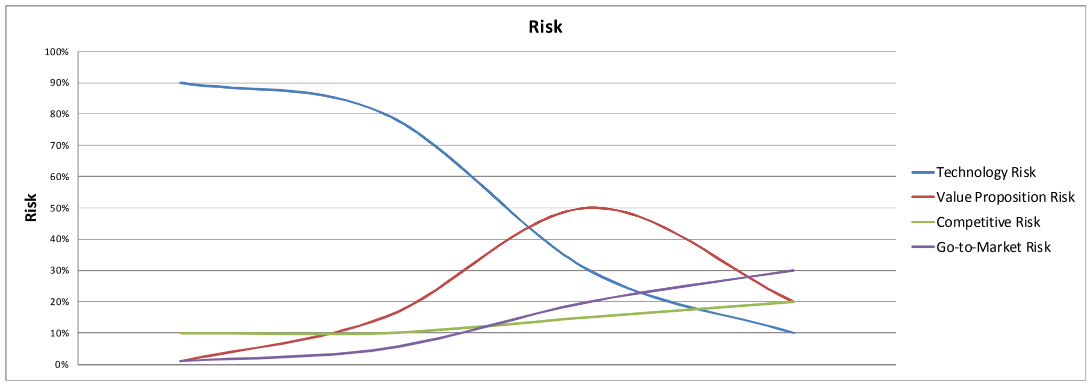
Stage	Exploratory (E)	Proof-of-Concept (C)	Development (D)	Growth (G)	Mature (M)
Milestones	LOI	T, P, F	C, D, ENG, IND	RU	
Description	Ideation & Innovation Planning	Value Proposition Creation & Advanced Development	Product,Services Development	Fast Growing Business	Mature Business
Technology Risk	90%	80%	40%	5%	
Value Proposition Risk	1%	40%	30%	15%	
Competitive Risk	10%	10%	20%	30%	
Go-to-Market Risk	1%	5%	20%	30%	
Stage Probability of Success	8,8%	10,3%	26,9%	39,6%	
Time	0	0	48	36	
R&D Costs/year	€ 0	€ 0	€ 4.000.000		
Total Cost	€ 0	€ 0	€ 16.000.000		
EBITDA margin				21%	44%

Appendix E Data Venture 2

Input Sheet

PHILIPS

Project	Venture2
Year	2011
Current Stage	Development
Sales Potential	€ 50.000.000
WACC	9%
NOC Turnover Ratio	4,0
Marginal Tax Rate	30%
Depreciation	10%
Terminal Growth Rate	5%



Stage	Exploratory (E)	Proof-of-Concept (C)	Development (D)	Growth (G)	Mature (M)
Milestones	LOI	T, P, F	C, D, ENG, IND	RU	
Description	Ideation & Innovation Planning	Value Proposition Creation & Advanced Development	Product,Services Development	Fast Growing Business	Mature Business
Technology Risk	90%	80%	30%	10%	
Value Proposition Risk	1%	15%	50%	20%	
Competitive Risk	10%	10%	15%	20%	
Go-to-Market Risk	1%	5%	20%	30%	
Stage Probability of Success	8,8%	14,5%	23,8%	40,3%	
Time	0	0	24	60	
R&D Costs/year	€ 0	€ 0	€ 2.000.000		
Total Cost	€ 0	€ 0	€ 4.000.000		
EBITDA margin				30%	42%

Appendix F Time-to-Market

Time-to-market has an effect on the value of an innovation project. To illustrate this, let's consider two investment options for an innovation project. In both cases a cumulative upfront investment of €600M and a cumulative net income of €1000M is the result. However, in the first case the project is rushed to market which results in profits to start in year 1. In the second case the R&D time is two years with results in profits to start in year 2. However, the profits per year are now higher, for example due to a higher product quality. In both cases the NPV is calculated at two different discount rates. In the fast time-to-market scenario NPV is 70 M€ when the cost-of-capital is 15% and -2 M€ when the cost-of-capital is 20% (Table 8). In the slow time-to-market scenario NPV is 60 M€ when the cost-of-capital is 15% and -11 M€ when the cost-of-capital is 20%. Thus the fast time-to-market option has a higher value then the slow time-to-market option as the future profits are discounted less in the first case. This example shows thus a feature of the NPV approach: a dollar now is worth more than a dollar tomorrow. The result of this is that the fast time-to-market scenario gets a higher NPV and is the preferred course of action (if our assumptions hold).

