ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

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Studijní program: **Elektrotechnika, energetika a management**

Studijní obor: **Ekonomika a řízení elektrotechniky**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Využití Realných opcí pro hodnocení investic cloudových technologií

Název diplomové práce anglicky:

Real Options Analysis and cloud computing investments

Pokyny pro vypracování:

- Specify the terms Real Options Analysis and cloud computing technology
- Make a systematic literature review of existing papers describing application of Real Options Analysis for IT investments evaluation
- Define possible interconnection between Real Options Analysis method and cloud computing technologies
- Create a methodology for usage of Real Options Analysis for cloud computing technology investments
- Verify your methodology by using selected practical examples defined by the supervisor of this thesis

Seznam doporučené literatury:

Scholleová, H.: Hodnota flexibility. Praha: C. H. Beck, 2007.
Starý, O.: Reálné opce. Praha: A plus, 2003.
Guthrie, G. A.: Real Options in Theory and Practice. Oxford University Press, 2009.
Smit H. T. J., Trigeorgis L.: Strategic Investment, Real Options and Games, Princeton University Press, Princeton and Oxford, 2004, ISBN: 0-691-01039-0

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III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

.

Datum převzetí zadání | Podpis studenta

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Department of economics, management and social sciences

Diploma thesis

Real Option Analysis and cloud computing investments

Bc. Martin Mastný

Supervisor: Ing. Pavel Náplava

12th July 2017

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Declaration

I hereby declare that the presented thesis is my own work and that I have cited all sources of information in accordance with the Guideline for adhering to ethical principles when elaborating an academic final thesis.

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In Prague on 12th July 2017 . . . .

Citation of this thesis

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Abstrakt

Tato práce popisuje teorii reálných opcí (ROT) a přirovnává její vlastnosti k charakteristikám cloud computingu. Na základě tohoto spojení vyslovujeme myšlenku o využití reálných opcí k ohodnocení flexibility, kterou cloud přináší oproti tradiční on-premises infrastruktuře. Poté provedeme rešerši dostupné literatury, abychom se seznámili s dosavadním výzkumem na toto téma. Nakonec s využitím ROT vytvoříme metodiku na ohodnocení přínosů cloudu a otestujeme ji na několika scénářích z prostředí startupů.

Klíčová slova reálné opce, cloud computing, on-premises, ROA, průchodově závislá opce, binomický oceňovací model

Abstract

This thesis describes the Real Options Theory (ROT) and likens its features to characteristics of cloud computing. Based on this connection we express a thought on the usage of real options for valuation of the flexibility cloud brings in contrast with traditional on-premises infrastructure. Afterwards, we perform a systematic literature review to see if there has been some research in this area. Eventually, with the use of ROT, we create a methodology for valuation of cloud benefits and test it on several scenarios from startup environment.

Keywords real option, cloud computing, on-premises, ROA, path-dependent option, binomial pricing method

Contents

List of Figures

List of Tables

List of Listings

Introduction

The digital era with its emerging technologies has disrupted the market and created new business models. It is also because of cloud computing that the starting technology firms, so-called ICT startups, have now a capability to scale their revenues rapidly in a relatively short period. In light of this, it is even more evident that the traditional valuation methods such as NPV or TCO are not convenient for the volatile Internet industry. We challenge this issue with a real options approach. The main objective of this thesis is to create a methodology for valuation of cloud's benefits (primarily its flexibility) using real options. In the end, we should be able to determine the value cloud brings us compared with traditional on-premises infrastructure. The thesis is divided into five chapters.

In the first chapter, we briefly define terms startup and cloud computing. The majority of this chapter is devoted to a description of Real Options Analysis. After the introduction of the essential parameters, we go through determination of the option value and the binomial pricing method which serves as the basis of our methodology.

The second chapter consolidates information from the previous one. We express a key thought on the interconnection of real options and cloud service. Specifically, the usage of a real option for valuation of cloud's flexibility. The convenience of this approach is argued by similarities of their characteristics.

In the third chapter, we perform a systematic literature review of existing articles on the use of real option for IT investments valuation. Special focus is on cloud services and path-dependent options which are used in our methodology.

The fourth chapter in four steps describes the methodology for valuation of cloud's benefits in comparison with standard on-premises infrastructure. The result tells us how much money we can save if we choose cloud over on-premises. Eventually, we look at algorithmization of the methodology.

The last chapter consists of several scenarios which test the methodology. All of them come up from a startup environment and simulate various situations which might occur. The results are first analysed separately, and then the methodology is discussed as a whole.

Chapter 1

Cloud computing and Real Options Analysis

The gap between IT and business is now shrinking. IT is not taken solely as a cost asset but contributes more and more to the business model of companies, thus being responsible for generating revenues.[1] In some sectors, IT (IT infrastructure to be specific) is a driving force of the company's business model. Starting technology firms, so-called ICT startups, are a perfect example where IT infrastructure in combination with the rise of devices connected to the Internet is a headstone of their business.[2] Neil Blumenthal, cofounder and co-CEO of Warby Parker, defines a startup as:

> *"A startup is a company working to solve a problem where the solution is not obvious and success is not guaranteed."*[3]

Although there is no globally recognised definition and other authors and entrepreneurs use slightly different ones, in all of them there is exercised one common feature of a startup - the uncertainty. In the above quotation, there are mentioned two ways how it affects the success. The fact that we don't know if the new product or service will do well in the market and the possible changes of its characteristics during development or even production phase based on our competitors and customer's demand. Determination and appropriate reaction to these market changes is crucial to maximise the chance to survive.

It would be wrong to think uncertainty is only an issue of small starting firms as it has been presented so far. Large corporations also need to invest in the development of new products to secure their position. The only difference is that they have some budget at disposal to cover the costs if the idea goes south. Given that, a startup is not defined by the size or age of a company but more by the meaning it represents. Guy Kawasaki, former chief evangelist of Apple and trustee of the Wikimedia Foundation, summarises that there is little difference in starting up a whole company, division or even a church:

> *"Great companies. Great divisions. Great schools. Great churches. Great not-for-profits. When it comes to the fundamentals of starting up, they are more alike than they are different. The key to their success is to survive the microscope tasks while bringing the future closer."*[4, Introduction]

Uncertainty in all of these projects can be described as the number of customers using the product or service. If no one buys the product or goes to the school neither the product nor the school will be profitable, and both will have to be shut down eventually. In that case, we end up in loss from the initial investment. Technology startup whose product is a software, however, have the option to use cloud computing to scale up or down the available performance while keeping the costs as low as possible. That gives us a tool to make managerial decisions at any time.

