Project financial evaluation in the context of Bosch Suppliers Club initiative: the case of AOF

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Despacho RT - 31 /2019 - Anexo 4

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Sumário executivo

Projeto de avaliação financeira no contexto do Clube de Fornecedores da Bosch: o caso da AOF

Este trabalho aborda o caso prático de avaliação de projetos de inovação. Sob a iniciativa ”Clube de Fornecedores”, a empresa António Oliveira Ferreira (AOF) apresentou à sua cliente, Bosch Braga, um projeto de inovação (JigSense) para melhorar os seus módulos de sensores. A avaliação deste projeto torna-se importante não só para a AOF, que assim estima o valor criado pelo projeto, como também para a Bosch Braga.

O objetivo deste trabalho é de analisar o caso prático e proceder à avaliação financeira do projeto JigSense. Numa primeira fase, a avaliação é realizada utilizando o método tradicional Valor Atual Líquido (VAL) que assenta na valorização pelos fluxos de caixa descontados. Contudo, este método é insuficiente para captar a flexibilidade que a empresa tem de continuar ou abandonar o projeto. De forma a corrigir este problema, eu recorro como alternativa à análise de opções reais através de árvores binomiais.

A minha análise revela que o valor do projeto JigSense difere com o método de avaliação utilizado. Esta diferença reflete o valor da opção que a empresa detém de prosseguir ou abandonar o projeto. Contudo, os resultados dos dois métodos mostram que o projecto JigSense cria valor para a AOF e, por conseguinte, este deve aceitá-lo.

Palavras-chave: análise de opções reais; avaliação financeira; caso prático; projectos de inovação.

Executive summary

Project financial evaluation in the context of Bosch Suppliers Club initiative: the case of AOF

This research addresses the practical case of innovative projects evaluation. Under the "Suppliers Club" initiative, the company António Oliveira Ferreira (AOF) presented to its client, Bosch Braga, an innovative project (JigSense) to improve its sensor modules. The evaluation of this project becomes important not only for the AOF, which estimates the value created by the project, but also for Bosch Braga.

The objective of this work is to analyze the practical case and proceed to the financial evaluation of the JigSense project. In a first stage, the evaluation is carried out using the traditional Net Present Value (NPV) method, which is based on the valuation by discounted cash-flows. However, this method is insufficient to capture the flexibility that the company has to continue or abandon the project. In order to correct this problem, I use as an alternative real options analysis (ROA) through binomial lattices.

My analysis reveals that the value of the JigSense project differs when using different valuation methods. This difference reflects the value of the option the company has to continue or abandon the project. Nevertheless, the results from the both methods show that JigSense project creates value for AOF and, hence, it should accept it.

Keywords: financial evaluation; innovation projects; practical case; real options analysis.

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1. Introduction

On July 30th 2014, Portugal and the European Commission settled an agreement in which €25 billion were handed over to Portugal to improve economic and social issues. To this end, Portugal has defined a set of objectives to be achieved, with the following standing out: 1) stimulate the production and the offering of services; 2) increase exports; 3) imbue companies with new knowledge and technology (Compete 2020, 2015).

This agreement follows the European Commission's 2020 strategy, which puts great emphasis on innovation especially in Small- and Medium-sized enterprises (SMEs). Recent statistics (European Commission, 2010, Annex) show that Europe is losing some ground to other countries abroad, and this is mainly due to the poor conditions for innovation. Contrary to big companies, SMEs struggle to find good ways to finance research and development (R&D) just as they struggle to prevent brain drain (i.e. to retain their best professionals). Moreover, when SMEs develop a discovery they find it very costly to protect it.

The creation of an Innovation Union by the European Commission intends to tackle all these problems and, hence, encouraging SMEs to invest more in R&D. Consequently, European Commission expects with this increase in innovation that companies of the member states of the European Union will be able to grow in a sustained manner so that jobs are created and thus people's quality of life improves equally (European Commission, 2010).

In this framework, the Portuguese XXI constitutional government created the Suppliers Club initiative (SCi) to promote that innovation inside SMEs (Compete 2020, 2015). Here, several SMEs gather together with the challenge of satisfying the requirements of the central companies. The latter will express its main concerns that wish to be solved through innovative projects. The potential suppliers that present conditions and projects that come closer to these requirements are picked to integrate the central company suppliers' club.

This is not complete before these projects going through an approval conducted by the SCi's regulators. If the project fulfills the legal requirements, the relation between the central companies and SMEs is finally established. Joining the project are the research institutes that will assist the SMEs to develop their submitted projects by sharing scientific knowledge (Compete 2020, 2017). Furthermore, the investment required to start the project is, to some extend, supported through public funds.

This work focuses on the suppliers club of Bosch Car Multimédia Portugal, S.A. (hereafter referred to simply Bosch Braga). Depending on Bosch Braga requirements, suppliers might have to present projects that increase their production capacity (productive process innovation projects), and/or improve or create new equipment (product innovation projects). Once the relationship is established, Boch Braga and its suppliers expect to create a trade-off as foreseen by the SCi (Compete 2020, 2018):

- On one hand, Bosch Braga hopes that these projects help improve its operational activities. In addition, it expects that these projects contribute to the suppliers' development so that they continue to provide quality projects in the future;
- On the other hand, SMEs hope that working with Bosch Braga will bring benefits such as the introduction of new concepts (e.g. industry 4.0 and circular economy), an increase in sales and the entry into an international value chain.

One of Bosch Braga's suppliers is António Oliveira Ferreira (AOF) which proposed a product innovation project that already started in September 2019. It is in the interest of both AOF and Bosch Braga that such a project delivers value to the supplier, in other words, that it returns more money than the one initially invested. Otherwise, AOF may drop potential new projects with consequences for Bosch Braga.

One issue that arises is how innovative projects, that depend on the R&D process, are addressed. Hartmann & Hassan (2006) survey pharmaceutical companies, which are driven by several R&D projects, and conclude that traditional criteria are often preferred for project evaluation. The traditional criteria assume that the project follows only one path and that the estimated cash-flows are certain. In such cases, however, companies have the flexibility to change the course of the project with the arrival of new information. To consider this flexibility, as well as the uncertainty surrounding the project, real options analysis (ROA) is a much better approach for project evaluation. ROA is still not yet widely used for such projects. This is mainly attributed to the lack of practical cases analyzed and its complexity to put into practice.

Hence, this study aims to show the benefits of financial analysis using ROA and addresses it using a practical methodology so that it can be easily reproduced. I emphasize not only the use of financial evaluation but also the use of ROA for this type of project instead of the traditional criteria. In that sense, I make a brief presentation of the nuclear company, Bosch Braga, in chapter 2 and, in chapter 3, I make a more deep introduction of AOF, as well as a brief introduction to its product innovation project. Given the problem raised, I highlight the relevant theory in chapter 4. Finally, I explain the methodology used to address this case in chapter 5 and run the analysis in chapter 6 with the respective considerations.

some products whilst the drop of the EBIT is attributed to the decrease of the high margin sector mobility solutions operating income. The economic situation has a clear impact on the automotive industry and, consequently, on the Bosch Group high margin sector. From here, Bosch Group has to readjust its strategic plans to address the current economic situation which extends to the rest of its affiliates.

In any case, Bosch Group continues to join efforts to continue innovating. In that sense, Bosch decided to build a research center to enhance the emerging of new ideas and, consequently, to pool several new projects. The main goals are to be a leading supplier in the areas of automated driving, electromobility, and the internet of things (IoT). For instance, Bosch Group wants to develop self-aware and self-developing systems, connected and intelligent systems, electric mobility and fully autonomous systems.

The major concerns for Bosch Group, however, relates to the development of Artificial Intelligence (AI) and IoT – these two combined compose the industry 4.0, in essence. Bosch Group believes that IoT will play a central role in the future, not only in our daily lives but also in the production process.

Generally speaking, IoT allows communication between machines with other machines and machines with people. This is particularly important during operational activities. Not only the company can establish more efficient communication, but all information from operations are saved. Consequently, any error or inefficiency during the production process will be identified and the company can adjust to solve this problem, hence, progressively lowering production costs.

2.2. Bosch Braga

Bosch Group operates in Portugal in five different locations (Lisbon, Ovar, Braga and Aveiro), combining a total of 4.800 collaborators and, in 2019, contributing with € 1.8 billion in total sales (Bosch Group, n.d.-a). In Braga, it is located the biggest Bosch plant of Portugal – Bosch Car Multimédia Portugal, S.A. It gathers more than 3.200 workers, of which 300 work on R&D. Bosch Braga operational activities are oriented to *car multimedia*, a specific area that adheres to *mobility solutions*.

Bosch Braga specialty is for automobile multimedia and safety systems. Its current projects concern the research and development of new solutions for autonomous and connected mobility (automated mobility). Bosch Braga receives from Bosch Group part of the investment for R&D. As the technology progresses, its products and services are becoming increasingly more sophisticated, that is, more customized. Consequently, Bosch Braga requires suppliers that can keep this level of sophistication by providing up-to-date material and equipment.

However, this task has not been easy to find in Portugal at competitive prices. This is the reason why

Bosch Braga has to import much of its material and equipment, often from Asia. Thus, not only Bosch has to support the costs of the material itself but also the cost of transportation, not to mention the time lead required until Bosch Braga receives the material. To address this problem, Bosch Braga decided to register in the SCi, gathering and working closely with several potential suppliers that can provide quality products at good prices.

Technological changes will not end here and the needs of Bosch Braga today will be different from those of tomorrow. In that sense, it is crucial that these suppliers can continue to thrive to be capable to respond when those new necessities appear. However, if innovative projects do not deliver value to the companies, they most likely will not engage in similar innovation projects. For this reason, Bosch Braga required a financial evaluation of these projects to understand the impact they have on the suppliers.

3. António Oliveira Ferreira, Lda

António Oliveira Ferreira, Lda (AOF) is a small enterprise, founded in 1996 by the hand of one investor, Mr. António Ferreira. Later on, in 2001, in order to increase the competencies and potential of the company, Mr. António Ferreira partnered with another investor, Mr. António Lopes, hence becoming a limited liability company (Jornal de Notícias, 2017).

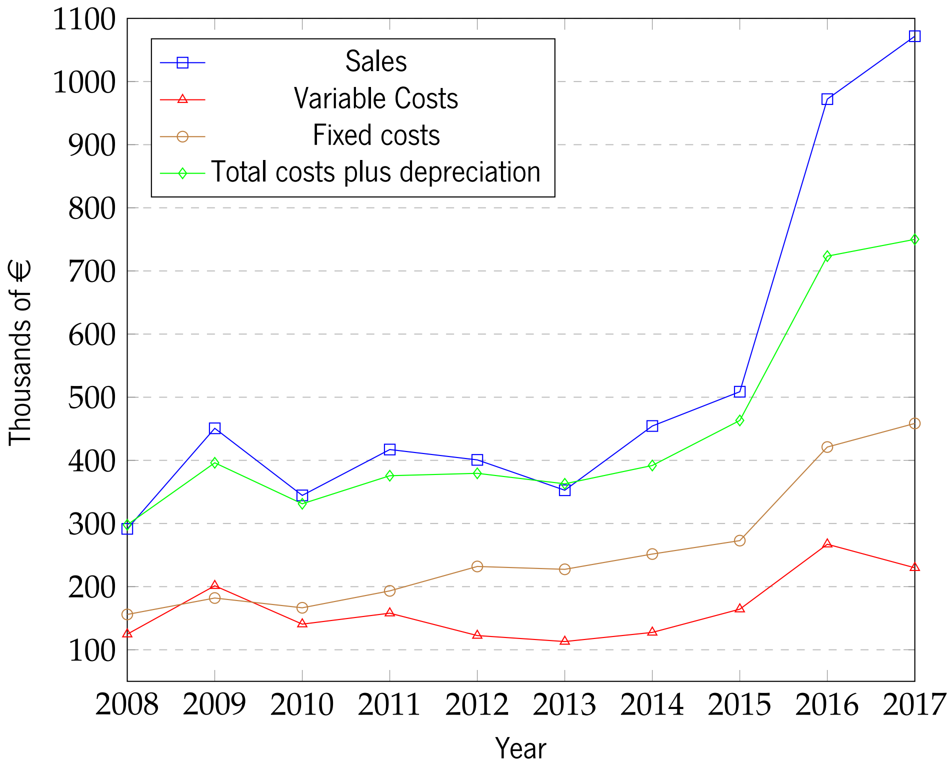
Since the beginning, AOF has focused on the conception of metallic moulds and production systems used for assembly lines, especially for the production of the mechanic and electronic components. Currently, AOF's biggest market is the automobile industry, but the company can design projects for other industries as well. The main goal of AOF is to diversify the industries for which it supplies (António Oliveira Ferreira, Lda, n.d.).

AOF follows a differentiation strategy as opposed to the cost leadership strategy since the offered service is differentiated (Palepu & Healy, 2012). AOF starts by designing a project that suits not only the client's needs, but also its production characteristics. During the operational process, the company makes sure that every established deadline is respected and that the quality and precision of the product are in perfect shape by running quality tests. Finally, AOF guarantees to its clients the installation and maintenance after-sale (António Oliveira Ferreira, Lda, n.d.).

There is a great concern regarding the quality of the product because this has significant importance in the operational activities of its clients, in general. This, in turn, requires excellent production materials and confidence that the product will not fail during the operations (Jornal de Notícias, 2017). AOF, in that regard, has already obtained a quality certificate (António Oliveira Ferreira, Lda, n.d.).

This strategy has proven to be successful as 90% of the customers were satisfied with the service provided, in a total of 427 projects developed in 2016 (António Oliveira Ferreira, Lda, n.d.). This way AOF wants to distinguish itself from its rivals by creating great value for its clients. With this client retention, AOF has some room to exercise a selling price that is above its marginal costs per unit. Since 2016, the financial situation of the company has greatly improved as seen in figure 3.1. However, the company needs to continue innovating to sustain its competitive advantage. This means that it needs to keep up the pace of the new technologies not only to improve its production process but also to develop products that can satisfy client's current needs, especially if these are extremely linked to technology.