Fast Time-to-Market (values in 000000s)							
	Invest	*Profits*					
Year	0	1	2	3	4	5	Cumulative
Net Income	€ 0	€ 200	€ 200	€ 200	€ 200	€ 200	€ 1.000
Net Investment	-€ 600	€ 0	€ 0	€ 0	€ 0	€ 0	-€ 600
Free Cash Flows	-€ 600	€ 200	€ 200	€ 200	€ 200	€ 200	€ 400
NPV (CoC=15%)	€ 70						
NPV (CoC=20%)	-€ 2						

Table 8: NPV fast time-to-market.

Slow Time-to-Market (values in 000000s)							
	Invest		*Profits*				
Year	0	1	2	3	4	5	Cumulative
Net Income	€ 0	€ 0	€ 250	€ 250	€ 250	€ 250	€ 1.000
Net Investment	-€ 300	-€ 300	€ 0	€ 0	€ 0	€ 0	-€ 600
Free Cash Flows	-€ 300	-€ 300	€ 250	€ 250	€ 250	€ 250	€ 400
NPV (C=15%)	€ 60						
NPV (C=20%)	-€ 11						

Table 9: NPV slow time-to-market.

Appendix G Model Logical Testing

To test the model, first a simple standard scenario was created;

Project	Logical Testing
Year	2013
Current Stage	Exploratory
Sales Potential	€ 10.000.000
WACC	9,2%
NOC Turnover Ratio	2,0
Marginal Tax Rate	25,0%
Depreciation	10,0%
Market Growth	5,0%

	Exploratory	Proof-of-Concept	Development	Growth	Mature
Technology Risk	0%	0%	0%	0%	
Value Proposition Risk	0%	0%	0%	0%	
Competitive Risk	0%	0%	0%	0%	
Go-To-Market Risk	0%	0%	0%	0%	
Time	12	12	12	24	
R&D Cost/Year	€ 1.000.000	€ 1.000.000	€ 1.000.000		
Total Cost	€ 1.000.000	€ 1.000.000	€ 1.000.000		
EBITDA Margin				20%	20%

Table 10: Logical testing standard scenario.

The second step was to build a simplified benchmark model with limited features that could be checked manually for inconsistencies, thus the benchmark model was very likely to give the correct output. The benchmark model used the sales curve from the risk based model as input. Calculations in the income statement were exactly the same as calculations of the rNPV. Five scenarios were created in order to check various elements of the risk-based model. Outputs of the risk-based model were compared with outputs from the benchmark model. For an example of the output from the benchmark model see Table 11.If the risk based model gave the same output as the benchmark model it behaved correctly. For the results, see Table 12.

Scenario 1

In this first scenario the risk is 0% for all stages and risk types. Thus exactly the same parameter values as in Table 10 were used. What this implies is that the project has a 100% chance of commercial success. The valuation should therefore be the same as a standard NPV valuation as all cash flows have a 100% chance of occurring. The risk based model gave a correct output (Table 12).

Scenario 2

In the second scenario the risk for all stages and risk types was 10%. The other parameter values are kept the same as in the standard scenario. This implies that only the cash flows in the explorative stage (year 0) have a 100% chance of occurring. The cash flows in proof-of-concept (year 1) have a (90%)^4 = 65,4% of occurring etc. The risk based model gave a correct output (Table 12).

Scenario 3

In the third scenario the risk for all stages and risk types was 100%. The other parameter values are kept the same as in the standard scenario. Thus only the cash flows in the explorative stage (year 0) have a 100% chance of occurring. Cash flows in later stages have a 0% chance of occurring. The risk based model gave a correct output: the rNPV is now equal to the R&D cost in year 0: €1.000.000 (Table 12).

Scenario 4

In the fourth scenario, the former 3 scenarios are run again but now with a zero upfront investment in R&D and for two different sales potentials: €10.000.000 and €20.000.000. The valuation should go up with a factor 2 for each of the 3 former scenarios, as the sales potential goes up with a factor 2. The risk based mode gave a correct output (Table 12).

Scenario 5

In the fifth scenario we will vary the time of one stage to check for discontinuities in the model. Correct behavior would be to see a linear decrease in the rNPV as the time of the exploratory stage is increased from 0 months to 24 months. In this scenario a uniform risk was applied of 10% for all stages. From Figure 21 it can be concluded that the model behaves correctly as the valuation decreases in a continuous way when the time of one stage is decreased.