Since this thesis aims mainly on investment of technology startups, in this chapter, I'm going to describe the theory of cloud computing and Real Options Analysis as a method of valuating IT investments while reflecting the uncertainty and flexibility.

1.1 Cloud computing

We've already established that IT infrastructure is essential, but what are the options to choose from? Articles published in Forbes[5], The Next Web[6] and many more discuss the advantages and disadvantages of on-premises and cloud computing delivery models. While on-premises software is installed and operated from a customer's house server and computing infrastructure, therefore "on premises", it is considered more secure. On the other hand, it cannot match cloud computing in the matter of initial costliness. Since it is probable that a startup (starting company or R&D division of enterprise) would not be willing or able to invest so many resources to an uncertain result, we will focus primarily on cloud computing.

There are, as with the startup, multiple ways to define cloud computing. Generally accepted, though, is the NIST (National Institute of Standards and Technology) definition:

> *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models."*[7]

1.1.1 Cloud computing characteristics

Following are the essential characteristics of cloud computing. Besides NIST definition, the characteristics, service and deployment models of cloud computing described below are also based on Hill's book *Guide to Cloud Computing.*[8]

1. On-demand self-service – Although it had been possible to outsource computing features, such as network time and network storage, without the need to purchase hardware itself from a service provider before, the request to increase time or capacity was usually fulfilled with some delay. Therefore, the system was not reactive, and these updates had to be planned in advance. Cloud computing should incorporate the provision of computing capabilities automatically in real time, without human intervention.

2. Broad network access – Cloud computing resources are available over networks such as the Internet and use standard protocols and mechanisms which make them accessible to all devices able to communicate through these protocols and mechanisms (e.g., mobile phones, tablets, laptops, workstations).

3. Resource pooling – *"The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand."*[7] As a result, cloud computing provider achieves large-scale efficiencies, lowering the cost for both sides. On the other hand, the customer can indicate the physical location of provisioned resources only to some extent (e.g., country, state, or datacenter).

4. Rapid elasticity – Capabilities (requests for extra resources) are provisioned automatically in relation to demand. From the customer's perspective, the availability and volume of resources seem limitless.

5. Measured service – Customers are charged only for what they use. The resources provided to the customer are measured in units according to the type of service (e.g., storage, processing, active user accounts). Monitoring, controlling and reporting benefit both provider and customer.

1.1.2 Cloud computing service models

Cloud services can be distinguished to several models based on the service provided. Duan et al.[9] list models such as PraaS, InaaS, SeaaS, etc., generally referred to as XaaS (Everything-as-a-Service). For our purpose, we will look only at the three basic models mentioned by NIST as depicted in figure 1.1

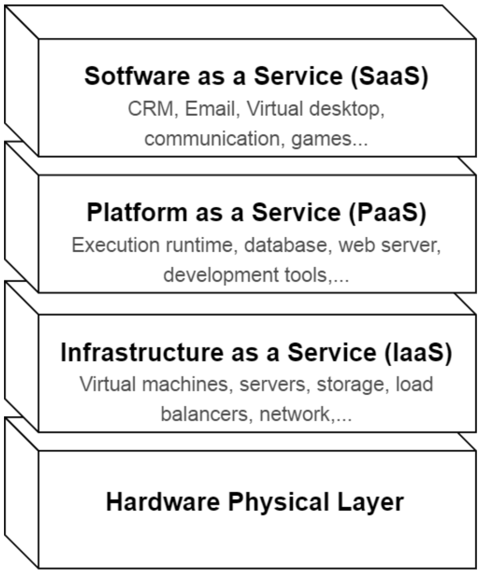

Figure 1.1: Cloud service stack with examples of software/device of each layer and underlying hardware physical layer [1]

1. Infrastructure-as-a-Service (IaaS) – This is usually the lowest level service available providing hardware related services like processing, storage, networks, and other virtual infrastructure upon which the customer can deploy operating systems, applications or any other software. The customer does not manage or control the physical hardware, but retains control over operating system parameters, storage and deployed applications as well as some aspects of security (e.g., host firewalls).

2. Platform-as-a-Service (PaaS) – The middle layer of cloud service stack has the most in common with traditional web hosting, where the customer rents remote servers with existing development platforms installed upon them. In the case of cloud, the capability provided to the customer is to deploy onto the cloud infrastructure applications created using operating system, language compilers, and other tools installed and managed by the provider. The customer might be allowed to install some additional tools of his own but generally controls only the deployed applications, having no control over the infrastructure itself. The key difference between web hosting and cloud computing, in this case, is the rapid elasticity of cloud and its unnecessary human intervention when increased demand.

[1] Figure created based on [8, Fig. 1.3] and http://www.slideshare.net/kerneltraining/amazon-web-services-introduction-aws-basics-demo-ppts

3. Software-as-a-Service (SaaS) – This model abstracts the customer away from the infrastructure and platform level leaving him only with the semi-configurable applications. The applications are accessible through either a thin client interface, such as web browser (e.g., Gmail), or a standard non-remote application with Internet-based storage or other network interactions, such as mobile phone app. Payment is usually made on a pay-per-use or charge-per-use basis. With this service model, the customer can fully focus on setting the specific parameters of applications to suit the best interest of his company and not to bother with anything else.

1.1.3 Cloud computing deployment models

Lastl, let's briefly have a look at the deployment models defined by NIST. They vary with the set privacy and thus, related security issues.

1. Private cloud – The cloud infrastructure is used only by one organisation comprising multiple consumers. It may be located on or off premises and owned, managed, and operated by the organisation itself or a third party.

2. Community cloud – This deployment model is the same as the Private model with the exception that there is not just one organisation but a community of organisations with shared concerns (e.g., mission, security requirements, policy, and compliance considerations).

3. Public cloud – The cloud infrastructure is openly used by general public. It exists on the premises of the cloud provider who can be business, academic, or government organisation.

4. Hybrid cloud – Hybrid clouds are a composition of two or more distinct infrastructures mentioned above where each cloud infrastructure is utilised for a particular situation, but remain connected through standardised technology that enables data and application portability. An example would be an organisation with a private cloud for sensitive data, located on their premises, and public cloud for other aspects of its business, on premises of the provider.