Figure 3.1.: AOF's production profits



Data was gathered from Amadeus database. I make some adjustments concerning the variable and fixed costs (see the explanation and AOF's financial tables in Appendix – AOF's financial statements)

3.1. AOF's financial analysis

AOF operates in the industrial *manufacturing of metallic moulds*[1] (activity code 25 734) , in which the level of intensity of the five forces of Porter (Porter, 1989) are not too strong, as we will see in a moment. This means that the existing companies will not engage in price wars, nor they will feel pressured of their clients to reduce the selling price. Consequently, existing companies can take advantage of this and develop good levels of profits.

The industry[2] is fragmented and composed by similar companies in size, generally speaking. Moreover, tracking the sales record one could state that the industry is growing somewhat slowly, with the exception of 2010–2011. These two reasons could instigate price wars (Palepu & Healy, 2012) if it were not for the technological factor.

Metal moulds – devices, equipment and pieces developed from metallic material – can be used for

[1] All information regarding AOF was gathered in the *AMADEUS* database and it is presented in Appendix – AOF's financial statements

[2] Data regarding AOF's industry was gathered from Banco de Portugal – sector tables (see Appendix – AOF's industry)

the production process, i.e. installed on the client's assembly lines, or used as part of a product. In any case, the technological factor (Porter, 2008) is changing the production processes and, by extension, the products' conception. Consequently, these metal moulds also have to be more sophisticated which may trigger some switching costs to the client if the products are unique to a company, alleviating the pressure of reducing the selling price.

The product itself might be a reason to keep off new competitors. Given the potential specialization, new entries might have to invest good money in talent and precise machinery to develop the products. Another reason that can discourage new competitors has to do with the emergence of new concepts such as the industry 4.0. As stated in chapter 2, this makes the production process more efficient, hence, lowering the production costs. Companies, however, have to be prepared to adopt such a concept with software, machines and staff training. This is something that requires more investment but also time to establish. As a consequence, existing companies are less stressed with the threat of new competitors and do not have to lower the selling price to keep them off (Palepu & Healy, 2012).

The intensity of these factors would leave some room for the existing companies to exercise their selling price without constraints which would produce abnormal returns. However, clients are in general more powerful than the existing companies given their size and the number of existing companies. The level of specification of the product, in the end, will dictate to what extent the switching costs reach and consequently if the client can contest the selling price.

Industry's return on equity (ROE), for the period 2009–2017, was always positive apart from 2010. It then had a steady improvement until 2015 when it had a small decrease and stabilized around the ten percentage points. AOF, on the other hand, for the same period had always positive ROE and managed to beat the industry except for 2013 (see Appendix – AOF's financial ratios table C.1). This means that, given the company's competitive advantages (translated into a differentiated service), it has been able to perform better compared to the industry.

During 2008–2015, AOF's ROE evolution was very irregular, with very ups and downs. From 2016, however, ROE had a huge improvement from 15,37% in 2015 to 45,71% in 2016. This year, AOF invested to change facilities with more space, to buy more machines and to hire more staff (Jornal de Notícias, 2017). This comes in response to the new set relationship with Bosch Braga. In exchange, net income improved which justifies the large variation in ROE.

Here, both sales revenue and variable costs – represented by raw material and material costs and part of the external suppliers (e.g. gas, light and water) – grew, suggesting that the number of projects ramps up. However, looking at figure 3.1 it becomes clear that sales had a higher increase than the variable costs. It is not certain the reason for these results, that is, whether the company increased the sales price of its new projects or became more efficient at producing. However, taking into account that fixed costs have also raised the company may have to increase the price of its projects to offset it.

In the following year, AOF improved again its net income but ROE did not follow this trend; in fact, it almost decreases 10%. To understand the reason behind this result, I need to decompose the ROE ratio following equation presented in Palepu & Healy (2012) (see Appendix – AOF's financial ratios equation C.1). The big difference that explains this result is in the first part of the equation, specifically $NOPAT/NetAssets$ ratio. In other words, the increase in the company's operating result did not follow the increase in net operating assets, meaning the company has lowered its operating efficiency.

Moreover, AOF has invested some money (Net Working Capital - NWC) to manage current assets (customer, inventory and other current assets) and current liabilities (suppliers and other current liabilities). In general terms, the absolute figures for the NWC have been increasing, with the exception to 2013 and 2016. The same trend appears in ratio NWC-to-sales. This suggests that AOF has been struggling to keep current operational assets at the same level as current operating liabilities. In the balance sheet (Appendix – AOF's financial statements A.1), since 2015, AOF does not have any inventory (perhaps given the fact that the company produces to order and not in series). Therefore, if NWC is increasing is due to the increase in the difference between clients and suppliers. This means that AOF has to lose some power over its clients and suppliers. The ratio average receivable and the ratio payable days support this hypothesis since the company is paying sooner and receiving much later from its clients.

It should also be noted that the company shows an excess of liquidity, mainly because of the excessive value in cash and equivalents. If one considers the net-debt ratio, the company can settle total debt solely with cash. Added to this, its ability to generate more than sufficient operating results to pay its financial expenses which gives the company a very low financial risk.

3.2. JigSense Project

As referred earlier, AOF has already been working with Bosch Braga before this initiative. At the beginning of this relationship, AOF started to supply sensor devices that were installed on the assembly lines of Bosch Braga. At some point, Bosch Braga expressed some struggle in moving these sensors between the lines due to their heavyweight. Furthermore, these devices soon started to be damaged due to their high cabling volume when Bosch's workers tried to move them.

Considering the benefits of entering the SCi, AOF decided to participate and proposed to re-design the sensor device to make it free of wires – without the heavy cabling. This upgrade makes the sensor module smaller and, consequently, lighter. It also tackles the problem of wearing too fast, which extends the life time of the device. The project, called *JigSense*[3], was later acce+ted by Compete 2020. The main benefit of this is the financial support since the investment required by AOF for this project is supported around 75% by public funds for three years.

Project JigSense is structured in three phases: research, test and commercialization. In the first phase, AOF will work with two other partners in order to investigate if it is technically possible to make this sensor module. International Iberian Nanotechnology Laboratory (INL) is responsible for the development of software and management of this product, whilst Centro de Nanotecnologia e Materiais Técnicos, Funcionais e Inteligentes (CeNTI) is responsible for the development of the solutions of the project (that is, lower cabling volume).

If the answer is positive, AOF proceeds to the next phase of testing the prototype. Here, AOF is responsible for the coordination and implementation of the product. It will set a working environment to run the prototype and make the last adjustments to conclude if the sensor devices are reliable.

Again, if the answer is positive, AOF will file a patent to protect its discovery and will proceed with the promotion of the upgraded sensor device and the company, and start commercializing the devices. The table with the required investment is presented in the Appendix – JigSense investment plan table D.1. This table also presents the dates that each phase has to start. It is imperative that at the end of the phase, AOF has a positive answer so that it can proceed to the next phase.

Note that the R&D process, composed by the research and test phases, has already begun in September. At the end of December 2020, it is expected that AOF starts testing the prototype which will continue until August 2022. At this time, if the new sensors module responds with quality to the demands, AOF will start commercialize it.

[3] see International Iberian Nanotechnology Laboratory website, in the JigSense section, for the technical objectives of this upgrade

4. Theoretical Framework

The fundamental objective of a manager is to maximize the company's value, regardless of whether it is a publicly or privately held company (Ross, Westerfield, & Jordan, 2009). Maximising the company's market value, or the market value of equity, meets investors' interests. In a sense, it can be argued that this objective also satisfies the interests of the rest of the stakeholders (Ross et al., 2009). Managers can only increase the company's value if they make good decisions. Accepting a project is only a good decision if it returns more than what the company has invested, which explains why financial evaluation is so important.

As referred to in section 3.2, AOF will make a gradual investment throughout the project, that is when it is possible to continue to the next phase. The decision to start this project depends on whether it generates enough cash-flows to compensate for the investment made. Although the investment is already defined with relative certainty, the truth is that the future cash-flows generated by the new product are far from being known, and so are the free-cash-flows (FCFs) – the difference between cash-inflows and -outflows, and that serves to pay investors and lenders.

The first step is then to estimate the future cash-flows and consequently the FCF for each period time of the project life. However, this alone would be incorrect because the FCFs are not discounted to take into consideration the rates of return demanded by the project agents (investors and lenders). For instance, investors might have other investment opportunities that generates higher returns, with the same level of risk. If one does not account for that possibility then the investor might just be losing money (Ross et al., 2009).

This is the logic behind the time value of money (Ross et al., 2009), that one unit of money is worth more today than one unit of money tomorrow because one can invest in today – for this reason, it is also important to know exactly when the cash-flows happen. The discounted cash-flow (DCF) evaluation is based on this assumption, meaning it discounts to the present moment at the required rate of return all the FCF (Ross et al., 2009). Only when this is accomplished, one can sum all FCFs and confirm whether the return surpasses the investment made. It is then up to the manager, with the assistance of the investment criteria to decide whether the project is worth the investment or not.

4.1. Cash-flows estimation

Each project has its nature and a different way of bringing value to the company (increasing sales or reducing costs). Companies invest at the beginning – although also in the course of the project – in assets that can fulfill these objectives. Ultimately, companies hope that the project generates FCFs that outweigh the investment made.

The big challenge here is to estimate those cash-flows that impact the company's variables (e.g. revenues, production costs, fixed costs, etc.) presented in the income statement. Yet, the record of the impact should be illustrated in a projected financial statement (Ross et al., 2009) instead of in the income statement (I discuss why at the end of this section). These statements should reflect the relevant cash-flows under an incremental basis and consistent in the way one treats inflation (Brealey, Myers, & Allen, 2010).

First of all, what should be accounted for are just the cash-flows and not the accrual, that is, whenever there is money leaving or entering the company (Brealey et al., 2010). Cash-flows should be recognized under the stand-alone principle. This way, the cash-flows of the project are separated by the cash-flows of the remaining company's activities (Ross et al., 2009). These effects are seldom limited to only sales and production affairs (Brealey et al., 2010):

- Project are dynamic enough to interact with other projects of the company. When this happens, *side effects* have to be considered in the evaluation, whether positive (e.g. project synergies (Damodaran, 2014)) or negative (e.g. product cannibalization (Damodaran, 2014));
- Companies often need to make additional investment in *net working capital (NWC)* to deal with current assets (clients receivables and inventory) and with current liabilities (suppliers payable). During the project, however, the company may have to increase or decrease this amount, depending on the current situation. At the end of the project, however, the remaining value is recovered by the company itself;
- The invested assets may still have some value at the end of the project – *salvage value*. Since these assets could be sold or used for other purposes within the company, the value should be recognized in the projected financial statement;
- As in the income statements, even the expenses that do not concern production – *overhead costs* – but are due to the project, should be accounted;
- The execution of the project can also prevent the company from getting other benefits. This arises when the project makes use of an already owned asset. The company, in turn, has to forgo potential cash-flows that it could earn with that asset – *opportunity costs*;
- *Taxes* are another type of cash-flow – in this case, cash-outflow. Therefore, whenever the situation requires it, the cash-flows should be adjusted for the after-tax;

- Certain cash-flows, however, should be ignored for project evaluation. For instance, costs that were already incurred before the investment decision – *sunk costs*;
- *Financial costs* should also be ignored. At the end of the day, what one wants to know is how much money the project generated; how that money is then distributed depends on financing decisions (capital structure).

Furthermore, project financial analysis should always be consistent concerning inflation. This means that the discount rate and all the estimated cash-flows must be on the same level, whether on real terms (accounts the inflation) or in nominal terms. It is up to the analyst to decide how these should be treated, as long as the analysis is consistent (Brealey et al., 2010).

Additionally, the impact should not be identified using an income statement basis because the determination of the net income is governed by certain accounting standards that allow the recording of non-cash-flows. For instance, capital expenditures (investment) are not registered for the net income calculation; instead, it depreciates during its lifetime. Therefore, depreciation or amortization cannot be considered cash-outflows because money is not effectively leaving the company; that money has already left when the investment was made. However, it must not be ignored the fact that depreciation and amortization are used for tax calculation. Hence, in the projected financial statement the tax shield value should be considered but not the depreciation and amortization itself (Damodaran, 2014).

4.2. Discount rate

To perform the DCF evaluation, one should compute an appropriate discount rate with which the cash-flows are discounted. The appropriate discount rate is used as the required rate of return to offset the risk perceived by those financing the project. Logically, one should demand a higher rate of return if the risk perceived is also higher. This has to do with how much the FCF can deviate from what it is expected – the greater the uncertainty regarding the estimated FCF, the greater the risk.

Several factors that can deviate a project's cash-flows from the expectations: project-specific risk, competitive risk, industry-specific risk, international risk and market risk. However, the different agents investing in the project do not bear the same factors. Only those supported by the different agents are considered for the reward, hence, having a direct effect on the cost estimation (Damodaran, 2014).

Generally speaking, companies turn to two types of capital to finance projects: equity (through their investors) and debt (through lenders). This in turn requires the calculation of both the cost of equity and debt, but also the capital structure (the amount of equity and debt used). The final rate of return required (cost of capital) is the result of the weighted average of these two costs – also known as the weighted average cost of capital (WACC) – and it is given by:

$$r_{WACC} = r_E \cdot \frac{E}{(E+D)} + r_D \cdot \frac{D}{(D+E)} \cdot (1+t) \ , \tag{4.1}$$

where r_{WACC} is the weighted average cost of capital, r_E is the cost of equity, r_D is the cost of debt, E is the market value of equity used to finance the project, D is the market value of debt used do finance the project, $E/(E+D)$ is the equity-to-capital ratio, $D/(D+E)$ is the debt-to-capital ratio, and t is the corporate tax rate. It is important to emphasize that both equity and debt used to finance the project must be valued on a market basis.