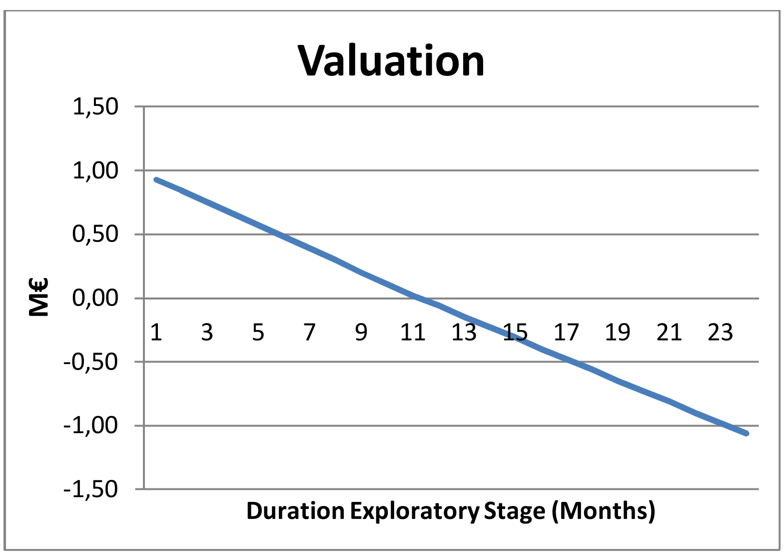


Figure 21: Model check for discontinuities.

Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Period	0	1	2	3	4	5	6
Sales	0,00	0,00	0,00	2,00	7,63	9,72	10,20
R&D Costs	1,00	1,00	1,00				
EBITDA	0,00	0,00	0,00	0,40	1,53	1,94	2,04
Depreciation	0,00	0,00	0,00	0,10	0,38	0,49	0,51
EBIT	0,00	0,00	0,00	0,30	1,14	1,46	1,53
Tax	0,00	0,00	0,00	0,07	0,29	0,36	0,38
Earnings	0,00	0,00	0,00	0,22	0,86	1,09	1,15
Net Operating Capital (NOC)	0,00	0,00	0,00	2,19	4,68	4,97	5,22
Depreciation	0,00	0,00	0,00	0,22	0,47	0,50	0,52
Gross Investment	0,00	0,00	0,00	2,41	2,96	0,78	0,77
Net Investment	0,00	0,00	0,00	2,19	2,49	0,28	0,25
Free Cash Flows	-1,00	-1,00	-1,00	-1,97	-1,63	0,81	0,90
Discount Factor	1,00	0,92	0,84	0,77	0,70	0,64	
PV Free Cash Flows	-1,00	-0,92	-0,84	-1,51	-1,15	0,52	
PV Terminal Value						13,79	
NPV	8,9						
Probability that cash flow occurs	100%	66%	43%	28%	28%	19%	
Risk-Adjusted PV Free Cash Flows	-1,00	-0,60	-0,36	-0,43	-0,32	0,10	
Risk-Adjusted PV Terminal Value	0,00	0,00	0,00	0,00	0,00	2,56	
rNPV	-0,1						

Table 11: Benchmark Model Output for Scenario 2.

#	Scenario name	Model element tested	Description	rNPV Benchmark model (M€)	rNPV Risk Based Model (M€)	Risk Based Model Behavior
1	0% risk	Risk/Value	0% risk for all risk types and stages	8,90	8,90	OK
2	10% risk	Risk/Value	10% risk for all risk types and stages	-0,01	-0,01	OK
3	100% risk	Risk/Value	100% risk for all risk types and stages	-1,00	-1,00	OK
4	Sales Potential*2	Value	Sales Potential*2 + no required upfront R&D	*M€10 market* 0% Risk: 11,65 10% Risk: 3,16 100% Risk: 0,0 *M€20 market* 0% Risk: 23,30 10% Risk: 3,16 100% Risk: 0,0	*M€10 market* 0% Risk: 11,65 10% Risk: 3,16 100% Risk: *M€20 market* 0% Risk: 23,30 10% Risk: 3,16 100% Risk: 0,0	OK
5	R&D time phase (24–0 months)	Time	The time for one phase is decreased from 24 to 0 months in steps of one month	Figure 21	Figure 21	OK

Table 12: Logical testing.