1.1.4 Cloud computing consequences

Cloud computing paradigm represents a service oriented mechanism of managing and dispatching resources. Its on-demand service orientation together with its other characteristics - Internet accessibility, pay-per-use charging model, flexibility, and resource pooling - makes it comparable to utilities such as water or electricity. Wang et al. in book *Cloud Computing: Methodology, Systems, and Application* recall: *"A hundred years ago, companies stopped* *generating their own power with steam engines and plugged into the newly built electric grid. The cheap power pumped out by such electric utilities did not just change how businesses operated – it set off a chain reaction of economic and social transformations that brought the modern world into existence."*[10, p. 4] Today, the similar transition could happen. Only instead of electricity, we would plug our homes and businesses into massive information-processing plants (clouds) and received seemingly unlimited on-demand computational power. Although this "fantasy" is far from reality, not only due to security reasons, it is important to realise the similar behaviour of cloud and utilities.

Besides utilities, cloud computing characteristics map to the needs of startups as well. For startups, usually having minimal resources to play with while striving for flexibility and scalability, it is vital to develop business ideas into service quickly, and at the same time be able to adapt to the customer feedback. Cloud computing brings both flexibility and with pay-as-you-go model of the Public cloud, which we will from now on consider when referring to "startup cloud", affordability. Cloud significantly decreases time to market due to its off-the-shelf design, allowing the users to concentrate more resources and time on their ideas.

As a consequence, startups became even better at bootstrapping, getting as far as possible on no or very little funding. The combination of cloud computing, high-quality open source software, better and less expensive network, open mobile network, and more evolved customer base, can keep the costs of startup low for a long time. This gives the founders time to wait and see if the idea proofs itself before investing more money.[10, Cloud computing and Startups]

In the next section, we will define Real Options Analysis which seems like an appropriate method for valuating cloud computing advantages.

1.2 Real Options Analysis

Real Options Analysis (ROA) is a method for valuating investments with a high level of uncertainty. It originates in financial options which were developed to address decisions taken in constantly changing financial markets. Both financial and real options differ from standard investment valuation methods, such as Net Present Value (NPV), Internal Rate of Return (IRR), Total Cost of Ownership (TCO), etc., in the sense of forecasting the future.[11]

Standard methods work with constant values of both costs and revenues and consider risk only encapsulated in the rate of discount, increased as the risk increases. They do not valuate uncertainty, managerial flexibility, and market development change which leads to an undervaluation of investments with a higher level of flexibility.[12] Starý in his book *Reálné opce*[13] points out that realisation of these high-risk projects is something which makes the difference between an average company and an excellent one. No one would probably invest in a highly uncertain project if there weren't an option to change a decision based on new information.

Options, on the other hand, work with a risk-free rate of return, today's market state and the rate at which today's state is losing value as the only guide to the future. They take into account possible changes in the market and thus, changing future profit. The manager then can decide whether or not to react (invest, quit, etc.) as long as the option is open.[11] In the next section, we will review the terminology of financial options and focus on the real option specifics later on.

1.2.1 Financial options

Options belong to financial derivatives. That means their value is drawn (derived) from tradable assets. In the case of options, this "attached" asset is called an underlying asset.[13] Holler et al. refer to financial option as *"an option to buy or sell a financial asset which already exists and is actively traded in a financial market in a standard form (stocks, shares, bonds, etc.). Buying and selling a financial option on the stocks or shares of business is a private 'bet' on its market price, between two investors, and this has no effect on the business itself (which need not even know that a financial option on its stock has been created)."*[11, p. 14] The word 'bet' implies that to gain this option we will have to pay a fee, called premium. By paying the premium, owner of the financial option has the right, not the obligation, to buy or sell the underlying asset at a specified price at the specified time.[14] It is important to emphasise the choice the owner (holder, buyer) has enabling him at any circumstances to lose the premium maximally. We will show an example later, but first, we need to go through fundamental option terms and divisions we haven't mentioned yet.[11][13]

Fundamental option terms

- **Exercise price (E)** – the specified price at which an option allows us to buy or sell a given underlying asset. Also known as Strike price.

- **Expiry date (T)** – the date when an option expires. For a European option, it is also the only date when we can exercise it.

- **Spot price (S)** - the price at which a commodity (underlying asset) could be transacted right now. Also known as Market price.

Division according to the:

1. Type of option
   - Call option – gives the owner the right to acquire (buy) an asset at some future time for a cost which is known now, regardless of the market selling price at that time.
   - Put option – gives the owner the right to sell an asset in future, at a price known now, regardless of the market selling price at that time.
2. Right to exercise
   - European option – option which can be exercised only on one fixed future date. That date is also its expiration date.
   - American option – option which can be exercised at any time until its expiration date.
   - Perpetual option – option which has no expiration date (relevant for decisions on land use, or for exchange of currencies)
3. Position
   - Long position – the position of the owner (buyer) of the option who paid the premium and can choose whether to exercise the option or not.
   - Short position – the position of the seller who received the premium and is bound by the contract to sell or buy the underlying asset if the buyer chooses to exercise the option.
4. Relationship of spot price and exercise price
   - In the money – option is profitable to exercise at the moment. For a call option, the exercise price is lower than spot price (vice versa for a put option).
   - Out of the money – option is not profitable to exercise at the moment. For a call option, the exercise price is higher than spot price (vice versa for a put option).
   - On the money – it doesn't matter if we exercise the option or not. Exercise price equals spot price.

These terms are necessary to determine the value of the option, discussed in the next section. Lists of divisions presented above are not complete but are sufficient for the purpose of this thesis. For example in the division according to the "right to exercise", there exist many more exotic types of options. In this thesis, however, we will consider the American option only, since we want to be able (and in reality usually are able) to exercise the option anytime.

1.2.1.1 Value of the option

The value of the option corresponds with the profit, owning the option can give us. It is a value which helps us to set the price (premium) of an option. In other words, how much is the option worth to the buyer and seller. The value of an option is the sum of its intrinsic and time value.

$$Option\ Premium = Intrinsic\ Value + Time\ Value$$

For a call option, intrinsic value is the difference between the price of the underlying asset (spot price) and the strike price (vice versa for a put option). Since it doesn't take into account the premium, it is a non-negative number at any circumstances. In figure 1.2, we can see an example of a call option which was contracted on one piece of the underlying asset (one stock).