4.2.1. Cost of Equity

Generally speaking, company cost of equity is used for the new project cost of equity (Brealey et al., 2010). This assumption is used when all company's projects and the new project share the same business sector and risk profile (Damodaran, 2014). To estimate company cost of equity there are some models [1] that can be used; however, the most common is the *Capital Asset Pricing Model (CAPM)* introduced by Lintner (1965); Sharpe (1964), which is given by:

$$r_e = r_f + \beta_e (r_M - r_f) \ , \tag{4.2}$$

(Ross et al., 2009) where the r_e is the cost of equity of the company (the expected return by the investor), r_f is the risk-free rate of return, β_e is the sensibility of the company to market variations, r_M is the market rate of return and $(r_M - r_f)$ is the market risk premium.

CAPM is grounded on the assumption that the company's investors can diversify their investment portfolio – the idea of diversification introduced by Markowitz (1952). In normal conditions, the average investor would bear the total risk (i.e. company-specific risk plus market risk). Investors, however, are not restricted to a single investment. In many cases – especially in publicly held companies – investors diversify their investments to other securities. If an investor manages to diversify the portfolio to the point that includes every exchangeable asset in the market (forming a *market portfolio*), then the investor can eliminate the company-specific risk (unsystematic risk) and bear solely the market risk (systematic risk).

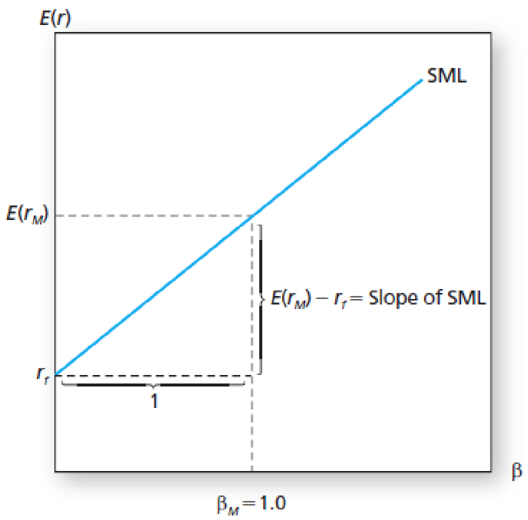
It should be noted that the investor will demand a premium for setting a market portfolio instead of

[1] Arbitrage Pricing Model (APM) introduced by Ross (1976), or a multifactor model such as the one introduced by Chen, Roll, & Ross (1986)

investing solely in risk-free assets – represented by the market risk premium $(r_M - r_f)$ (Ross et al., 2009). Thus, assuming that one is investing in a new company, CAPM considers only the contribution of the company's market risk to the market portfolio (Brealey et al., 2010).

Company's market risk is translated into its sensitivity towards market variations (β_e) which can be estimated by $\beta_e = \sigma_{iM}/\sigma^2_M$, with σ_{iM} being the covariance between the returns of the company i and market returns (M) and σ^2_M the variance of the market returns (Brealey et al., 2010). Alternatively, one can estimate β_e by computing a linear regression between the dependent variable (historical company returns) and an independent variable (historical market returns) (Brealey et al., 2010). The linear regression is given by $Y = \alpha + \beta \cdot X$, in which Y is the dependent variable (company returns), α the intercept value of the linear regression, X the independent variable (market returns) and β the slope of the regression line which corresponds to the company's market risk.

Figure 4.1.: Security Market Line



source: Bodie, Kane, & Marcus (2014)

CAPM further assumes that investors will adjust the risk depending on their aversion to it, as long as it keeps proportional to the required rate of return. This follows the theory of the Security Market Line (SML), represented in figure 4.1 (Brealey et al., 2010). Equation 4.2, thus, reflects these assumptions setting a minimum rate of return (r_f) demanded by the investor, plus the contribution of the company's market risk, $\beta_e(r_M - r_f)$.

Cost of equity of *publicly held companies* can be computed with CAPM because here investors can diversify their investments. Furthermore, the estimation of β_e with linear regression requires a lot of data (i.e. observable returns). Otherwise, standard errors will be very high meaning that the test statistic of the parameters (i.e. α, β) will not be significant when they are different from zero. This is not a problem for public companies given the fact that their stock prices move frequently and are available for consultation in the open market.

In *privately held companies*, however, CAPM is more difficult to put into practice. For one, because the returns of a private company are seldom available for consultation. Even if the company opts to communicate its results, these do not come as frequently as the results of public returns (at the limit, results of the private company are presented quarterly).

The other problem concerns the investor itself, especially in small private companies. Generally speaking, small private companies are owned by a very restricted number of investors. To build the company, they have to apply part – if not all – of their savings (Damodaran, 2012). This makes it difficult for them to diversify their portfolio. Consequently, the estimated beta mentioned earlier needs some adjustments because now they bear more than just the market risk.

To tackle the first problem (scarce data), Damodaran (2012) [2] presents *bottom-up beta* as an alternative to linear regression. Company sensibility to market variations can be decomposed into operational and financial factors. All companies within one industry share the same operational risk ($\beta_{unlevered}$). However, each company will see its sensibility to the market variations enhanced with its levels of debt (turning into a $\beta_{levered}$). Using the bottom-up method, the β_e estimation is given by:

$$\beta_e = \beta_u \cdot \left[1 + (1 - t) \cdot \frac{D}{E}\right] \quad , \tag{4.3}$$

(Damodaran, 2012), where β_e is company's market risk, β_u is the company unlevered beta (equal to the operational risk of the industry), t is the tax rate, E is the market value of equity, D is the market value of debt and D/E is the debt-to-equity ratio that measures the financial risk given the levels of debt.

Bottom-up beta does not solve the non-diversification problem (second problem mentioned earlier). To tackle this, the estimated β_e requires an adjustment. Damodaran (2012) addresses this issue by computing the total beta that should account the extra risk that non-diversify investors bear. Total beta (β_T) is given by:

$$\beta_T = \frac{\beta_e}{\rho_{iM}} \quad , \tag{4.4}$$

Damodaran (2012), in which β_T is the company total beta, β_e is the company market beta and ρ_{jm} is the coefficient of correlation between the company i and the market, M.

Damodaran works on the equation that represents the portion of the company's total risk σ_i that is related to the market σ_M times the correlation between the company value and the market ρiM. This relation represents the market beta of the company (β_e). Rearranging the equation such that the correlation coefficient goes to the left-hand side, one set in evidence the fraction σ_j/σ_M which is the same as the total beta β_T (Damodaran, 2012).

[2] Damodaran (2012) presents other alternatives such as accounting betas, or the fundamental betas first introduced by Beaver, Kettler, & Scholes (1970)

4.2.2. Cost of Debt

Equity is not the only resource available to companies to support their projects. Additionally, companies can support their projects with debt and they will often explore this alternative. Raising debt brings some advantages to the company, beginning with the cost itself. In comparison to equity, debt is cheaper because the return on debt is more certain (Brealey et al., 2010). Just remember that, as long as the company has positive operational results, the interests are always paid before dividends (which may never be claimed if the company decide to not distribute).

Another reason why companies raise debt relates to taxes. Contrary to equity, debt can be used by the companies for interest tax shield, i.e. interests that are deducted from the profit before taxes (Brealey et al., 2010). This directly affects the FCFs used to pay the stock and debtholders; the higher the interest (debtholder payments) the less the company has to pay in taxes. Thus, FCFs and the company's value will be higher (Ross et al., 2009) – the primary goal of the manager.

Cost of debt quantifies the risk that the company will be unable to meet its financial obligations (that is, the probability of default). There are some indications to how the company might be struggling to pay its financial obligations. For instance, the weight of its most liquid assets, the difference between the cash-flows generated and the amount of its financial obligations, and the variation in its cash-flows (Damodaran, 2014).

Companies have alternatives to raising debt. The most common – especially for big public companies – is to issue debt through bonds. Each bond is available in the market at a given selling price. One can estimate the cost of debt by computing the Yield-to-Maturity (YTM) – the rate of return required by bondholders – provided the rest of bonds' characteristics [3] are known. Alternatively, the cost of debt can be simply the interest rate associated to the bond rating (Ross et al., 2009).

Bonds are not the only alternative, and companies may choose to raise debt through bank loans. The cost of debt in this case would be the interest of the new borrowing (Ross et al., 2009). However, it raises a problem when the company does not raise new loans because these are not securities (i.e. not traded in the market). Ratio *interest paid / total debt* can be a good proxy if the company has borrowed recently; otherwise is not a great indicator of the cost that the company may incur in the future. An alternative method is to assume that the cost of debt tends to the industry average (Damodaran, 2012).

[3] Face value, time to maturity, coupon rate and the frequency of the coupon payments are required to compute the YTM

4.3. Evaluation techniques

Evaluations techniques assist the managers to make the best decision regarding the project. Traditional investment criteria rely on the traditional DCF approach (Brealey et al. (2010) ;Ross et al. (2009)). For these criteria, projects have just one path along which the estimated FCFs are certain. The most common traditional investment criteria [4] is the *Net present value (NPV)*. NPV gives a straight forward answer of whether the project is valuable or not, since it adds all discounted FCF_t and the initial investment I_0, that is:

$$NPV = \sum_{t=1}^{n} \frac{FCF_t}{(1 + r_{WACC})^t} - I_0 \ , \tag{4.5}$$

where, NPV is the Net Present Value, FCF_t is the free-cash-flow at time t, r_{WACC} is the weighted average cost of capital and I_0 is the initial investment. Managers should accept a project if the NPV is positive since it means project creates value - the project generates discounted FCF that surpass the initial investment; with a negative NPV, the project should be withdrawn.

Real options analysis (ROA) use option pricing theory fundamentals (initially used in financial options) to value projects with embedded options. Options always have z positive value, since the company only exercise when their price (K) relative to the value of the underlying asset (S_0) generates a positive payoff:

- in a call option (option to buy), $S_0 - K > 0$;
- in a put option (option to sell), $K - S_0 > 0$.

The limit date to exercise the option (T) depends on the type of option: the option is European when the company can exercise it *only* at the maturity date; the option is American when the company can exercise it up to the maturity date, which grants the company with the option of deferring.

Consequently, these three factors (S_0, K and T) affect directly the value of the option; but they are not the only ones (Hull, 2014). In addition, the option value is influenced by:

- the volatility (σ), that is the standard deviation of the returns of the underlying asset;
- risk-free rate (r_f);
- dividend yield (b), the cash-flows lost during the project [5]

Although options generate cash-flows, its valuation is not performed with the DCF. For one, because options value derives from the underlying asset, but, for another, because cash-flows depend on the context (Damodaran, 2014). Alternatively, options can be valued with the *replicating portfolio* (Brealey et

[4] Internal Rate of Return (IRR) and the Payback are the other traditional investment criteria

[5] For instance, when a company foregoes cash–flows to rivals for waiting to exercise the option

al., 2010) or *risk-neutral valuation* (Brealey et al., 2010).

Replicating portfolio mimics the cash-flows of the option by combining the Δ of the underlying asset with B units of money of borrowing (in a call option) or lent (in a put option) (Damodaran, 2014). When the value of the underlying asset goes up (S_u) or down (S_d), the portfolio will always return the same payoff as the option and, thus, will always have the same value as the option.

However, consider, for a moment, a financial option where its value does not equal the replicating portfolio. In such a case, investors would profit with this arbitrage opportunity. Other investors would follow the same strategy and would take advantage as well until the market adjusts the option price (Mun, 2002). This demonstrates that the option price does not depend on the risk profile of the holder of the option, but rather on the risk-free rate – the minimum return required by the holder. Risk-neutral valuation is grounded on this assumption. Here it is not required to estimate the replicating portfolio but instead the risk-neutral probability to occur an event.

However, one has to account innumerable events in order to reach the final value of the option. Some models extend those possibilities using one of the two valuations described above. The most used ones are the closed-form equations, such as the equation introduced by Black & Scholes (1973); Merton (1973) and lattices, such as the binomial lattice introduced by Cox, Ross, & Rubinstein (1979).

What distinguishes these two models, mainly, is how each treats the evolution of the underlying asset value. Closed-form equations assume the evolution is continuous and it return the exact option's value. Whilst lattices discretely reflect the evolution, that is, it only moves at certain periods of time (represented in time steps) and returns an approximation of the option's value . If one increases the number of time steps, however, the result returned by the lattice approaches the result of the closed-form equation (Mun, 2002).

Binomial lattice is divided into a defined total number of time steps (N). In each time step τ, S_0 can increase by the factor *u* or decrease by the factor *d* that represent a possible event. These factors are given by:

$$u = e^{\sigma\sqrt{\delta\, t}} \tag{4.6}$$

$$d = e^{-\sigma\sqrt{\delta\, t}} = \frac{1}{u}\ , \tag{4.7}$$

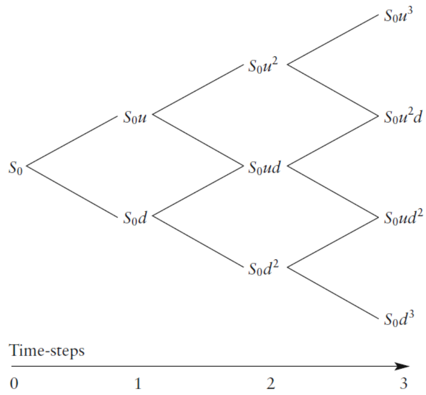
where σ is the annualized volatility of the underlying asset and $\delta\, t = T/N$ the time-scale.

Equations 4.6 and 4.7 derive from the stochastic process geometric Brownian motion (gBm) (Mun, 2002). This process was first introduced to reflect the main characteristics of the evolution of a stock price. Nevertheless, this is still used in real options to describe the evolution of the underlying asset value.