Appendix H Model stress testing

Stress testing was performed on the model to check how stable the model is in extreme circumstances. Some limitations of the model are discussed below. First of all, consider that the tool uses Monte-Carlo simulation. For the input variables triangular distributions were used that are defined by minimum, most-likely and maximum values. It must be kept in mind that the model should behave correctly for any combination of input values within their respective ranges. For example, if for the all times maximum values are used the model should still behave correctly. In this thesis we used the following ranges for distributions: (-30%, +30%).

High market growth

When a high long-term sales growth rates are used, the tool will give a false output. The reason for this is that in the mature stage a terminal value is calculated. This formula has one limitation: the value it has as output goes to infinity when WACC = Market Groth. Thus market growth < WACC.

Long time from exploratory stage until mature market

The exploratory stage until the growth stage is considered explicitly in the model. The explicit forecasting period is 25 years. After that a terminal value is calculated. Hence, for simulation purposes, the time from exploratory until mature market should be less than 25/1,3 = 19,2 years or 230 months.

Time growth phase

The growth phase is modeled via an S-curve. For very short duration growth markets (for example 1 year) the output curve does increasingly less resemble a real S-curve. Hence, it should be kept in mind that the growth phase should not be chosen too short (at least 2 months or larger for simulation purposes as the minimum duration should be larger than 1 in any case.

Trivial requirements

Furthermore, there are some trivial requirements. For example, that the tax rate should be less than 100%, time for the stages >0, 100% >Risk >0%.

Appendix I Risk Management

Of course some risks can be controlled. The whole purpose of stage-gated innovation is risk-reduction. In the forthcoming paragraph some measures through which risk can be reduced are discussed.

Management of Technology Risk

Technology risk can be reduced via two ways. The first option is to buy an innovation position. This can be done by acquiring knowledge, people, IP, prototypes, databases or even the acquisition of complete start-up companies. Note that this requires an environment capable and willing to absorb such positions like a corporate R&D environment. In essence this provides a fast-track option to acquire the necessary competencies to successfully research and develop a product. To second option is to form an alliance (team-up) with an external partner. In this way the technology curve can be pushed down.

Management of Value proposition Risk

The value proposition risk curve can be moved to the left and pushed downwards in three ways. The first two options are 1. early customer insight validation (market studies) and 2. performing a fair market evaluation (is there a market and how large is it?). Performing these tasks as quickly as possible helps to find out whether there really is a value proposition to the customer for the offering and whether the market is large enough to support large scale investment decisions. A way to reduce value proposition risk is through scaling (differentiation) options. This implies that multiple product market combinations can be found (multiple applications). This increases the probability that a market and the related valid customer need(s) are found.

Management of Competitive Risk

Competitive risk can be reduced by establishing early IP to protect the innovation. Another option is to perform an early competitive position evaluation which prevents the situation that markets are entered where fierce competition develops at an early stage. Such an evaluation is easier to perform when the markets are known, but harder in the case of adjacencies and ventures.

Management of Go-to-market risk

Go-to-market risk can be reduced via alliances with partners that have effective channels in target markets. Another option is to use sales/distribution channels used for existing products. Furthermore, low risk channels can be used (online sales channels are easy to set up and require few resources). Having operational and commercial experts in the right position can also significantly reduce go-to-market risk.

Appendix J Monte Carlo Simulation

Introduction

In this appendix a short discussion is made about Monte-Carlo simulation. First, an introduction will be given about how standard calculations are performed and make a link to scenario analysis. After that Monte-Carlo simulation will be discussed. This appendix concludes with a discussion of @Risk; the software tool that was used to perform Monte-Carlo simulations.

Standard calculations

Normal calculations combine single point value estimates of the model's variables to predict a single result (e.g. the profit). Suppose we have a business with revenues and costs. A standard excel model calculates the profit in a year by subtracting the costs from the revenues:

Revenues =	100
Costs =	90
Profit =	10

Estimates of expected values of these input variables have to be made. However, the probability is high that does not reflect reality; there is almost always considerable uncertainty with regard to the input variables.