Solid blue line displays the owner‘s potential profit or loss based on the spot price just before expiration of the option. Dashed red line shows the same from the seller's perspective. As we can see, from the view of both players, the option is a zero-sum game. The picture also confirms the statement that the maximum loss an owner can suffer from is the premium (when S < E). The maximum profit, however, is "infinite" as the underlying asset's price may rise significantly (when S > E). Solid green line depicts the intrinsic value of the

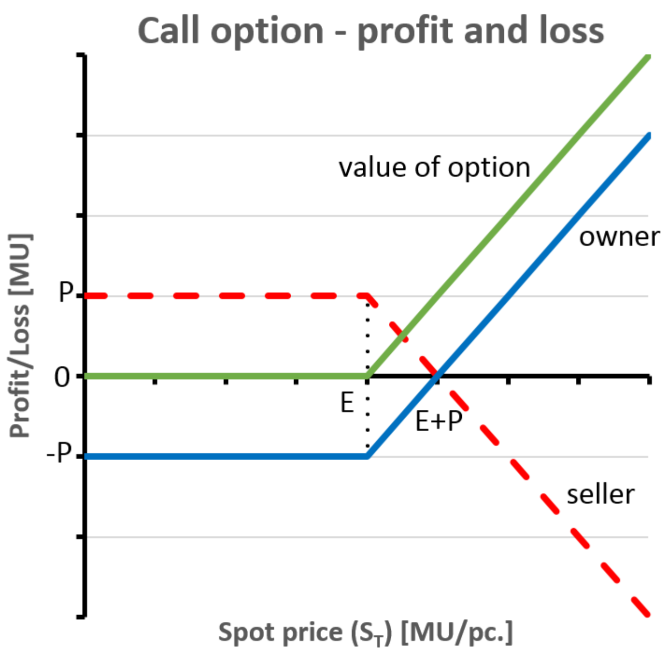

Figure 1.2: Value of a call option with marked profit/loss line of owner and seller[13, Fig. 5]

option. It is the same as the owner's profit line but increased by the premium. If we set V_c as the intrinsic value of a call option, following formula is valid:

$$V_c = max(S_T - E, 0) \tag{1.1}$$

Similarly, figure 1.3 shows an example of a put option contracted on one piece of the underlying asset. In this case, owner's maximal profit is limited by the set exercise price. On the other hand, the maximal loss is again only the premium. Conversely, it works for the seller. The value of a put option V_p follows, as in the case of a call option, the owner's profit increased by the premium:

$$V_p = max(E - S_T, 0) \tag{1.2}$$

Time value of an option, unlike the intrinsic value, takes into account the premium. The premium which exceeds the intrinsic value of an option is a time value. Therefore time value is a difference between the premium and the intrinsic value of an option. As the intrinsic value was defined by the exercise and spot price, the time value is influenced by expected volatility and time until expiration.

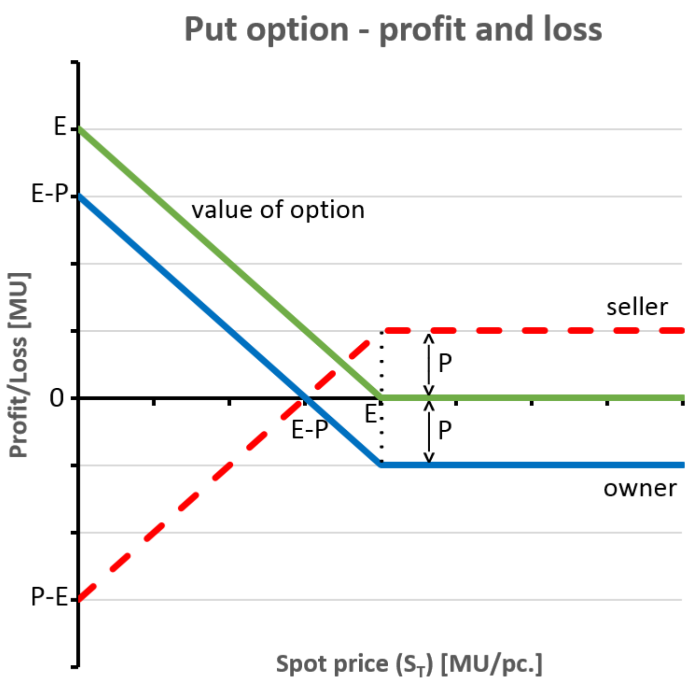

Figure 1.3: Value of a put option with marked profit/loss line of owner and seller[13, Fig. 6]

- Expected volatility – volatility is the degree of variation in which the price of the underlying asset changes (no matter the direction). The higher the volatility, the higher option value because it is a promise of possible high profit. The unpredictability obviously goes both ways, but if we were to lose, we would simply not exercise the option and lose only the premium instead.

- Time until expiration – the longer an option has until expiration, the higher is the chance that it will end up profitable (in-the-money). As a result, an option loses its value towards its expiration. This factor is also correlated with the volatility. Long time until expiration together with highly volatile asset leads to a high time value.

Last, interest rates and dividends also affect the option value. If the interest rates rise, call values increase and put values decrease. This is caused by the higher purchase price (increased by the interest cost) the buyer would have to pay for the underlying asset – underlying asset is more valuable. Set lower exercise price is, therefore, more profitable.

In the case of dividends, the underlying asset's price usually drops when a dividend is paid out. That means if dividend increases, call values decrease and put values increase. Conversely, if the dividend decreases, call values increase and put values decrease.[13][14]

1.2.1.2 Pricing models

In the previous section, we discussed the factors which influence the option value (either intrinsic or time) and thus, the premium. It is important to understand the difference between an option premium and its theoretical value. We already know that the premium is the price the buyer pays to the seller to get the right to decide in the future. On the other hand, the theoretical value of an option is a value (price) estimated by a model. Inputs of these models, such as time until expiration, exercise price, volatility are either known or based on an educated guess. Some of these factors fluctuate in time, and so as the theoretical value changes, premium changes accordingly. However, it does not mean the premium and the theoretical value are the same. Market practitioners usually calculate model value first and adjust it by their own view (based on market demand and supply). To summarise, we could say the difference between value and price of an option is just difference between what we believe the value should be and what the market believes the value should be.

Scholleová defines in her book *Hodnota flexibility*[14] two main pricing models:

- Black-Scholes Model

- Cox-Rubenstein Binomial Model

Black-Scholes pricing model was published by Fisher Black and Myron Scholes in 1937.[15] It enables us to calculate the premium of an option with a continuous distribution of expected future values of the underlying asset. In other words, it is a tool for valuation of assets with a high level of volatility.[13] Nevertheless, it is applicable for European options only. Since in the practical application part we will work with American options i.e. the Binomial Model, we are going to describe in detail only this one.

Binomial pricing model

Binomial option pricing model was first proposed by John Carrington Cox, Stephen Ross and Mark Edward Rubenstein in 1979.[16] Although it is based on the Black-Scholes model, it doesn't consider the underlying asset's price at one point in time only but works with its changes over multiple periods of time. Between these periods, the price can either go up by index u with the probability p or go down by index d with the probability $(1-p)$. One of this model's assumptions is that we divide the lifetime of an option into a finite number of periods – binomial model is discrete. If there were to be an infinite number of periods, we would get a continuous distribution of spot prices, thus the Black-Scholes model. Other assumptions of the binomial model are:

- There is no possibility of arbitrage.
- The market is perfectly efficient (no taxes, transaction costs, limitations on trade; underlying asset is infinitely dividable).