Figure 4.2 illustrates a binomial lattice with three-time steps. At the end of the lattice there will be $N+1$ end-branches (j) corresponding to $E_{t=T,j}$. The given values are used to confront with the exercise price so that the best decision is taken depending on the option:

- if call option, the decision is $V_{t=T,j} = Max[E_{t,j} - K; 0]$;
- if put option, the decision is $V_{t=T,j} = Max[K - E_{t,j}; 0]$

Figure 4.2.: Underlying asset evolution binomial lattice



source: Mun (2002)

The most difficult task in real options valuation is often assessing the market value of the underlying asset of a project. In financial options, the underlying asset is traded in the market which simplifies its calculation. In real options, however, the underlying asset might not be traded in the market. This requires some assumptions in order to derive its market value.

The approaches presented in the literature have different perspectives regarding the market itself. For instance, the classic approach says that the market is complete, in such a way that it is possible to replicate the cash-flows of the project with a twin traded security. However, this approach fails to consider the private risks (that cannot be hedged) that the project might have (Schneider et al., 2007). The extended classic approach, on the other hand, suggests two methods but can only be applied in the extreme: when the project is dominated by public risk or when the project is dominated by private risks.

Copeland & Antikarov (2001) proposed an alternative approach to address this issue, called Market Asset Disclaimer (MAD). In this approach, one assumes the present value of the project, without flexibility, as the underlying asset. Even though this approach considers that the market is incomplete, it is assumed that the present value of the project is the best-unbiased market value of the project if it was traded – as if it was its twin security.

5. Methodology

I start the JigSense evaluation using the traditional investment criteria NPV, assuming that the project has not yet started. This criterion is preferred from the other traditional criteria due its simplicity and efficiency to compute the project value. The value returned by the NPV criteria is enough to decide whether to accept the project or not. Although the other criteria provide further information regarding the project [1], they exhibit more drawbacks that need extra attention which remove some of the efficiency.

For instance, IRR is as objective as NPV since the result returned answers the question of whether one should accept the project or not. However, it can become tricky to interpret the result if the accumulated FCFs signal changes. If such a situation occurs, IRR will return more than one minimum required rate of return. Payback, on the other hand, does not give a straight forward answer, since one has to set a subjective cutoff date to decide if the project should be accepted.

From equation 4.5, both the expected FCF and the appropriate discount rate (cost of capital) are required to compute project value. Furthermore, for a more truly evaluation, the NPV criteria should use the probability-weighted cash-flows considering the probability of success of each phase, similar to Shockley, Curtis, Jafari, & Tibbs (2002). The rate of success of each phase is not given by the company. To complement this lack of information, I consider subjectively the rate of success of each phase or, in other words, the probability to start the following phase. Thus, the NPV with probability-weighted cash-flows can be computed by:

$$NPV = \theta_1 I_0 - \sum_{\tau}^{N} \theta_i \frac{FCF_{\tau i}}{(1 + r_{WACC})} \quad , \tag{5.1}$$

where I_0 is the initial investment; θ_i is the rate of success of phase i; $FCF_{\tau i}$ is the free-cash-flow regarded to the phase i at the time period τ; r_{WACC} is the weighted average cost of capital.

5.1. Free Cash-Flows

JigSense project is isolated from the rest of the company so that every estimated cash-flow is due to the project. In a first stage, AOF requires a list of items to run the stipulated phases as shown in Appendix – JigSense investment plan table D.1. The items are fully, or partly, covered by SCi funds. For the company to receive the public funds, it has to record first the investment.

For simplicity, I assume that AOF receives the funds at the moment it records the investment. This

[1] Minimum rate of return required (IRR), or how long the project takes to be paid (payback)

means that the items that are fully covered have their investment cancelled out – i.e., the moment money comes out, AOF receives the funds. Regardless of whether they are covered or not, the items still generate cash-flows that affect AOF.

In that sense, I start by identifying all cash-flows generated by the items required in the investment plan. Only then I forecast the cash-flows generated by the devices. All figures in the investment plan are measured in nominal terms which means that inflation is not considered. For the sake of consistency, the forecast cash-flows and the cost of capital are in nominal terms as well.

Concerning the forecast cash-flows, I am forced to consider all the generated by the devices and not just the incremental. In this particular case, AOF is trying to upgrade an existing product. Even though the way it works is innovative, this is not a brand new product but rather an improvement of the previous version. Note that Bosch Braga was already a customer of the company (see chapter 3). Even if project JigSense is unsuccessful, Bosch Braga will still need the previous version to run its operational activity.

In theory, the incremental cash-flows should be only the improvements produced during project JigSense in comparison to the previous version. For instance, let us imagine that Bosch Braga will buy two devices instead of one; assuming everything else stays constant, then, the incremental cash-flows are the difference in sales (one device) times the selling price. However, given the lack of information regarding the previous version, I consider all generated cash-flows.

All the effects are illustrated in the projected financial statements, in chapter 6. Additionally, I present the estimations of the input variables as well as the assumptions for their growth rates.

5.2. Cost of Capital

Cost of Equity

Damodaran (2014) highlights three potential situations that companies may face. Under each of these situations, the way the project cost of equity is computed changes. In this case, the first situation is observed, that is, AOF works in just one business sector and project JigSense has not a particularly different profile risk from AOF core business. In that sense, I relax the assumption to consider the project cost of equity equal to company cost of equity.

CAPM is still well accepted by the academics and used by practitioners to compute the cost of equity. For one, it describes fairly the relation return and risk bear by the investor, but also because it is simple since the only information needed concerns the company and the market in general.

However, the assumptions that ground CAPM cannot be applied for this particular case, specifically how beta is estimated. AOF is owned by only two investors that spent much of their time and savings to build this company. This means that they have not the capacity to diversify away completely company-specific risk. Furthermore, the fact that this company is private prevents the obtaining of enough data to run a linear regression for beta estimation. In this framework, I turn to the bottom-up beta to estimate AOF market risk as if all investors had a market portfolio.

This approach is more appropriate than the other approaches mentioned by Damodaran (accounting betas and fundamental betas). The bottom-up beta has a great advantage because it relies on industry beta. Note that this is the average of all companies beta within that industry. Thus, the estimation error of each company beta tends to cancel out (Brealey et al., 2010). This way, I am much more confident on the industry beta than I would be if I estimated AOF beta solely with AOF data.

Estimating with company data is how accounting beta is performed. This way, I would face high estimation errors with this approach due to the lack of available accounting information of AOF. Similarly, fundamental beta approach, as the one introduced by Beaver et al. (1970), presents a very low R^2 – i.e. how much the model is able to explain company returns with the explanatory variables. Once again, this indicates high estimation errors.

Bottom-up beta approach is used to tackle the problem of limited AOF's information. I still have to adjust the beta due to the inability of AOF's investor to diversify their portfolio, hence, support more than just company market risk. In that sense, I adjust beta accordingly with the total beta given by equation 4.4. This way, I consider the extra risk that the two investors have to face given their non-diversification.

Fortunately, Professor Damodaran has access to a lot of companies and market information. With this information, Professor Damodaran computes his own estimation for several variables in his website (Damodaran, n.d.). In the topic "Discount Rate Estimation", Professor provides his estimation of the total beta by industry sector [2], using equation 4.4.

Furthermore, Professor Damodaran provides both the levered and unlevered total beta which allows me to use the bottom-up beta approach. With the unlevered total beta (the operational risk that all non-diversify investors within the industry share), I can finally compute AOF beta by levering it with AOF's levels of financial risk [3].

Basing on CAPM equation 4.2, r_f is considered next. The risk-free rate should respect some conditions as stated by Damodaran (2014). Government bonds usually meet these conditions because it is always

[2] Professor Damodaran sorts the companies by industry. The list of companies composing each industry is provided the Professor in a excel document

[3] This level is measured by the weight of debt over equity, both on market value – I address this problem later

expected that governments fulfil their obligations (i.e. default-free). Additionally, the security should not provide another source of income, like coupons. Another condition is that security duration should be similar to the project's lifespan. In short, risk-free rate should be the YTM (rate of return required by the investors) of government zero-coupon bonds with the same duration as the project.

Market risk premium ($r_M - r_f$), as stated by Damodaran (2014), should consider all markets that influence the company. This influence represents the level of exposure to that country risk. In this particular case, JigSense project is influenced by the Portuguese market risk given where the company operates but also given the main target client (Bosch Braga) of this project. However, Bosch Braga is somewhat dependent on the strategic decisions of Bosch Group which in turn are taken considering, above all, the economic situation of Germany. In that sense, I calculate the weighted risk premium considering the level of exposure of these two country markets.

In normal conditions, all countries would share the same market risk premium. However, the market risk premium is adjusted to consider the default risk that each country presents. Professor Damodaran provides the market risk premium of each country already with the adjustments, on his website (Damodaran, n.d.). This information is presented in the "Discount Rate Estimation" topic, more specifically "Risk Premiums for Other Markets´ ´ It should be noted that Professor Damodaran estimates the risk premium from a $6,01\%$ using the implied premium for the index S&P 500 (updated at April 1st, 2020).

Cost of Debt

Estimating the cost of debt becomes necessary when AOF does not raise more debt to finance the project. In addition, the company still has debt to pay (see Appendix – AOF's financial statements table A.1), which means that the investment covered by AOF is a mix of equity and debt. Furthermore, AOF has opted to raise debt through bank loans. As such, the assessment of the cost of debt requires other alternatives since bank loans are not securities.

Ratio $Interest\ Expenses/Total\ Debt$ can be used as a proxy for the cost of debt. However, this does not tell the cost that AOF has to bear in the future, but only today. Therefore, Professor Damodaran does not recommend its use and suggests other alternatives.

One is to add a spread to the risk-free rate, accordingly with the interest coverage ratio. AOF presents a very high-interest coverage ratio (see Appendix – AOF's financial ratios table C.1). This means that AOF is capable of paying its obligations with operational results. This puts the company on top of the rating and, therefore, it would bear solely the risk-free rate. This is not expected to happen, since AOF will continue to rely on bank loans to raise more debt. This means that on top of the risk-free interest rate will be added a spread that represents the profit margin that banks benefit from.

The last suggestion is simply to use the average cost of debt of the industry. This way, one is assuming that, in the future, AOF cost of debt tend to industry cost of debt. Consequently, this will be the required rate of return demanded by the debtholders at that time.

Capital Structure

For the cost of capital calculation, both equity and debt must be on market value. Given the fact that AOF is a small private company, this measurement is more complex to perform than with publicly held companies. For one, AOF is not being traded in the market so its value is not accessible and, besides, all raised debt come from bank loans and not from securities.

In the event of not having market values to estimate capital structure and, consequently, debt-to-equity ratio, Professor Damodaran suggests two ways to address this problem: 1) investigate what the optimal capital structure is in the context of the firm, or the target structure pursued by the firm; 2) assume that the market values of the firm are the same as the average industry's .

I exclude the former alternative. For one, the target structure was not disclosed by the company. Moreover, the optimal structure estimation might have a direct effect on the cost of debt, since the risk of default can increase (Damodaran, 2014). Thus, for simplicity, and as suggested by Damodaran (2012), I use the average capital structure of the domestic industry. This way I can be consistent with the measures used to compute the cost of debt.

With this alternative, I assume that the capital structure of AOF, in the long-term, tend to the average industry capital structure. Consequently, the ratio debt-to-equity can also be estimated. For the sake of consistency, the debt-to-equity ratio with industry-level should be used to calculate the levered AOF beta. Data regarding AOF domestic industry – basing on its activity code (see chapter 3) – is gathered from Banco de Portugal database (sector tables).

5.3. Real Option

As seen in the literature, criteria that rely on DCF valuation assume that the project has only one path during which the estimated cash-flows are certain. R&D projects, however, are characterized by their immense uncertainty, both technical and market. Furthermore, AOF is not obliged to run the project in a single path. During the R&D process, AOF has the option to abandon at the end of each phase, as new information arrives.

The uncertainty factor can be alleviated using sensitivity analysis, scenario analysis, break-even estimations, decision trees [4] or even monte Carlo simulation. However, none of these alternatives estimates the value of the strategic options. To address this issue, one must rely on real options analysis (ROA) (Mun, 2002).

I choose to use binomial lattice to perform ROA. The positive side of the binomial lattice is that it is easier to explain and are more flexible to adapt the features of the practical cases, comparing to closed-form equation [5]. The negative side is that it takes more computational time and the option value returned by the binomial lattice will not be as precise as the returned by closed-form equation. This can be mitigated by increasing the number of time steps.

To value the options, I turn to the risk-neutral probabilities rather than replicating portfolio, for practical reasons. Both approaches should return the same result but the latter requires its computation at each node throughout the binomial lattice. The former, on the other hand, requires simply the calculation of the risk-neutral probability given by:

$$p = \frac{e^{(r_f - b)\cdot\delta t} - d}{u - d} \ , \tag{5.2}$$

where, p is the risk-neutral probability, r_f the risk-free rate, b the dividend yield, δt the time-scale, d the down factor and u the up factor.

Concerning the six factors that affect option value, Perlitz, Peske, & Schrank (1999) makes an overview to their characteristics and how they can be addressed. Here, the underlying asset is consider to be the commercialization of the devices, that which attributes value to the project embedded with options. The diffusion-jump stochastic process could be a good process to depict the evolution of the underlying asset market value if one admits that at any given shock (technological changes) the market value varies abruptly – making certain jumps (Lint & Pennings, 1998). For the sake of simplicity, however, I assume that the current market value (S_0) evolves through the stochastic process gBm. Although the process is continuous, binomial lattice exhibits discretely.