"What-if" scenario analysis

The first step to solve this with respect to uncertainty in input variables is to make "what-if" scenarios. "What-if" scenarios show what happens to the output (profit) when the inputs change. One way to do this is to define negative and positive scenarios:

Positive		*Negative*	
Revenues =	110	Revenues =	90
Costs =	80	Costs =	100
Profit =	30	Profit =	-10

This example shows that the profits can become negative in the negative scenario and much higher than the base case in the positive scenario.

Introduction to Monte-Carlo simulation

Instead of just 3 different values for the input variables, more different scenarios can be created where the input variables are drawn from a specified range. To illustrate this principle, take the previous example, but now randomly selection value in the range for revenues (90; 110) and costs (80; 100):

Simulation 1		*Simulation 2*		*Simulation 3*		*Simulation 4*	
Revenues =	110	Revenues =	105	Revenues =	91	Revenues =	99
Costs =	82	Costs =	96	Costs =	99	Costs =	87
Profit =	28	Profit =	9	Profit =	-8	Profit =	12

What Monte-Carlo simulation thus does is recalculating the same calculation again en again, each time using different randomly selected sets of values for the model inputs. So in effect thousands "what-if" scenarios are calculated.

We can take this principle even one step further by increasing the number of possible combinations for the input values. In order to do this, the range of possible values and their probability has to be specified. This range and probability of each value within this range occurring is determined by a probability distribution for the input. From these distributions we can then draw different combinations of values. This is the start of a real Monte-Carlo simulation which incorporates the following steps:

1) Build model (define inputs, calculations and outputs)
2) Define probability distributions for input variables
3) Select a set of values from the input distributions
4) Perform calculations with these values and calculate output
5) Repeat (iterate) step 2-4 a large number of times (e.g. 10000 times).
6) Evaluate output

Input

For example, we can define two PERT distributions for the revenues and costs (Figure 22 and Figure 23). A PERT distribution takes minimum, most likely and maximum values from an expert opinion and transforms these 3 values to a distribution that most closely resembles a normal distribution (which is the most common distribution). The reason for asking minimum, most likely and maximum values is that this is easier than asking a mean and a standard deviation, which define the normal distribution.

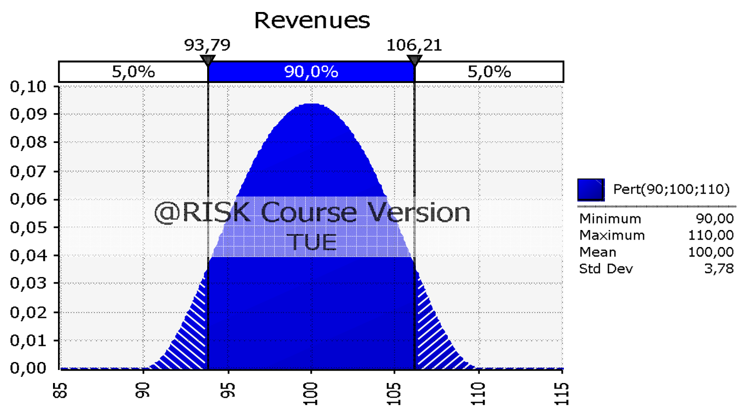


Figure 22: Input distribution for revenues.

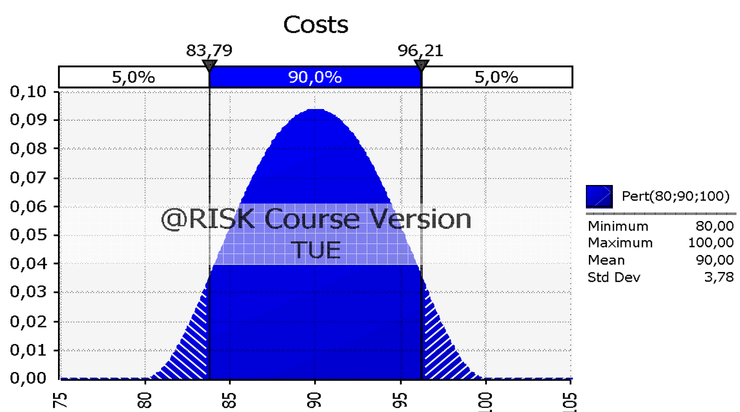


Figure 23: Input distribution for costs.

Output

Via the steps described before an output distribution for the profit is calculated. The output is also a distribution (Figure 24). The distribution approximates a normal distribution with (mean; standard deviation) = (10; 5,25).