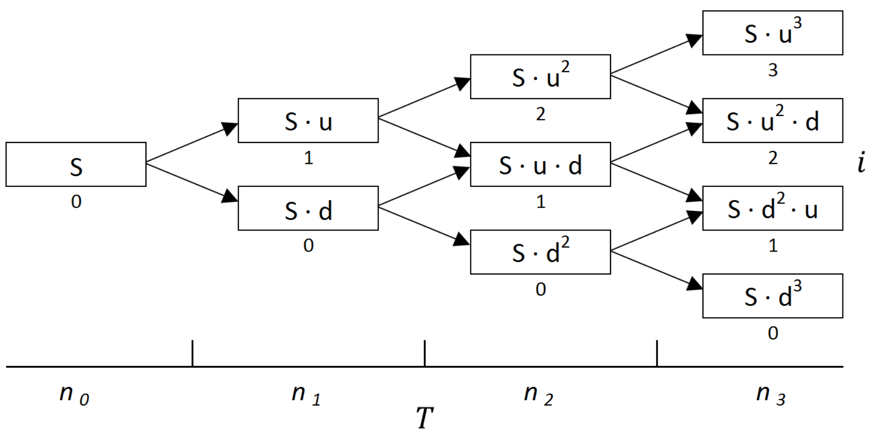

Figure 1.4: Binomial tree with expiration time of T years divided into n periods. Figure creation based on *Hodnota flexibility*[14]

- There is a risk neutral environment – all individuals are indifferent towards risk. As a result, expected returns are equal to the risk-free rate of interest which is constant through out the life of the option.
- Between each period, the underlying price can either go up or down and never both simultaneously.

We will demonstrate the usage of the binomial model on valuation of an American call option. The model consists of three steps.

First, we need to construct a binomial tree (or lattice) as displayed in the figure 1.4. Starting node is the current price of the underlying asset S_0 at the time of valuation n_0. From there, during each period n_i the price can either rise by the index u or fall by the index d. Since u is a multiplicative inverse of d, when the price goes up and then down, it is as it never changed. Consequently, at time period n_i the tree has $(i+1)$ nodes, where $i \in (0...n)$. In order to set the indexes u and d, we need to define the volatility (standard deviation of revenues) of the underlying asset σ and the number of periods n in T years. Given that, indexes u and d are defined as:[16]

$$u = e^{\sigma\sqrt{\frac{T}{n}}} \tag{1.3}$$

$$d = e^{-\sigma\sqrt{\frac{T}{n}}} \tag{1.4}$$

$$\left.\begin{matrix} u \\ d \end{matrix}\right\} u = \frac{1}{d}$$

Now the binomial tree shows us the range of values the underlying asset may have. Although the output values depend on the set volatility and number of periods, it gives us an insight into what the maximal and minimal spot prices may be at the expiration date.

In the second step, we will compare the possible spot price with the initial investment E at each node of the tree. In other words, at each node, we will compute the intrinsic value of the option. Consider C_u as the value in the event of increase and C_d in the event of decrease, at the end of the first period the intrinsic values would be equal to:

$$C_u = max(S \cdot u - E, 0) \tag{1.5}$$

$$C_d = max(S \cdot d - E, 0) \tag{1.6}$$

Third and the last step is to calculate the final value of an option C. To do so, we need to define the probability p and $(1-p)$ using a risk-free rate of interest r:

$$p = \frac{(1+r)^{\frac{T}{n}} - d}{u - d} \tag{1.7}$$

$$1 - p = \frac{(1+r)^{\frac{T}{n}} - u}{d - u} \tag{1.8}$$

Then, to continue with our example of a call option[2] contracted for only one period, the final (discounted) value is:

$$C = \frac{p \cdot max(S \cdot u - E, 0) + (1-p) \cdot max(S \cdot d - E, 0)}{1+r}$$

In reality, we want to calculate the value of an American option with not just one period. To do that, we have to modify equations 1.5 and 1.6 from the previous example to determine the intrinsic value at each node. Considering $i \in (0...n)$ for each period of n (shown in figure 1.4 as the number below each node), the intrinsic value of any node $(C_i)_n$ is:

$$(C_i)_n = max(S \cdot u^i \cdot d^{n-i} - E, 0)$$

and from that, the recurently calculated final value of a node $(C_i)_{n-1}$ is:

$$(C_i)_{n-1} = max\Big[\frac{1}{(1+r)} \cdot (p \cdot (C_{i+1})_n + (1-p) \cdot (C_i)_n), max\big((S_i)_{n-1} - X, 0\big)\Big]$$

As we can see, when calculating the value of an American call option we start from the end nodes and recurrently set the values of previous nodes by comparison of their intrinsic values with the value we could get if we kept the option open. The value of the first node is the value of the option in the present. This system represents the ability of an American option to make the best decision at any time. Analogically, we can derive the formula for an American put option:

$$(P_i)_n = max(E - S \cdot u^i \cdot d^{n-i}, 0)$$
$$(P_i)_{n-1} = max\Big[\frac{1}{(1+r)} \cdot (p \cdot (P_{i+1})_n + (1-p) \cdot (P_i)_n), max\big(X - (S_i)_{n-1}, 0\big)\Big]$$

The valuation process of European option is simpler. Once we have the intrinsic values of the end nodes, we just calculate their weighted sum and discount it to the present. Following are the formulas for the European call and put options:

$$C = \frac{1}{(1+r)^n} \cdot \sum_{i=0}^{n} \frac{n!}{i! \cdot (n-1)!} \cdot p^i \cdot (1-p)^{n-i} \cdot max(S \cdot u^i \cdot d^{n-i} - E, 0)$$
$$P = \frac{1}{(1+r)^n} \cdot \sum_{i=0}^{n} \frac{n!}{i! \cdot (n-1)!} \cdot p^i \cdot (1-p)^{n-i} \cdot max(E - S \cdot u^i \cdot d^{n-i}, 0)$$

[2]With only one period, it doesn't matter if it's American or European option.

Binomial model's biggest drawback is the assumption of constant probability to grow or fall by the same index u or d. Besides that, it is also crucial not to set these indexes misleadingly.