To estimate the market value of the underlying asset, I consider Copeland & Antikarov (2001) MAD assumption. For one, because it is very challenging to find in the open market a twin asset that replicates the same payoff. In that sense, the forecast cash-flows during the commercialization determine the

[4] Decision trees can also be used to evaluate projects with options as demonstrated by Brandão, Dyer, & Hahn (2005); Smith & Nau (1995)

[5] For instance, the closed-form equation introduced by Black & Scholes (1973) is only suited for a single European call option whilst the one introduced by Geske (1979) only considers two sequential phases

underlying asset market value.

To start this project, AOF has to make an initial investment (I_0). To continue the project, AOF has to pay the exercise price at the end of the phases (K_i), corresponding to the investment required to start the phase. Both initial investment and the exercise prices are already quantified (see Appendix – JigSense investment plan table D.1). Further, I do not assume that AOF will need to invest more than what is defined. This means that both are considered fixed and deterministic.

The deadlines for each stage (t) are also defined, similarly to the exercise price. Further, I consider that each stage results do not appear before the establish dates. This situation would allow AOF to start the new stage, if possible, before the scheduled date. Moreover, AOF has no intention to defer the option because this enhances the risk of losing cash-flows to its rivals (e.g. first-mover advantage). As a result, 1) every option is European and 2) the dividend yield (b) is zero.

Volatility estimation runs the same problem as the current market value, that is, the challenge of finding a twin asset that provides volatility to be used in this case. Cassimon, Backer, Engelen, Wouwe, & Yordanov (2011) in its practical 6–fold project access Damodaran's website to obtain information regarding the volatility of the industry as a proxy for the project's volatility. In the topic "Option Pricing Models", Professor Damodaran provides the average firm's value standard deviation for each industry sector.

This risk is market-related and has the power to influence the underlying asset variables and, consequently, its market value. Thus, the greater the volatility the higher the potentially upside and downside of the market value. Because the company will exercise the option to maximize potential gains or limit potential losses, the higher the volatility, the higher the value of the option.

This volatility is assumed to remain constant throughout JigSense's life. It seems reasonable to think, however, that uncertainty will gradually be resolved as time passes, and the company is more certain about the FCF regarding the product. However, this would mean that I would use a non-constant volatility which goes against the basic assumptions of the gBm process.

Note, however, that this calculation concerns market risk which is different from technical risk. This latter reflects the potential catastrophic events that would lead to an abandonment of the project. Such events are only felt during the three phases previous to commercialization. The technical risk, contrary to market risk, lowers the option value; it lowers potential outcomes determined by the market volatility. Technical risk was already addressed at the beginning of this chapter, in equation 5.1. I consider subjectively, the rate of success of each stage (θ_i), the same as the probability to enter the next phase.

Binomial lattice

I start by performing a lattice that illustrates the current market value evolution of the JigSense project. In a forward movement, the evolution starts from the present moment (τ_0) to the end of the marketing phase (τ_3) – three years in total ($T = 3$). As time progresses, market value increases (up) or decreases (down) at each time step. I divide the three years in months so that each time step n represents a month. This gives a total of 36 time steps ($N = (3 \cdot 12) = 36$), with $\delta t \approx 0,083(3)$. Moreover, since I assume that the market value follows a stochastic process gBm, the up and down factors are represented by equations 4.6 and 4.7, respectively.

At the end of the lattice, I will end up with $N + 1 = 37$ end-branches that represent the potential true market value of the underlying value at τ_3. These values are confronted with the exercise price, if exists, to start the commercialization. In each end-branch $j, j = 1, ..., 37$, the decision to start the commercialization is taken if the payoff is positive. That is:

$$E_{\tau_3,j} = Max[(MV_{\tau_3,j} - K_3) \cdot \theta_4;\ 0] \ , \tag{5.3}$$

where $E_{\tau_3,j}$ is the payoff in the end-branch j at τ_3; $MV_{3,j}$ is the market value in the end-branch j at τ_3; K_3 is the exercise price to start commercialization discounted at the moment τ_3; θ_4 is the probability to start the commercialization. Note that AOF has θ_4 to reach the end of the marketing phase – start the commercialization.

The next step is to use these payoffs to discount back, in a backwards movement to perform the second binomial lattice. This lattice will return the value of the options. Remember that these options are European, meaning that AOF only exercises the options at their maturity date. The process in the second binomial lattice has two different moments: when at the maturity date; when not at the maturity date.

When AOF is not at the maturity date, the payoffs are simply discounted back because AOF cannot take any action. Thus, considering the risk-neutral probabilities, the discount value is given by:

$$C_{\tau,i} = (C_{(\tau+n),i} \cdot p + C_{(\tau+n),(i+1)} \cdot q) \cdot e^{-r_f \cdot \delta t} \ , \tag{5.4}$$

where $C_{\tau,i}$ is the discounted value in the node i at the moment τ; $C_{(\tau-n),i}$ is the discounted value in the node i but at the moment $(\tau + n)$ (a step further); p is the risk-neutral probability with $q = 1 - p$.

When AOF is at the maturity date, the company has to decide whether it exercises the option or not. The decision is taken to maximize value. It is considered the discounted value at that time, the exercise price and the probability to start the phase. Thus:

$$V_{\tau,i} = Max[(C_{\tau,i} - K) \cdot \theta;\ 0] \ , \tag{5.5}$$

where $V_{\tau,i}$ is the option value in the node i at time τ; $C_{\tau,i}$ is the value discounted at time τ in the node i; K the exercise price to start phase discounted at the moment τ; θ the probability to start phase. I will use this equation for the moments τ_1, τ_2 (for the moment τ_3 it was already addressed).

As I continuously decide to maximize and discount back, the binomial lattice shortens. At the moment τ_0, I should have just one figure that represents the value of the sequential options. This is confronted with the initial investment required to start the project. The difference between these two returns the value of the project embedded with sequential options. Similarly to what is done using the NPV, if this difference is positive, it means the project creates value to the company and, therefore, it should accept it; otherwise it should withdraw right away.

6. JigSense Project evaluation

As you may recall from the brief introduction of project JigSense in section 3.2, the project is initially structured in three phases which are monitored by SCi. The investment required to run these three phases, that last in total three years, is to some extent covered by public funds.

Some of the required items have their investment cancelled out since they are fully covered (e.g. computer, software and the items for the test phase). Once AOF records the investment made, it receives the funds to compensate it. In practical terms, there is no money leaving or entering the company.

This does not mean, however, that the items do not generate other cash-flows. When closing the accounts and report the amount of taxes to be paid, the depreciation and amortization of the computer and software, respectively, allow AOF to save some money in taxes (tax shield). The same effect applies to the personnel costs and the expenses incurred during the test and marketing phase. These are costs that are reported in the income statement. Consequently, they influence the income before taxes and, hence, the amount of tax to be paid.

It is important to recognize the moment the cash-flows take place. I assume that the investment for research, test and marketing phase occurs at their given moment as shown in table D.1. For simplicity, personnel costs and taxes are reported only at the end of each year (i.e. at the closing of the accounts). Table 6.1 illustrates, in essence, the FCFs that result from the investing plan to run JigSense project. For a more comprehensive table of the cash-flows due to each phase, see the Appendix – JigSense investment plan table D.2.

JigSense project starts with the research phase. This stage lasts from the end of September of 2019 until the end of December 2020. By this time, AOF must have the confirmation of whether it is possible to develop a sensor device without wires. To run this phase, AOF invests in new high-performance computer, a new software to design PCBs and five new workers to start the research phase. The role of each worker has not been disclosed but I assume they are involved in the three phases. This means that when a new phase starts the expenses incurred with the new employees are due to that phase.

In terms of cash-flows, both the computer and the software are fully covered by public funds, meaning their investment is cancelled out. AOF still benefits with the tax shield generated by the depreciation and amortization of these two assets, with both having a useful life of 3 years, according to Ministério das Finanças e da Administração Pública (2009). I use the straight-line method to compute the depreciation (amortization) such that, each year both wear $33{,}3(3)\%$. Thus, AOF can save in taxes the amount

Table 6.1.: Investment plan cash-flows

	09/19	12/19	12/20	12/21	08/22	09/22	12/22
τ	0,00	0,25	1,25	2,25	2,92	3,00	3,25
Research Investment	(8.000)						
Test Investment			(115.600)				
Marketing Investment					(10.100)		
Employees		(17.917)	(71.667)	(71.667)			(53.750)
Effect on Taxes		3.763	39.326	15.050			13.408
Tax Shield		140	560	560			420
Total Investment	(8.000)	(17.917)	(187.267)	(71.667)	(10.100)		(53.750)
Covered	8.000	13.437	169.350	53.750	9.600		40.312
Supported		(4.479)	(17.917)	(17.917)	(500)		(13.437)
Total effect on Taxes		3.903	39.886	15.610			13.408
FCF		(576)	21.969	(2.307)	1.621		(29)

Figures in €. Deviations on the results are caused by rounding. Cash-outflows represented inside parenthesis. Cash-inflows represented without parenthesis. Effect on Taxes combines the effect produced by the personnel costs and by the test and marketing phases investment

depreciated times the tax rate (21%).

The test phase is planned to begin in early 2021. AOF will acquire material to build prototypes which will be tested under a working environment set by AOF. During this time, AOF's confidence in the sensor devices should grow, hopefully to the point it is possible to register a patent. Everything should be set at the end of August 2022 so that the last phase can start.

All the expenses in this phase are fully covered by public funds. The items composing the test phase investment are recorded in the income statement, meaning that they lower the profit before taxes and, consequently, the amount of tax to be paid. That amount is included in the "Total effect on Taxes" category illustrated in table 6.1.

The marketing phase will pave the way to commercialization of the sensor devices. It has a shorter time, lasting only the month of September 2022. AOF will promote not only its discovery but also itself. The investment for promotion is almost fully covered, leaving only €500 off that coverage, treated as cash-outflow. Furthermore, all the items are recorder in the income statement as well, and therefore, will lower the income before taxes. The amount lowered is again included in the "Total effect on Taxes" line.

In relation to the new employees, the costs will be attributed to the phase ongoing. Table 6.1 does not illustrate that distinction; for this see table D.2. Meanwhile, 75% of the amount spent on the new employees is covered by SCi, with only 25% considered cash-outflow. These costs will lower the profit before taxes which, consequently, lowers the amount of taxes to be paid. Therefore, I account 25% of these costs after-tax.

AOF can capitalize on the expenses incurred in R&D activities – used to create or improve a new product – to estimate the value of the patent. This value will later be amortized during the patent lifespan. This creates another cash-flow that will be addressed in the next section.

Forecast cash-flows

Under the DCF valuation, it is assumed that AOF will finish this process and start to commercialize the devices. During this period, I expect commercialization will affect the following company variables:

- *Sales* which are the result of the number of sensor devices sold (demand) times the selling price;
- *Variable Costs* related to the production costs of the devices;
- *Corporate tax* (in Portugal is IRC – Imposto sobre o Rendimento Coletivo), simply applied over the difference between sales and variable costs;
- *Tax shield* due to the depreciation of the patent.

For the start of production, I do not assume fixed costs such as human resources. AOF indeed hires five new workers during this project but there is no information that the company will extend their contract after the R&D process.

Marketing phase is expected to start in August 2022. For simplicity, however, I assume that commercialization starts only in January 2023 and it continues for the next three years (late 2026). This is the time that, on average, AOF's products stay in the market, according to AOF information. After three years, I assume that technology change to such a point that AOF can upgrade its sensor devices or clients start demanding a different product.

Demand has two sources: 1) the number of units required by Bosch Braga and 2) the number of units sold through marketing. Earlier I mentioned that every cash-flow concerning Bosch Braga would be incremental given the lack of information regarding the previous version. Consequently, I consider for the base case the number of units that Bosch Braga requires currently (before project JigSense) which are ten sensor devices, according to AOF. Moreover, all sensors are bought in the first year and Bosch Braga does not require to purchase more units until the end of the project. This last assumption has to do to one of the goals of this project of reducing the maintenance of the devices. Without devices wearing so rapidly, Bosch Braga does not require to replace the devices.

The second source of demand is rather challenging to quantify considering the lack of inside information.

Several factors that can influence the success of a new developed product and, hence, determine how the market respond to it (Henard & Szymanski, 2001; Montoya-Weiss & Calantone, 1994). It should be considered also, the desirable effect from SCi of expanding SMEs network, and this includes the number of clients. For the normal scenario, I simply consider three assumptions:

- every sale is for international customers (exports);
- it has similar weight to the average weight of the industry's exports (around 50%, see table A.2);
- it grows at the average growth rate of the industry's exports for the period 2010–2018 (around 22%)

The selling price is simply based on the selling price of the previous equipment. According to AOF, on average, the previous version was selling at €7.000 per unit. Yet, I go a little bit further and include to this price 5% that Bosch Braga intends to increase in purchases to its national suppliers under SCi. Moreover, this selling price stays constant for the rest of the project.

Since 2016, AOF has become operationally more efficient. In addition, its differentiation strategy allowed AOF to exercise a selling price per unit well above marginal cost per unit. I expect that this difference – that reflects the added value to the clients – lingers on. To estimate the variable costs, I base on 2017 AOF gross profit, not considering the fixed part of the external services (around 87%).

I do not consider any other cost, therefore, the tax rate is applied over the difference between sales and variable costs. Currently, Portuguese corporate taxes – imposto sobre o rendimento das pessoas colectivas (IRC) – stands at 21% (Ministério das Finanças, 2014). There is no strong reasons to believe that it will change in the future, despite some pressure to reduce it. In addition to IRC, companies under certain conditions pay other taxes, such as the municipal spill and state spill. Nevertheless, for simplicity, I assume that AOF pays only the normal tax.

Expenses used to improve products can be capitalized as R&D expenses. Later when registering a patent – as AOF intends to do – these amount reflects the value of the patent (Ordem dos Contabilistas Certificados, 2017). AOF then can amortize the value of the patent throughout project JigSense life. For this matter I consider only the expenses incurred in the test phase. This patent will wear in a straight line for 3 years, having a value equal to the total amount needed for the test phase, €115.600.