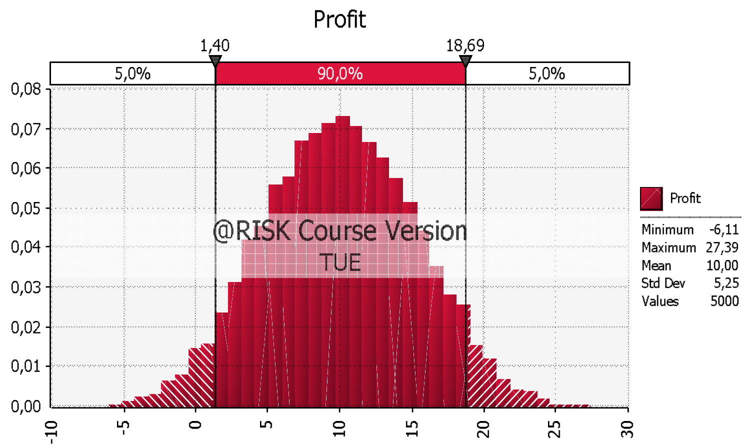


Figure 24: Output distribution for profit.

What this example shows is that Monte-Carlo simulation gives more information than a standard calculation of the profit or a "what-if" analysis. All possible values are shown for the profit, given the input distributions defined by us. Of course, the rigor of the output depends on how well we known the input distributions. If the characteristics (type, mean, range) of the input distributions are not well known we can't for example say that there is a 5% probability that the profits are higher than 18,69 for the example below. We only have some indication about the range of possible values for the output. In this sense, uncertainty that was first in the input value is now lifted to a higher level: uncertainty in the distribution.

Sensitivity Analysis

Monte-Carlo simulation also allows for an easy sensitivity analysis. With a sensitivity analysis, it is checked how much an output variable changes when the input variable changes. Results from a sensitivity analysis can be represented in a tornado diagram (Figure 25). In this figure the regression coefficients for the output with respect to the input parameters are shown. For example, the regression coefficient of 0,72 for the revenues implies that if the revenues increase with one standard deviation (3,78) that the profits increase with 0,72 standard deviations (0,72 x 5,25 = 3,78).

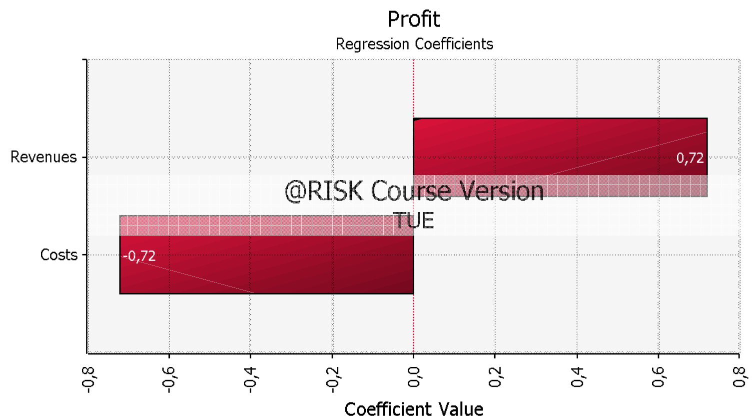


Figure 25: Sensitivity analysis for the profit.

In the next analysis, we will evaluate the impact of the characteristics of a distribution (type, mean, range) on the output distribution and its sensitivity to inputs.

Impact of input distribution type

To evaluate the impact of a different distribution, the revenues input distribution was changed from a PERT distribution to a triangular distribution with the same characteristics: (min, most likely, max) = (90, 100, 110). All other things are kept equal. For the impact on the output distribution, see Figure 28. It can be seen that there is almost no impact on the standard deviation: increase from 5,25 to 5,50. As expected, the mean value still is 10. For the impact on the regression coefficients for the profit, see Figure 29. There is almost no impact on the regression coefficients: the regression coefficient for revenues increases from 0,72 to 0,74 and the regression coefficient for costs decreases from -0,72 to -0,69.