On the other hand, the model is possible to use for both American and European options. It also gives us a free hand in the level of granularity which affects the precision of the result. Last but not least, it is deemed less complicated than Black-Scholes model and because of that preferred by more managers. These properties make it convenient for practical application part of this thesis.[13][14]

1.2.2 Real options

The term "Real option" was coined by Stewart Mayers in his article *Determinants of Corporate Borrowing* in 1977. Professor Mayers likens call options to corporate investments, particularly growth opportunities, and defines real options to grow, to defer and to abandon a project on the basis of new information.[17]

As with the financial options, owner of a real option has right, but not obligation, to buy or sell an underlying asset at a specified price at the specified time. There is, however, the difference in the underlying asset. Howell et. al. define a real option as *"an option to change 'real' physical or intellectual activity of a business (e.g. to create or to bring to market a new technology, a new brand, a new factory or an extra unit of output). This means the business has to bring together new, non-standard non-traded combination of 'real' resources, such as time and effort by people, wear and tear on machinery, use of consumable supplies, etc."*[11] Unlike the financial options, it is not a contract between two individuals. We can think of real options as a contract between the business itself and the entire outside world (the market). As a result, the option can change the economic value of the business and should be actively managed as long as it stays open.[11]

We might consider any business investment as a real option – a combination of initial investment, expected revenues, time and uncertainty. However, ROA is not convenient to use for all types of contracts. The biggest advantage of options is the fact that they incorporate flexibility in the factor of volatility. For low volatile contracts, such as long-term partnerships, should be used traditional methods such as NPV. The added flexibility would increase the investment because ROA is not a substitute for the conventional methods but their complement.[18] The value of a project is a sum of NPV and option value, as shown in the following formula.[14]

$$Investment\ Value = NPV + Real\ Option\ Value$$

Consequently, real options should be used for investments with a significant level of uncertainty, thus, increased need for flexibility. This example also shows the positive correlation between volatility and flexibility.

1.2.2.1 Value of real options

Determination of option value described in sections 1.2.1.1 and 1.2.1.2 is applicable for real options as well. However, some differences are coming from the distinct environments of their usage. Let's first look at what information does the real option value poses.

According to Howell et. al., it gives us answers to questions such as: *"How much should we spend to create a technology? How much extra should we invest in a production system to give it greater flexibility?"*[11] Both these questions focus on the cost of acquiring an option. Whereas a financial option is sold in a fairly efficient market, so we cannot control its price, and the market price is fair so far as anyone knows at that moment, expenditures to create a real option do not have these properties. Investors might end up spending more money than the option value is worth because there is no market value against which to check. The cost may also vary among individuals since each of them can have different resources to begin with (for example in the case of research).

Last, competition also influences the option value and expiry date. Real options are often shared or available to many contestants and exercising the option by one may result even in closing the option for others. In other words, delivering a product (service, technology) to market first gives us a significant competitive edge.

Volatility

Comparison of financial and real option parameters necessary to determine the value of an option are in table 1.1. The last stated parameter, volatility, is arguably the most difficult to set. Scholleová defines three ways how to predict future revenues of the underlying asset:[14]

1. Expert methods – based on previous similar projects, volatility of industry

2. Computational methods – based on historical data, approximation by linear regression

3. Mathematical-Analytical methods – analytic, numeric, simulation

Whatever method we use it must correspond to the character of the underlying asset. Since we have no experience with similar projects nor can we use simulation methods, in the practical application we will use the typical volatility of the industry (based on historical data). Volatility is measured as a standard deviation of underlying asset's revenues. The higher volatility the higher is the chance the business ends up profitable. However, it is harder to predict the future changes and thus, the risk increases. The high volatility suggests, the industry (ICT, the Internet) is relatively new and is inclined towards new ideas. Lower volatility, on the other hand, appears in old industries with well-established competitors where there is minimal space for innovation (railways, appliances).[19]

Parameter	**Financial option**	**Real option**
Stock price (S)	Price of the underlying asset (stock) set by the market. (changes continually)	NPV of the potential investment, if we were to make this investment today. (changes continually)
Underlying asset	Unit of stock.	Potential physical or intellectual investment.
Right of the option holder	To buy (call) or to sell (put).	Opportunity to invest (call) or disinvest/sell up (put).
Continuity of the holder's right	Continuous up to maturity (American), only at maturity date (European), continuous for ever (perpetual).	All these, plus combinations of them.
Exercise price (E)	Fixed price at which we can buy (call) or sell (put) a unit of stock.	Fixed price at which we can make a business investment or sell it up.
Time to expiry (T)	The amount of time that remains prior to the expiration date.	Period for which opportunity is valid.
Risk-free interest rate (r)	Rate of government bonds.	Rate the market is willing to pay on an asset whose payoffs are completely predictable.
Volatility (σ)	Based on historical prices of the underlying asset.	Based on expected revenues of the underlying asset, industry, etc.

Table 1.1: Comparison between financial and real option paramaters[11]

1.2.2.2 Types of real options

There are several types of real options. However, they are still based on a basic call or put option, or more precisely a combination of them. Options are combined either independently or serially, where exercising (success of) the first option opens the second one and so forth.[19] These compound options can be made of various combinations, similarly as the financial options are combined into spreads.[13]

Hommel defines less granular but comprehensive division into three main types:[20]

- **Options to learn** - these options give us right to postpone our decision to see how the risk factors will turn out. Therefore, they are convenient to use before making an investment. Their characteristic feature is waiting until there is more information available and based on it make a qualified decision. A typical example is an option to wait (to defer a realisation of a project) and an option to stage (to divide a project into parts). If the newly gained information makes the project undesirable, we simply do not exercise the option but minimise our loss. The option type is mostly call.

- **Options to grow** - these options create an environment (resources) for future potentially successful investments. Therefore, we receive the right to their value. These opportunities are available due to previous investment (e.g. research, increased capacity). Such an example is an option to innovation (to create new products) and an option to expansion (to enter new markets or take a greater share of the current ones). They are often a compound of call options.

- **Options to hedge** - these options give us right to react to the unpleasant market development and minimise our losses. We can use them in the production phase or even during execution of a project. A typical example is an option to substitution (to change inputs of production), option to interrupt (to temporarily close production due to seasonal fluctuation) and option to exit (to quit unsuccessful project with minimal costs). The option type is mostly put.

Summary of the chapter

In this chapter, we defined cloud computing and Real Options Analysis in order to set a theoretical background for the next chapter, in which we will discuss possible interconnection between these paradigms. Special focus will be on their usage in a startup environment.