Besides all of this, AOF will have to manage its current assets and liabilities (NWC). According to AOF's ratios (see Appendix – AOF's financial ratios table C.1), the company has been paying to its suppliers much quicker than it receives from its clients. Moreover, it should be noted that the company does not register any value on inventory, which means that this investment on NWC is especially towards receivable and payable. If the current situation continues for this specific case, then the company, at some point, has to pay first to its suppliers before receiving from its clients. Thus, the amount needed at the beginning of each year is for the variable costs expected to be incurred during that year. If variable costs increase from one year to another, the company has to strengthen NWC (i.e. invest more money); on the other hand, if it lowers, the company does need so much money and it will recover the difference. At the end of the project, AOF recovers what is left.

Table 6.2 illustrates all cash-flows generated during the project JigSense and, consequently, the FCF at each time period. Table 6.3 illustrates the forecast values of the input variables (selling price per unit, variable cost per unit and demand) during the three years that the devices are expected to stay in the market.

Table 6.2.: Pro-forma of the forecast FCF

	12/22	12/23	12/24	12/25
τ	3,25	4,25	5,25	6,25
Sales		110.250	448.49	54.732
Var. Costs		(142.29)	(5.788)	(7.064)
EBIT		96.021	39.061	47.669
Taxes		(20.164)	(8.203)	(10.010)
Tax Shield		8.092	8.092	8.092
Cash-Flow		83.949	38.950	45.750
Δ NWC	(14.229)	(8.441)	1.276	7.064
FCF	(14.229)	92.389	37.674	38.686

Figures in €. Cash-outflows represented inside parenthesis. Cash-inflows represented without parenthesis

Table 6.3.: Input variables

		12/22	12/23	12/24	12/25
τ		3,25	4,25	5,25	6,25
Selling price p/unit			7.350	7.350	7.350
Var. Cost p/unit			(949)	(949)	(949)
Bosch			10	0	0
Marketing	22%		5	6	7
Demand			15	6	7

Demand through marketing is expected to grow 22% per year. Selling price and variable cost per unit in €

Cost of Capital

Professor Damodaran has updated the industry beta on January 5 2020 – that is, concerns the year 2019. Given the companies that integrate industry machinery,[1] I consider that this industry suits better

[1] Professor Damodaran provides an excel sheet with all companies that compose each industry

AOF core business. At this date, machinery total unlevered beta reached $4,01$.

To lever this beta at the debt-to-equity market value, I use the domestic industry average debt-to-equity ratio that Banco de Portugal provides. The latest information is of 2018 and it reached $86,20\%$. To match the years, I simply assume that this ratio will continue in 2019. Using the bottom-up approach to reach the total beta levered of AOF, this reaches $6,74$.

Given today's economic situation, zero-coupon bonds from countries without default risk (highest rating) are yielding negative returns (negative YTM). In theory, this means that investors are paying to have their money allocated in these bonds, even though in practice this does not happen. European Central Bank gathers all bonds issued in euro by euro area central governments and estimates the zero-coupon bond YTM (European Central Bank, 2020). Currently, 10–year zero-coupon AAA-rated bonds have a YTM of $(-0,491\%)$.

The market risk premium considers the effects that both Portugal and Germany have on this project. Their level of importance varies reason why I attribute, yet subjectively, a 75% weight to Portugal risk premium and a 25% weight to Germany risk premium. According to the estimates of Professor Damodaran (provided in his website), Portugal market risk premium stands at $10,04\%$ while Germany market risk stays at $6,01\%$. The difference between the two countries reflects Portuguese default risk, an increase of $4,03\%$.

Both costs of debt and the capital structure are based on the domestic industry average. Again, this data is provided by Banco de Portugal but the information available dates to 2018. To match information data, I assume that in 2019 these averages stay equal. Industry average cost of debt, in 2018, reached $2,2\%$, while equity-to-capital and debt-to-capital were around $53,71\%$ and $46,29\%$, respectively.

Cost of capital can finally be calculated through equation 4.1. Table 6.5 summarizes all variables require to compute the cost of capital, remembering that I first need to compute the total levered beta, then the cost of equity and only then the cost of capital (WACC).

Table 6.4.: Cost of Equity

Total Unlevered Beta (β_u)		4.01
Debt-to-Equity (D/E)		86,20%
Total Levered Beta (β)		6,74
Portugal Market Risk	75%	10,04%
Germany Market Risk	25%	6,01%
Market Risk Premium (r_M)		9,03%
Risk-free Rate (r_f)		0.21%
Cost of Equity (r_E)		61,09%

Table 6.5.: Weighted Average Cost of Capital

Cost of Equity (r_E)	61,09%
Equity-to-Capital (E/V)	53,71%
Cost of Debt (r_D)	2,20%
Debt-to-Equity (D/V)	46,29%
Tax Rate (t)	21%
Weighted Av. Cost of Capital (r_{WACC})	33,24%

Valuation

To compute the NPV according to equation 5.1, I sort the FCF with respect to each phase. Furthermore, I attribute, subjectively, a 50% chance to obtain positive results from the research phase and, hence, starting the test phase. I consider that the test phase has a 75% rate of success and 95% rate of success for the marketing phase.

Table 6.6.: JigSense project Net Present Value

	τ	Probability to start	Cummulative Probability	FCF	Weighted FCF	PV (33,24%)
		100%	100%			
Research Phase	0,00					
	0,25			(577)	(577)	(537)
	1,25			(2.307)	(2.307)	(1.611)
		50%	50%			
Test Phase	1,25			24.276	12.138	8.479
	2,25			(2.867)	(1.433)	(751)
		75%	38%			
Marketing Phase	2,92			1.621	608	263
	3,00			(29)	(11)	(4)
		95%	36%			
Commercialization	3,25			(14.229)	(5.069)	(1.995)
	4,25			92.389	32.914	9.720
	5,25			37.674	13.421	2.975
	6,25			38.686	13.782	2.293
NPV						18.882

FCF, weighted FCF and PV (NPV) figures in €

Table 6.6 exhibits the FCF occurred in each phase, the weighted FCF considering the probability of the phase starting and the present value of the weighted FCF that, ultimately results in the NPV of the project. Note that the first phase is always certain to start, once AOF begins this project. The test phase has only 50% chance to start due to the probability of success of the research phase. Passing the test phase, marketing phase has 75% chance to start; cumulatively, however, this probability is down to 38%. Finally, there is 95% chance that AOF starts to commercialize one it passes the marketing phase but, cumulatively, only 36%.

NPV, that relies on the DCF valuation, returns a positive value of € 18.487. That is to say that JigSense project creates value to AOF and therefore, should be accepted. This criteria, however, fails to recognize the possibility that AOF can withdraw the project at the end of each of the three phases. Furthermore, although I introduced the technical risk in this valuation using NPV, it fails to recognize the uncertainty that affects the commercialization. This has a direct impact on the value of the project.

6.1. Real Option Analysis

Similar to other R&D projects, JigSense project has a process that plays out sequentially, that is, the process is divided by phases that only start if the previous was successful to proceed. AOF will only start the next phase if 1) the results of the previous phase were positive (represented by the rate of success) and 2) the value of the option to continue is greater than the investment.

To perform the first binomial lattice, I require the current market value of the JigSense project. Ultimately, it is during commercialization that AOF receives cash-flows. Assuming MAD, the market value of the project is given by the present value of all FCF generated during this time.Table 6.7 illustrates all the FCF, their present value and, consequently, the JigSense project market value.

Table 6.7.: JigSense's Market Value

		2019	2022	2023	2024	2025
τ			3,25	4,25	5,25	6,25
FCF			(14.239)	92.389	37.674	38.686
Present Value	33,62%		(5.559)	27.285	8.351	6.436
Market Value		36.472				

figures in €

Table 6.8 summarizes all the inputs necessary to perform the two binomial lattices. The first lattice runs the evolution of the market value of the underlying asset. The second lattice runs and computes the value of the sequential options.

Table 6.9 illustrates the evolution of the current market value of the underlying asset. For ease presentation, I opt to include only the values at the exercise dates ($\tau_0, \tau_1, \tau_2, \tau_3$) and the step immediately after the start of the project. Each month (the time scale) the underlying asset market value either increases by the factor u or decreases by the factor d. For instance, at the end of October 2020, $MV = 36.472$ has increased to $MVu = 39.783$ or decreased to $MVd = 33.437$. This process continues until the end of the marketing phase. For the complete binomial lattice see tables E.1 and E.2 in Appendix – JigSense options valuation.

Table 6.10 performs the estimation of the value of the sequential options (for the complete binomial lattice see tables E.3 and E.4 in Appendix – JigSense options valuation). Here, the lattice starts at the end τ_3. Commercialization does not require any further investment, thus the end-branches of the first lattice equals the end-branches of the second lattice times the probability to start commercialization. The first

Table 6.8.: Summary of the inputs for the binomial lattices

MV	Present market value of the underlying asset	36.472
I_0	Initial investment (research investment)	(1.689)
K_1	Test phase investment (discounted at τ_1)	22.124
K_2	Marketing phase investment (discounted at τ_2)	1.595
σ	Annualized volatility of the underlying asset	30,10%
T	Time to expiration (09/2022)	3
t_0	Start of the project (9/2019)	0
t_1	Start of test phase (12/2020)	1,25
t_2	Start of marketing phase (08/2022)	2,92
N	Number of steps	36
δt	Time-scale	0,083
r_f	Risk-free rate	(0,49%)
b	Losses for deferring	0%
u	Up factor	1,09
d	Down factor	0,92
p	Probability of increasing	47,89%
$q = 1 - p$	Probability of decreasing	52,11%
θ_1	Probability to start Test Phase	50%
θ_2	Probability to start Marketing Phase	75%
θ_3	Probability to start Commercialization	95%

$MV,\ I_0,\ K_{t=2}$ figures in €

end-branch of this second binomial lattice is given by: $832.668 * \theta_3$. This is performed for the remaining 36 end-branches.

These results are, then, discounted back until τ_2, one month earlier when the marketing phase starts. At this time, the discounted values are used to confront with the exercise price regarding the marketing phase given the likelihood of starting this phase. For instance, at this time the best decision is to choose $Max[((791.035 \cdot p + 664.849 \cdot q) \cdot e^{-r_f \cdot \delta t} + 1.595) \cdot \theta_3;\ 0]$.

Table 6.9.: Evolution of JigSense project market value

	09/2019	10/2019		12/2020		08/2022	09/2022
τ	0	0,08	...	1,25	...	2,92	3,00
	36.472	39.783		134.279		763.371	832.668
		33.437	...	112.859	...	641.598	699.841
				...		...	...
				9.906	...	56.318	61.430
						...	...
						1.743	1.901
							1.598

Figures of €

Table 6.10.: Sequential Options value

	09/2019	10/2019	...	12/2020	...	08/2022	09/2022
τ	0	0,08		1,25		2,92	3,00
	23.041	25.905	...	59.502	...	545.098	791.035
		23.644		51.871		458.334	664.849
				...		...	...
				15.194	...	41.322	58.359
						...	...
						2.438	1.806
							1.518

Figures in €

This whole process repeats itself until the beginning of the project (τ_0). At this time, the value of the sequential options is around € 23.041. This offsets greatly the initial investment that is around € 1.689. This means that JigSense project, embedded with sequential options, creates value to AOF around € 22.234 and, therefore, AOF should accept it.

6.2. Considerations

AOF benefits greatly with this project under SCi. The investment required to start this project is almost fully covered by public funds (around 75%). From the € 358.700 required investment, AOF has to cover solely € 90.175, in gross terms. Furthermore, the fact that all of the expenses (excluding the computer and software) are recorded in the income statement allows the company to save some money in taxes. The operational nature of JigSense project exhibits high uncertainty and AOF is never sure during the whole project that the sensors devices will be available for commercialization. But SCi assists and, hence, remove a great amount of risk. The combination of all these factors is a good kickoff for a positive value project.

The forecast cash-flows have strong and subjective assumptions. If AOF uses this methodology, it can easily readjust this part with better inside information without modifying the methodology. For instance, I assumed the upgraded sensor modules have the same lifetime as the average AOF's product. AOF, however, may consider that they stay in the market longer. As a result, the generated FCF will extend over time which has a direct impact on the current market value of the underlying asset, should the company assume MAD as well.

The cost of capital raises some concern given its high level. The reason for this is the rate required by the owners of the company. Both investors are highly exposed to market variations since they do not have a diversified portfolio. One could wonder if this level is too high which has a strong impact on the cost of capital. Comparing the cost of capital with operating ROA (see table C.1), as Palepu & Healy (2012) suggests, both are on similar levels. If we assumed that the cost of capital estimated for this case was the same in 2017, then, the company was creating more than all investors (owners and lenders) were demanding. But as we can see, those levels are not very different.

Nevertheless, the cost of capital case does not have great influence since the investment is so low and the positive effects generated by the investment plan are substantial. But not always projects with these characteristics appear, and the company may have to support the major part of the investment. In those situations, AOF will have to generate more cash-flows from the commercialization to offset the investment, otherwise, these project will not create value.

In the end, both NPV and ROA return a positive value, meaning that JigSense project creates value to AOF. Even with a very low amount of investment, the results have a difference of € 3.402. JigSense project revealed technical and market risks. For the NPV I included the technical risk by weighting the FCF with the rate of success of each phase. The market uncertainty that surrounds the commercialization of the sensor devices as well as the AOF flexibility to withdraw the project are not considered by NPV.

7. Conclusion

This study addresses the evaluation of projects using a practical case between Bosch Braga and its supplier, António Oliveira Ferreira, Lda (AOF). In the beginning, Bosch Braga wanted to understand how valuable the projects are for its suppliers under Supplier Club initiative (SCi). For the specific case of the supplier AOF, the results from the evaluation using both the traditional criteria net present value (NPV) and the real options analysis (ROA) show that JigSense project does create value to AOF.