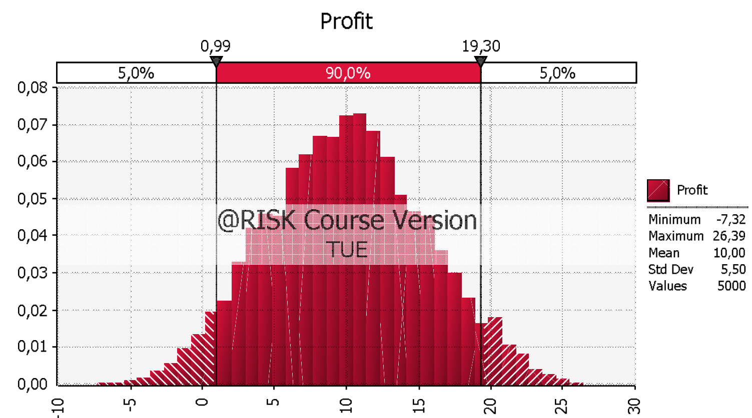


Figure 26: Impact of different input distribution for revenues on profits.

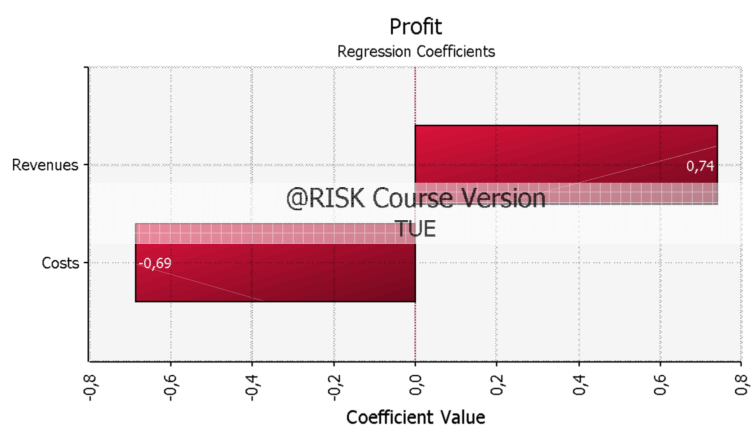


Figure 27: Impact of different input distribution on regression coefficients.

Impact of input distribution mean

To evaluate the impact of a different mean of one of the input distributions, for the revenues a PERT distribution was used with (min, most likely, max) = (100, 110, 120). Thus the distribution for revenues is shifted +10 higher. All other things are kept equal. For the impact on the output distribution, see Figure 28. It can be seen that there is almost no impact on the standard deviation: increase from 5,25 to 5,32. As expected, the mean value increases with 10. For the impact on the regression coefficients for the profit, see Figure 29. There is almost no impact on the regression coefficients: decrease from 0,72 to 0,71.

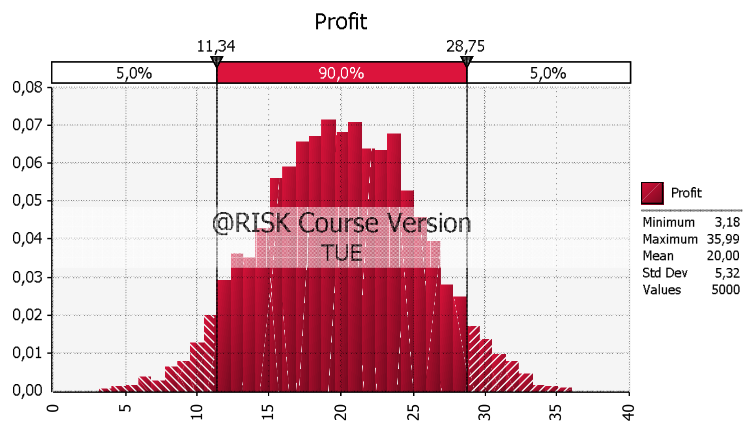


Figure 28: Impact of higher mean for revenues on profits.

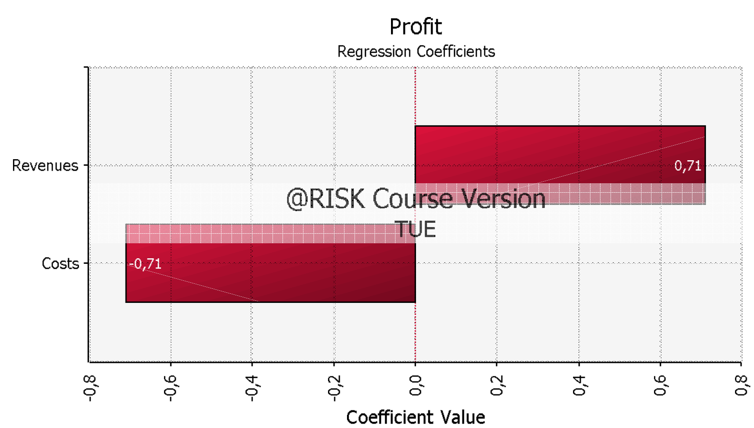


Figure 29: Impact of higher mean on regression coefficients.