Chapter 2

Interconnection between Real Options Analysis and cloud computing

The purpose of this chapter is to consolidate the information defined it the previous chapter and set up a link between Real Options Analysis and cloud computing. In other words, based on characteristics of ROA and CC we will express a thought which will serve as a basis for the practical application.

We have already said that technology startups are the ones who will benefit from this connection the most. Let us recapitulate what their primary objectives are and link them to cloud computing characteristics, as shown in table 2.1.

Startup objectives	**Cloud computing characteristics**
Keeping the costs low as long as possible (bootstrapping).	Pay-per-use charging model while achieving broad network accessibility.
Being able to react to the changes in the market.	Scalable and flexible on-demand provisioning of resources.
Minimal time to market.	Customisable off-the-shelf design.

Table 2.1: Comparison of startup objectives with cloud computing features

The more detailed comparison was described in subsection 1.1.4, but even from this simplified one, we can clearly see that cloud computing is a go-to choice for this type of starting firms. Furthermore, we have mentioned that

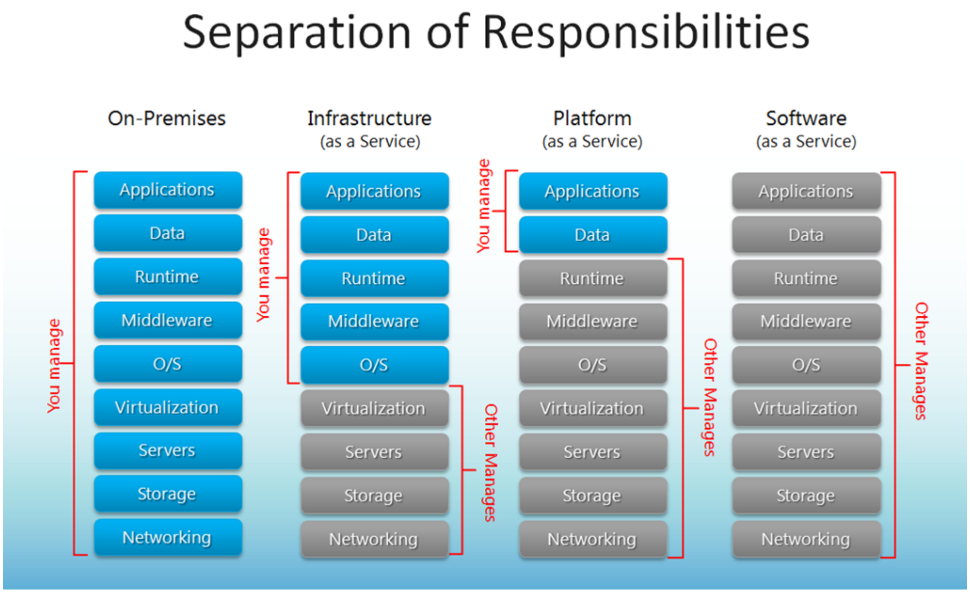

Figure 2.1: Cloud service stack showing level of management based on chosen service [3]

the only deployment model of the cloud to consider is the Public cloud for its combination of affordability and public accessibility. In the case of service model, however, the decision is not that apparent. The description of service models with corresponding layers of ownership is depicted in figure 2.1.

At first sight, we can discard the SaaS model since it only allows us to customise already made applications. The difference between PaaS and IaaS is mainly in the responsibility for the operating system. While with PaaS we can only focus on development, testing and hosting of our application, with IaaS we also need to choose which and how many operating system licences to buy. As Joseph Foran[21] explains, cloud licencing is complicated even for experienced IT managers, so there's no point in dealing with this matter early on. Moreover, their focus should be primarily on the business itself, and because of that, we will consider PaaS as the service model used from now on.

The connection between startups and cloud computing is set but what role does the Real Options Analysis play in this arrangement? As mentioned in subsection 1.2.2, cloud computing's scalability is incorporated in ROA's volatility. In other words, ROA enables us to valuate possible changes in customer's demand. Additionally, the flexibility of exercising the option (American) is similar to the flexibility of the cloud, when we can increase (option to grow), decrease (option to interrupt) or completely quit (option to exit) the cloud

[3]Figure taken from http://www.netwatch.me/2016/02/29/microsoft-azure-cloud-series-understanding-the-stack-who-manages-what-part-2

infrastructure due to migration to on-premises at any time.

The last mentioned example, moving from cloud to on-premises, is discussed in Náplava's article.[22] For this type of decision is the most convenient to use an option to wait. The amount of money paid to cloud vendor before making the decision (to invest/not to invest) would equal the option premium (p). By paying the premium, we gain right to defer the decision of investing in our own infrastructure. During the option lifetime, if we consider the investment viable, that is, the expected discounted cash flow we would receive from our own infrastructure (S) is higher than the investment price (E), we simply quit the cloud, make the investment and thus exercise the American call option. Correspondingly with the ROA, the maximal loss from the investment is the premium, and the investition is irreversible.[23]

In the practical part of this thesis, we will work with the assumption that every successful startup will eventually consider moving from cloud computing to on-premises. This shift may be made for numerous reasons – related to security, managerial rights or economic. Cloud computing brings continuous costs which increase as the business (number of users) increases. It is arguable that investing into our own infrastructure (with the cost of support) will be in the long run more economic viable. The main objective of this thesis is to answer this question by creating an easy-to-use methodology for startup founders to help them to determine at what state to shift to on-premises and when to continue with cloud based on the customer's demand.

Summary of the chapter

We have reviewed the link between startups and cloud computing and established the interconnection between cloud computing and Real Options Analysis. It appears that real option is a convenient method for valuation of cloud-related investments. This work's goal is to present a methodology mapping the shift from cloud to on-premises. Before we proceed to this part, however, let us see whether there has been some research in this area so far. In the next chapter, we will perform a literature review on existing articles which consider ROA as a method for valuating IT investments, particularly cloud services.

Chapter 3

Literature review

In the previous chapters, we defined necessary terminology and expressed a thought on the possible link between real options and cloud technology. This chapter consists of the systematic literature review of currently available articles on the usage of Real Options Analysis as a tool for valuating IT investments. The review should answer to following questions:

1. Are there any attempts to valuate IT investments using Real Options Analysis?
2. If so, are there any attempts to valuate cloud computing investments with ROA?
3. If so, what methodology and type of options are usually used for this purpose?
4. Is there any methodology which uses the binomial model of real option and allows information to be passed from previous nodes to next ones? In other words, it allows determining the sequence of nodes which lead to the current one and the attached parameter (e.g. the amount of hardware purchased on the way).