As shown in this research, for projects embedded with options, ROA can reflect better its characteristics than NPV, even with low levels of investment. This difference reflects the value of the sequential options. NPV criteria assumes that AOF cannot abandon the project and, therefore, will end up commercializing the sensor devices. ROA, instead, considers that possibility and translates it into value. It considers also the sensitivity affecting the underlying market value, something that NPV cannot provide, other than using sensitivity analysis.

The decision does not change with these two approaches, however. This is mainly because the uncovered investment is very low. Moreover, investment generates positive effects that reduce even more investment. Even considering the high uncertainty that characterizes this project, both technical and market uncertainty, AOF should accept the project since it creates value and, therefore, this decision looks after the stakeholders' interests.

A. Appendix – AOF's financial statements

Every data related to the company was gathered from AMADEUS database with the available time period 2008–2017. For table A.1 and A.2, I have changed the layout originally provided by Amadeus.

In the income statement, I have calculated the variable costs concerning the external services (e.g. gas, light, water) as to get a better idea of the size of the production costs. For this task, I start by determine the percentage of external services (ES) ($\% \, ES_n = ES_n / Sales \,, \;\; n = 1, ..., 10$) and proceed to calculate the average of that percentage ($\overline{\% \, ES}$) for the period of analysis ($\overline{\% \, ES} = 1/n + 1 \sum_{t=1}^{n} \% \, ES_n$). Then, at each year, I compute the variable share of the external services by multiplying the external services with the average ($VariableES_n = ES_n \cdot \overline{\% \, ES}$); consequently, fixed proportion of external services is simply the total minus the variable.

Table A.1.: AOF's balance sheet

	2008 GAAP	2009 GAAP	2010 IFRS	2011 IFRS	2012 IFRS	2013 IFRS	2014 IFRS	2015 IFRS	2016 IFRS	2017 IFRS
Tangible Assets	39,10	41,02	72,32	51,74	46,22	33,91	35,87	99,45	139,37	207,90
Intangible Assets	-	-	-	-	-	-	0,80	0,13	0,46	14.93
Other Assets	0,62	0,62	0,62	0,62	0,62	0,62	0,64	0,81	1,83	2,26
Total Fixed Assets	39,72	41,64	72,94	52,36	46,84	34,53	36,59	100,39	141,24	225,10
Stock	34,83	2,61	4,45	3,85	4,75	27,03	1,25	-	-	-
Clients	74,27	126,13	164,81	167,13	178,22	105,81	160,49	271,99	339,43	476,68
Other Current Assets	1,38	0,693	37,53	42,86	38,62	47,44	42,91	48,43	61,29	141,03
Cash	25,86	17,10	-	81,66	38,76	52,59	60,14	21,29	233,65	230,02
Total Current Assets	136,34	146,53	206,79	295,51	260,34	232,87	264,79	341,71	634,37	847,72
Assets	176,06	188,17	279,72	347,87	307,18	267,40	301,38	442,11	775,61	1.072,82
Equity	75,33	92,75	100,29	133,38	153,95	162,64	192,62	227,60	419,21	669,63
Long-term Debt	7,47	-	21,70	15,00	7,75	-	-	35,57	53,81	67,63
Other Non-Current Liabilities	-	-	-	82,54	37,26	-	-	-	-	-
Total Non-Current Liabilities	7,47	-	21,70	97,54	45,00	-	-	35,57	53,81	67,63
Short-term Debt	-	10,00	-	-	-	7,74	0,83	15,12	26,25	39,94
Suppliers	57,47	39,06	31,78	63,44	82,52	52,73	45,73	64,88	108,41	112,89
Other Current Liabilities	35,79	46,35	125,94	53,51	25,71	44,29	62,95	98,95	167,93	182,73
Total Current Liabilities	93,26	95,42	157,72	116,95	108,23	104,76	108,76	178,95	302,58	335,56
Total Liabilities	100,73	95,42	179,42	214,49	153,23	104,76	108,76	214,52	356,40	403,19
Total Equity and Liabilities	176,06	188,17	279,72	347,87	307,18	267,40	301,38	442,11	775,61	1.072,82

figures in thousand of €

Table A.2.: AOF's income statement

	2008 GAAP	2009 GAAP	2010 IFRS	2011 IFRS	2012 IFRS	2013 IFRS	2014 IFRS	2015 IFRS	2016 IFRS	2017 IFRS
Sales	291,51	450,77	344,50	417,15	400,75	352,68	454,41	508,71	972,12	1.071,76
Operating Revenue	314,50	420,62	346,21	420,23	408,00	376,57	432,45	508,64	972,48	1.075,14
Cost of Sales	91,96	163,84	114,23	126,50	73,20	67,99	74,12	110,16	162,00	138,32
Supplies and external services	102,71	117,83	82,76	98,69	154,73	141,35	167,46	169,91	329,94	287,17
Variable	32,74	37,56	26,38	31,46	49,32	45,05	53,38	54,15	105,16	91,53
Fixed	69,97	80,27	56,38	67,23	105,41	96,30	114,09	115,75	224,78	195,64
Employee costs	85,98	101,69	110,11	126,05	126,55	131,13	137,54	157,13	196,31	262,85
EBITDA	33,86	37,26	39,11	68,99	53,53	36,11	53,33	71,45	284,23	386,81
Depreciation and Amortizations	17,27	12,77	24,14	24,42	25,00	22,40	12,75	26,00	35,20	61,69
EBIT	16,59	24,49	14,97	44,57	28,53	13,71	40,57	45,44	249,03	325,11
Interests Income	0,43	0,507	-	-	-	-	-	-	-	-
Interests Expenses	1,36	1,05	0,15	0,23	-	-	0,30	-	0,84	1,01
Profit before taxes	15,27	23,94	14,82	44,54	28,53	13,71	40,57	45,44	248,19	324,10
Taxes	3,79	3,91	3,28	11,46	7,96	5,02	10,59	10,46	56,58	73,68
Net Income	11,48	20,04	11,54	33,09	20,57	8,69	29,98	34,98	191,61	250,42

figures in thousand of €

the difference between sales and revenues should be a consequence of the change in inventories

B. Appendix – AOF's industry

Information regarding AOF's industry - manufacturing metallic mould (activity code $25\,764$) - was gathered from Banco de Portugal, more specifically from its sector tables. The available time period is 2009–2018.

Table B.1.: Metallic Moulds Industry characteristics

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Micro companies	387	392	382	383	389	396	401	413	427	448
SMEs	208	205	217	223	231	243	262	268	281	277
Big companies	1	1	1	1	1	1	1	1	1	2
Total	596	598	600	607	621	640	664	682	709	727
Sales Average (Av.)	890,12	862,69	1.014,02	1.172,03	1.183,40	1.202,15	1.307,39	1.391,51	1.406,85	1.372,90
Growth		(3,08%)	17,54%	15,58%	0,97%	1,58%	8,75%	6,43%	1,10%	(2,41%)
Exports (Av.)	474,94	459,00	577,41	711,95	695,31	693,08	753,24	771,71	269,13	770,41
Growth		(3,36%)	25,80%	23,30%	(2,34%)	(0,32%)	8,68%	2,45%	(65,13%)	186,26%
Exports weight	53,36%	53,21%	56,94%	60,75%	58,76%	57,65%	57,61%	55,46%	19,13%	56,12%
Gross Profit (Av.)	75,71%	72,97%	69,93%	71,31%	72,61%	72,85%	74,31%	74,23%	74,86%	74,79%
EBIT Margin (Av.)	28,71%	34,43%	37,03%	42,00%	41,36%	41,29%	41,33%	40,97%	40,70%	39,16%

Sales and Exports figures in thousand of €

C. Appendix – AOF's financial ratios

To decompose ROE, I based on the equation provided by Palepu & Healy (2012):

$$ROE = \frac{NOPAT}{Net\ Assets} \cdot \left(1 + \frac{Net\ Debt}{Equity}\right) - \frac{Net\ Interest\ Expense\ after\ Tax}{Net\ Debt} \cdot \frac{Net\ Debt}{Equity}\ , \tag{C.1}$$

Where:

- ROE is the return on equity;
- Net Interest Expense after tax is obtained by *(Interests Expenses — Interests Income)* $\cdot$ *(1−t)*, with t being the tax rate;
- NOPAT is the net operating profit after tax and it is obtained by *Net Income* + *Net Interest Expense after tax*;
- Net Assets is obtained by *Operating Working Capital + (Total long-term assets — Non-interest-bearing long-term liabilities)*;
- Net Debt is obtained by *Total interest-bearing liabilities — Cash and equivalents*.

Table C.1.: AOF financial ratios

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ROE industry		0,94%	(0,73%)	3,29%	6,17%	7,87%	13,55%	11,58%	12,33%	10,15%
ROE	15,23%	21,60%	11,50%	24,81%	13,36%	5,34%	15,57%	15,37%	45,71%	37,40%
NOPAT	12,47	20,49	11,66	33,10	20,57	8,69	29,99	34,98	192,27	251,20
Net Interest after tax	0,99	0,46	0,12	0,02	-	-	-	-	0,65	0,78
Net Assets	56,94	85,65	121,99	66,71	122,95	117,80	132,57	256,99	265,62	547,18
NWC	17,22	44,01	49,05	96,89	113,36	83,27	95,97	156,60	124,38	322,09
Net Long-term Assets	39,72	41,64	72,94	(30,18)	9,58	34,53	36,59	100,39	141,24	225,10
Net Debt	(18,39)	(7,10)	21,70	(66,67)	(31,00)	(44,85	(60,05)	29,39	(153,59)	(122,45)
Operating. ROA	21,90%	23,93%	9,55%	49,62%	16,73%	7,38%	22,62%	13,61%	72,38%	45,91%
Gross Margin	68,46%	63,65%	66,84%	69,67%	81,73%	80,72%	83,69%	78,35%	83,34%	87,09%
NWC to sales	5,91%	9,76%	14,24%	23,23%	28,29%	23,61%	21,12%	30,78%	12,79%	30,05%
Days' receivables	93	102	174	146	162	109	129	195	127	162
Days' inventory	44	2	5	3	4	28	1	0	0	0
Days' payables	72	32	34	56	75	55	37	47	41	38
Equity-to-Capital	90,98%	90,27%	82,21%	89,89%	95,21%	95,46%	99,96%	81,79%	83,96%	86,16%
Debt-to-Capital	9,02%	9,73%	17,79%	10,11%	4,79%	4,54%	0,04%	18,21%	16,04%	13,84%
Debt-to-equity	9,91%	10,78%	21,64%	11,25%	5,03%	4,76%	0,04%	22,27%	19,10%	16,06%
Net-debt-to-equity	(0,24)	(0,08)	0,22	(0,50)	(0,20)	(0,28)	(0,31)	0,13	(0,37)	(0,18)
Interest Coverage	12,2	23,7	99,8	1937,7	-	-	13524,1	-	295,8	321,6

D. Appendix – JigSense investment plan

Information regarding the investment for the JigSense project was provided by the company itself, AOF. In the first phase (research), AOF will need a high-performance computer, a software to design the PCBs and five new workers. The computer costs €5 000 and the software costs €3 000 but both are fully covered by SCi. Furthermore, the company will spent for the 3 year a total around €250 000 with the new employees. This gives five workers earning an average salary of around €827 for 14 months, considering the vacation allowance plus the taxes that reach 23,75%. The costs with the new workers are covered up to 75%.

In the test phase, AOF will need raw materials, metallic and electronic components, consumable tools to produce prototypes. AOF, further, will need material to set a test bench for the prototypes and, finally, an auditor to check the technicalities of the project. All the expenses for these variables are fully covered by the funds.

As for the marketing phase, AOF will promote the devices and itself with the promotion material, new website, travelling (representation expenses) to participate on conferences. Moreover, it will acquire the services of another technical-scientific auditor and a chartered accountant. Only the expenses for the latter are not fully covered – €500 has to be covered by AOF; the rest is covered.

Table D.1.: JigSense Project gross investment

	Coverage	09/19	12/19	12/20	12/21	08/22	09/22	12/22
τ		0,00	0,25	1,25	2,25	2,92	3,00	3,25
High performance Computer	100%	3.000						
Software PCB's design	100%	5.000						
Raw Material	100%			40.000				
Metallic Components	100%			20.000				
Electronic Components	100%			15.000				
Consumables	100%			10.000				
Test Bench (Material)	100%			30.000				
Auditor	100%			600				
Promotional Material	100%					2.500		
Representation Expenses	100%					1.500		
Website Expenses	100%					1.500		
Conferences participation	100%					1.000		
Auditor	100%					600		
TOC/ROC	83%					3.000		
Employees	75%		17.917	71.667	71.667			53.750

Figures in €

Table D.2.: Cash-flows of the phases

	09/19	12/19	12/20	12/21	08/22	09/22	12/22
	0,00	0,25	1,25	2,25	2,92	3,00	3,25
Computer	3.000						
Tax Shield ($t = 21\%$)		53	210	210			158
Software PCB's design	5.000						
Tax Shield ($t = 21\%$)		88	350	350			263
Employees		17.917	71.667				
Amount of Taxes lowered		3.762	15.050				
Gross Investment	(8.000)	(17.917)	(71.667)				
Covered	8.000	13.437	53.750				
Cash-outflow		(4.479)	(17.917)				
Cash-flow (save on taxes)		3.902	15.610	560			420
FCF (Research Phase)	(1.689)	(537)	(1.611)	294			165
Raw Material			40.000				
Metallic Components			20.000				
Electronic Components			15.000				
Consumables			10.000				
Test Bench (Material)			30.000				
Auditor			600				
Employees				71.667			
Amount of Taxes lowered			24.276	15.050			
Gross Investment			(115.600)	(71.667)			
Covered			115.600	53.750			
Cash-outflow				(17.917)			
Cash-flow (save on taxes)			24.276	15.050			
PV(FCF) - Test Phase	15.455		16.958	(1.503)			
Promotional Material					2.500		
Representation Expenses					1.500		
Website Expenses					1.500		
Conferences participation					1.000		
Auditor					600		
TOC/ROC					3.000		
Employees							53.750
Amount of Taxes lowered					2.121		13.408
Gross Investment					(10.100)		(53.750)
Covered					9.600		40.312
Cash-outflow					(500)		(13.437)
Cash-flow (save on taxes)					2.121		13.408
PV(FCF) - Marketing Phase	690				702		(11)

Tax rate is 21%. Both the computer and software wear 33,33% per year. FCF discounted at 33,24%. Deviations in the sums due to rounding.