Impact of input distribution range (input uncertainty)

To evaluate the impact of a different distribution range for one of the input distributions, for the revenues a PERT distribution was used with (min, most likely, max) = (80, 100, 120). All other things are kept equal. For the impact on the output distribution, see Figure 30Figure 28. It can be seen that there is a large impact on the standard deviation: increase from 5,25 to 19,22. The mean value is the same. This result is logical as an increase in the uncertainty for inputs should imply an increase in the output. For the impact on the regression coefficients for the profit, see Figure 29. There is a large impact on the regression coefficients: revenues increase from 0,72 to 0,98 and costs decrease from -0,72 to -0,20. This implies that an increase in the uncertainty of one input variable implies that the output becomes more sensitive to this variable and less sensitive to the other variables. The reason for this is that the absolute uncertainty in the output is for the largest part causes by the most uncertain input variable.

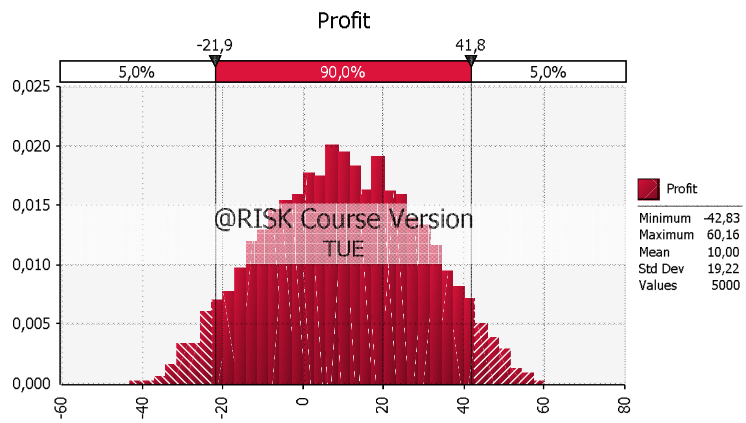


Figure 30: Impact of a larger range for revenues on profits.

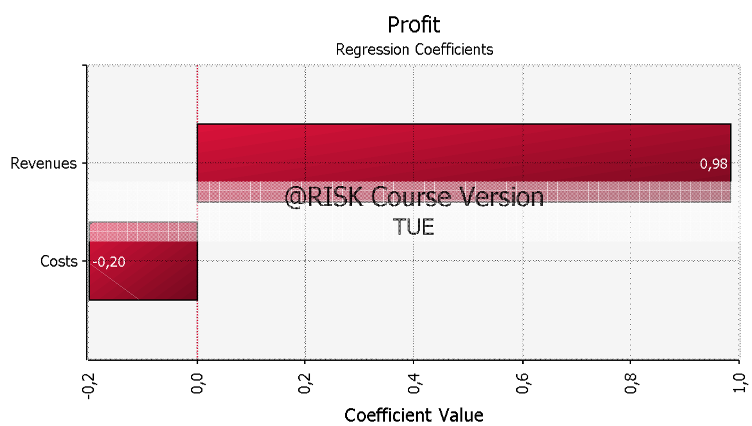


Figure 31: Impact of a larger range for revenues on regression coefficients.

Conclusions on Monte-Carlo simulation

Our preceding analysis showed that the distribution type on distribution mean have only a limited impact on the regression coefficients. The relative input range does have a high impact on the regression coefficients. This implies that the valuator should give careful thoughts about how uncertain the input variables are in his/her view. Thus, although Monte-Carlo simulation is a helpful technique and solves some problems with respect to uncertainty in input variables it introduces a higher order uncertainty with respect to the distribution types; it certainly isn’t the Holy Grail when it comes to the valuation of early stage R&D projects.

@Risk

Throughout this study a simulation excel plugin - @Risk - was used to perform simple Monte-Carlo simulations. @Risk is an excel plugin by the Palisade Corporation (www.palisade.com). It allows for the quick and easy risk analysis by using Monte Carlo simulation. According to Palisade any risky business, engineering and science problem can be modeled.