E. Appendix – JigSense options valuation

For ease of presentation, I brake both binomial lattices in two. The order is reversed to facilitate the demonstration.

Table E.1.: Market Value Evolution binomial lattice (1)

τ	04/2021 1,58	05/2021 1,67	06/2021 1,75	07/2021 1,83	08/2021 1,92	09/2021 2,00	10/2021 2,08	11/2021 2,17	12/2021 2,25	01/2022 2,33	02/2022 2,42	03/2022 2,50	04/2022 2,58	05/2022 2,67	06/2022 2,75	07/2022 2,83	08/2022 2,92	09/2022 3,00
	190 088	207 343	226 165	246 696	269 091	293 518	320 164	349 227	380 929	415 509	453 229	494 372	539 250	588 202	641 598	699 841	763 371	832 668
	159 765	174 268	190 088	207 343	226 165	246 696	269 091	293 518	320 164	349 227	380 929	415 509	453 229	494 372	539 250	588 202	641 598	699 841
	134 279	146 469	159 765	174 268	190 088	207 343	226 165	246 696	269 091	293 518	320 164	349 227	380 929	415 509	453 229	494 372	539 250	588 202
	112 859	123 104	134 279	146 469	159 765	174 268	190 088	207 343	226 165	246 696	269 091	293 518	320 164	349 227	380 929	415 509	453 229	494 372
	94 856	103 466	112 859	123 104	134 279	146 469	159 765	174 268	190 088	207 343	226 165	246 696	269 091	293 518	320 164	349 227	380 929	415 509
	79 724	86 961	94 856	103 466	112 859	123 104	134 279	146 469	159 765	174 268	190 088	207 343	226 165	246 696	269 091	293 518	320 164	349 227
	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104	134 279	146 469	159 765	174 268	190 088	207 343	226 165	246 696	269 091	293 518
	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104	134 279	146 469	159 765	174 268	190 088	207 343	226 165	246 696
	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104	134 279	146 469	159 765	174 268	190 088	207 343
	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104	134 279	146 469	159 765	174 268
	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104	134 279	146 469
	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104
	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466
	19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961
	16 685	18 200	19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089
	14 024	15 297	16 685	18 200	19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430
	11 787	12 857	14 024	15 297	16 685	18 200	19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631
	9 906	10 806	11 787	12 857	14 024	15 297	16 685	18 200	19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395
	8 326	9 082	9 906	10 806	11 787	12 857	14 024	15 297	16 685	18 200	19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472
	6 998	7 633	8 326	9 082	9 906	10 806	11 787	12 857	14 024	15 297	16 685	18 200	19 852	21 654	23 620	25 764	28 103	30 654
		6 416	6 998	7 633	8 326	9 082	9 906	10 806	11 787	12 857	14 024	15 297	16 685	18 200	19 852	21 654	23 620	25 764
			5 882	6 416	6 998	7 633	8 326	9 082	9 906	10 806	11 787	12 857	14 024	15 297	16 685	18 200	19 852	21 654
				5 392	5 882	6 416	6 998	7 633	8 326	9 082	9 906	10 806	11 787	12 857	14 024	15 297	16 685	18 200
					4 943	5 392	5 882	6 416	6 998	7 633	8 326	9 082	9 906	10 806	11 787	12 857	14 024	15 297
						4 532	4 943	5 392	5 882	6 416	6 998	7 633	8 326	9 082	9 906	10 806	11 787	12 857
							4 155	4 532	4 943	5 392	5 882	6 416	6 998	7 633	8 326	9 082	9 906	10 806
								3 809	4 155	4 532	4 943	5 392	5 882	6 416	6 998	7 633	8 326	9 082
									3 492	3 809	4 155	4 532	4 943	5 392	5 882	6 416	6 998	7 633
										3 201	3 492	3 809	4 155	4 532	4 943	5 392	5 882	6 416
											2 935	3 201	3 492	3 809	4 155	4 532	4 943	5 392
												2 691	2 935	3 201	3 492	3 809	4 155	4 532
													2 467	2 691	2 935	3 201	3 492	3 809
														2 262	2 467	2 691	2 935	3 201
															2 073	2 262	2 467	2 691
																1 901	2 073	2 262
																	1 743	1 901
																		1 598

figures in €

Table E.2.: Market Value Evolution binomial lattice (2)

	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020	08/2020	09/2020	10/2020	11/2020	12/2020	01/2021	02/2021	03/2021
τ	0	0,08	0,17	0,25	0,33	0,42	0,50	0,58	0,67	0,75	0,83	0,92	1,00	1,08	1,17	1,25	1,33	1,42	1,50
	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104	134 279	146 469	159 765	174 268
		33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104	134 279	146 469
			30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466	112 859	123 104
				28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961	94 856	103 466
					25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089	79 724	86 961
						23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430	67 007	73 089
							21 654	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631	56 318	61 430
								19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395	47 334	51 631
									18 200	19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472	39 783	43 395
										16 685	18 200	19 852	21 654	23 620	25 764	28 103	30 654	33 437	36 472
											15 297	16 685	18 200	19 852	21 654	23 620	25 764	28 103	30 654
												14 024	15 297	16 685	18 200	19 852	21 654	23 620	25 764
													12 857	14 024	15 297	16 685	18 200	19 852	21 654
														11 787	12 857	14 024	15 297	16 685	18 200
															10 806	11 787	12 857	14 024	15 297
																9 906	10 806	11 787	12 857
																	9 082	9 906	10 806
																		8 326	9 082
																			7 633

figures in €

Table E.3.: Sequential Option binomial lattice (1)

	04/2021	05/2021	06/2021	07/2021	08/2021	09/2021	10/2021	11/2021	12/2021	01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022
τ	1,58	1,67	1,75	1,83	1,92	2,00	2,08	2,17	2,25	2,33	2,42	2,50	2,58	2,67	2,75	2,83	2,92	3,00
	136 641	148 935	162 346	176 974	192 929	210 333	229 317	250 025	272 612	297 250	324 124	353 438	385 414	420 291	458 335	499 833	545 098	791 035
	115 036	125 369	136 640	148 934	162 345	176 973	192 928	210 332	229 316	250 024	272 611	297 249	324 123	353 437	385 413	420 290	458 334	664 849
	96 878	105 562	115 035	125 368	136 639	148 933	162 344	176 972	192 927	210 331	229 315	250 023	272 610	297 248	324 122	353 436	385 412	558 792
	81 616	88 915	96 877	105 561	115 034	125 367	136 638	148 932	162 343	176 971	192 926	210 330	229 314	250 022	272 609	297 247	324 121	469 653
	68 788	74 923	81 615	88 914	96 876	105 560	115 033	125 366	136 637	148 931	162 342	176 970	192 925	210 329	229 313	250 021	272 608	394 734
	58 007	63 163	68 787	74 922	81 614	88 913	96 875	105 559	115 032	125 365	136 636	148 931	162 341	176 969	192 924	210 328	229 312	331 766
	48 946	53 279	58 006	63 162	68 786	74 921	81 613	88 912	96 874	105 558	115 031	125 364	136 635	148 930	162 340	176 968	192 923	278 843
	41 330	44 972	48 945	53 278	58 005	63 161	68 785	74 920	81 612	88 911	96 873	105 557	115 030	125 363	136 634	148 929	162 339	234 362
	34 929	37 990	41 329	44 971	48 944	53 277	58 004	63 160	68 784	74 919	81 611	88 910	96 872	105 556	115 029	125 362	136 633	196 976
	29 549	32 122	34 928	37 989	41 328	44 970	48 943	53 276	58 003	63 159	68 783	74 918	81 610	88 909	96 871	105 555	115 028	165 554
	25 028	27 190	29 548	32 121	34 927	37 988	41 327	44 969	48 942	53 275	58 002	63 158	68 782	74 917	81 609	88 908	96 870	139 145
	21 227	23 044	25 027	27 189	29 547	32 120	34 926	37 987	41 326	44 968	48 941	53 275	58 001	63 157	68 782	74 916	81 608	116 949
	18 033	19 560	21 226	23 043	25 026	27 188	29 546	32 119	34 925	37 986	41 325	44 967	48 940	53 274	58 000	63 156	68 781	98 293
	15 349	16 632	18 032	19 559	21 225	23 042	25 025	27 187	29 545	32 118	34 924	37 985	41 324	44 966	48 939	53 273	57 999	82 613
	13 092	14 171	15 348	16 631	18 031	19 558	21 224	23 042	25 024	27 186	29 544	32 117	34 923	37 984	41 323	44 965	48 938	69 435
	11 196	12 102	13 091	14 170	15 347	16 630	18 030	19 557	21 223	23 041	25 023	27 185	29 543	32 116	34 922	37 983	41 322	58 359
	9 602	10 364	11 195	12 101	13 090	14 169	15 346	16 629	18 029	19 556	21 222	23 040	25 022	27 184	29 542	32 115	34 921	49 049
	8 262	8 902	9 601	10 363	11 194	12 100	13 089	14 168	15 345	16 628	18 028	19 555	21 221	23 039	25 021	27 183	29 541	41 225
	7 136	7 674	8 261	8 901	9 600	10 362	11 193	12 099	13 088	14 167	15 344	16 627	18 027	19 554	21 220	23 038	25 020	34 649
	6 190	6 642	7 135	7 673	8 260	8 900	9 599	10 361	11 192	12 098	13 087	14 166	15 343	16 626	18 026	19 553	21 219	29 121
		5 774	6 189	6 641	7 134	7 672	8 259	8 899	9 598	10 360	11 191	12 097	13 086	14 165	15 342	16 625	18 025	24 476
			5 394	5 773	6 188	6 640	7 133	7 671	8 258	8 898	9 597	10 359	11 190	12 096	13 085	14 164	15 341	20 572
				5 044	5 393	5 772	6 187	6 639	7 132	7 670	8 257	8 898	9 596	10 358	11 189	12 095	13 084	17 290
					4 724	5 043	5 392	5 771	6 186	6 638	7 131	7 669	8 256	8 897	9 595	10 357	11 188	14 532
						4 430	4 723	5 042	5 391	5 771	6 185	6 637	7 130	7 668	8 255	8 896	9 594	12 214
							4 161	4 429	4 722	5 041	5 390	5 770	6 184	6 636	7 129	7 667	8 254	10 265
								3 914	4 160	4 428	4 721	5 040	5 389	5 769	6 183	6 635	7 128	8 628
									3 688	3 913	4 159	4 427	4 720	5 039	5 388	5 768	6 182	7 252
										3 480	3 687	3 912	4 158	4 427	4 719	5 038	5 387	6 095
											3 290	3 479	3 686	3 911	4 157	4 426	4 718	5 123
												3 116	3 289	3 478	3 685	3 910	4 156	4 305
													2 956	3 115	3 288	3 477	3 684	3 619
														2 809	2 955	3 114	3 287	3 041
															2 674	2 808	2 954	2 556
																2 551	2 673	2 148
																	2 438	1 806
																		1 518

figures in €

Table E.4.: Sequential Option binomial lattice (2)

	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020	08/2020	09/2020	10/2020	11/2020	12/2020	01/2021	02/2021	03/2021
τ	0	0,08	0,17	0,25	0,33	0,42	0,50	0,58	0,67	0,75	0,83	0,92	1,00	1,08	1,17	1,25	1,33	1,42	1,50
	23 041	25 905	27 187	28 585	30 111	31 776	33 593	35 574	37 737	40 096	42 669	45 477	48 539	51 881	55 526	59 502	105 564	115 037	125 370
		23 644	24 721	25 895	27 177	28 576	30 102	31 767	33 583	35 565	37 727	40 086	42 659	45 467	48 530	51 871	88 917	96 879	105 563
			22 648	23 634	24 711	25 886	27 167	28 566	30 092	31 757	33 573	35 555	37 718	40 076	42 650	45 457	74 925	81 617	88 916
				21 734	22 638	23 625	24 701	25 876	27 158	28 557	30 082	31 747	33 564	35 546	37 708	40 067	63 165	68 789	74 924
					20 896	21 725	22 629	23 615	24 692	25 867	27 148	28 547	30 073	31 738	33 554	35 536	53 281	58 008	63 164
						20 128	20 887	21 715	22 619	23 606	24 682	25 857	27 139	28 537	30 063	31 728	44 974	48 947	53 280
							19 423	20 118	20 877	21 706	22 610	23 596	24 673	25 847	27 129	28 528	37 992	41 331	44 973
								18 776	19 413	20 108	20 868	21 696	22 600	23 587	24 663	25 838	32 124	34 930	37 991
									18 182	18 766	19 403	20 099	20 858	21 686	22 590	23 577	27 192	29 550	32 123
										17 638	18 173	18 757	19 394	20 089	20 848	21 677	23 046	25 029	27 191
											17 139	17 628	18 163	18 747	19 384	20 080	19 562	21 228	23 045
												16 680	17 129	17 619	18 154	18 737	16 634	18 034	19 561
													16 260	16 671	17 119	17 609	14 173	15 349	16 633
														15 874	16 250	16 661	12 104	13 093	14 172
															15 519	15 864	10 366	11 197	12 103
																15 194	8 904	9 603	10 365
																	7 676	8 263	8 903
																		7 137	7 675
																			6 643

figures in €

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