In the thesis, I have already referenced articles (namely Náplava's [12] and [22]) which meet some of these questions, so it is certain there will be a positive result. Nonetheless, it is important to get acquainted with all available articles written so far before continuing to the creation of the methodology itself.

3.1 Research approach

The systematic review was performed on the basis of the methodology by Budgen & Brereton.[24] To ensure the highest quality and expertise of output information, only reviewed articles from following digital sources were searched: ACM Digital Library, EBSCO, IEEE Xplore, Scopus, SpringerLink and Web of Science. The research considered only content whose full text was available online and was written in either English or Czech language. Furthermore, only results issued after 2010 were taken into account. The search results used for this study were generated during the period between 13 March 2017 and 31 March 2017. The search covered published papers up to these dates depending on what data a particular digital source was searched for. For each of them, we documented the search strategy and the dates of the search. While reading the searched articles, some referenced publications were added to the scope. The complete list of 22 reviewed articles can be found in Appendix B.

3.1.1 Research process

The search process started with a pilot on the ACM Digital Library to answer the first question of the review. For this purpose, we searched titles, abstracts and keywords of articles for following strings: "real option", "information technology" and lately added "information system". From the search results, having over 100 eligible records, it was evident that ROA has been suggested for valuation of certain IT investments. We chose 4 representatives from various business areas and continued to second question, as those examples also prove the usage of ROA for valuation of IT.

In the second pilot, we specified the search to articles which discuss real options only in relation to cloud computing. Correspondently with the first pilot, we searched titles, abstracts and keywords, however, this time for strings "real option", "ROA", "cloud" and "SaaS". From the digital libraries and constraints stated above, we registered 14 relevant sources of information. After reading the full text of each article, we found 5 of them eligible for our research.

The third and last pilot was performed to find an example of a "real option with memory" described in the fourth question. This time we aimed not only at the area of computer science but looked for any occurrence across industries. Considering that, we searched for strings "real option", "ROA" and "binomial". No methodology which would meet the specific features was found, but we identified two types of real options which showed the most similarities. For further inspiration, we selected 4 articles as representatives of these approaches.

3.2 Identified results

From the beginning of the review, it was evident that Real Options Theory is primarily applied in the area of information technology and energetics. In the case of IT, it is mostly connected to emerging technologies, Internet of Things

(IoT) specifically, discussing challenges for enterprises[25], adoption of RFID in retail[26], or Smart Grid.[27]

The number of articles which consider ROA for valuation of cloud computing is significantly lower. Articles eligible for our work are described below. They are those which match the best with the objectives of this paper – usage of the binomial pricing model, comparison of on-premises and cloud, and the inclusion of an exemplary case. In other words, they do not consider using real options only argumentatively but also financially.

- Alzaghoul and Bahsoon take an option-based approach to valuate technical debt in Cloud-based Service-Oriented Architecture (CB-SOA). They do not discuss the question of switching from cloud to internal IT but focus only on improving Quality of Service (QoS) and reducing of technical debt through scaling up the capacity of web services. They achieve this by switching from one service to another, either by comparing the old one and the new[28], contemplating two substitutional grow options[29] or by examining the flexibility and time value of waiting/deferring the switching decision under uncertainty.[30]
- Jede[31], on the other hand, focuses especially on the comparison between SaaS and traditional on-premises systems. He raises the question of how the option to abandon service can be valuated in a formal decision model. For this purpose, he calculates NPV and real option-adjusted NPV of both on-premises and SaaS provider and on a case study financially demonstrates that the possibility of abandoning favours cloud service.
- Yam et. al.[32] address the issue of migration from standard IT infrastructure to cloud. Although they do not use the binomial pricing model, they in detail investigate the transition cost connected with the switch. Special focus is put on the security concerns of the cloud which are brought into the business valuation and decision as a part of the uncertainty.

Besides papers listed above, it is worth to mention articles which look on this matter the from the provider's perspective. Quanbari et. al.[33] apply financial option theory to find the optimal premium price of the cloud federation options to utilise cloud computing resources which in the end benefit the customer as well. Another representative, Rogers et. al.[34], propose a broker-based federation approach.

Last, there is the question of a real option which would keep information (or parameter) of its path through the binomial tree. That way we would be able to determine the sequence of nodes leading to the current one and acknowledge it during valuation. In our case, by the parameter we mean information about hardware infrastructure purchased in the lifetime of the option. From now on, we will call the option with this capability as an “option with memory”. The necessity of this kind of option is further on discussed in subsection 4.1.3.1.

We did not find any article where such option would appear, but we identified two approaches which seem the most similar. First, it is a usage of compound/sequential option where call options are executed progressively based on the revealed future. However, the decision is triggered by demand at a certain time only, not with accordance to the previous evolution of demand.[35] Second, Targiel[36] uses dynamic programming to create binomial trees with more than one state variable. Herewith, the binomial lattice is not valuated only by the deviation of the value of the project (as it usually is the observed variable) but by second variable (e.g. value of the firm’s stock on the market) as well, resulting in a 3-dimensional tree.

3.2.1 Statistical data

From the statistical point of view, we looked only at the articles which contemplate ROA for valuation of cloud computing, no matter the method. The number of published articles from the examined period is shown in figure 3.1. We can see that the peak was in years 2012 and 2014.

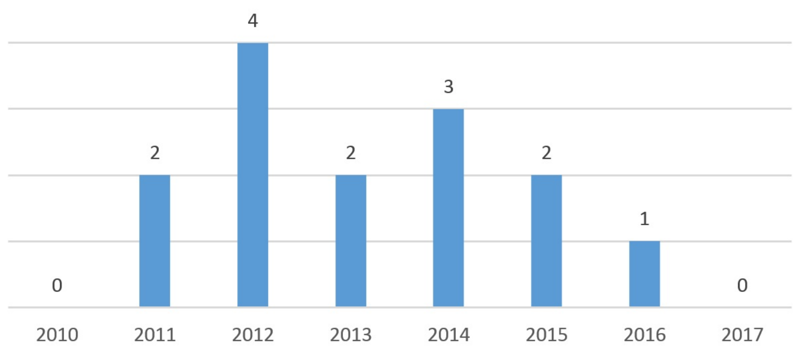

Figure 3.1: Number of relevant articles based on year of publishing

Demographic data, depicted in figure 3.2, are not that balanced. It is primarily because some authors published several papers, so it is more the matter of individuals than countries. On the other hand, we only considered the first author and the institution beyond which the paper was published, with no relevance to the author’s nationality.

Examining the sources of these articles, all of them came from either SpringerLink or IEEE, the latter including all the papers eligible for our research. Nonetheless, some articles were referenced in different digital libraries as well.

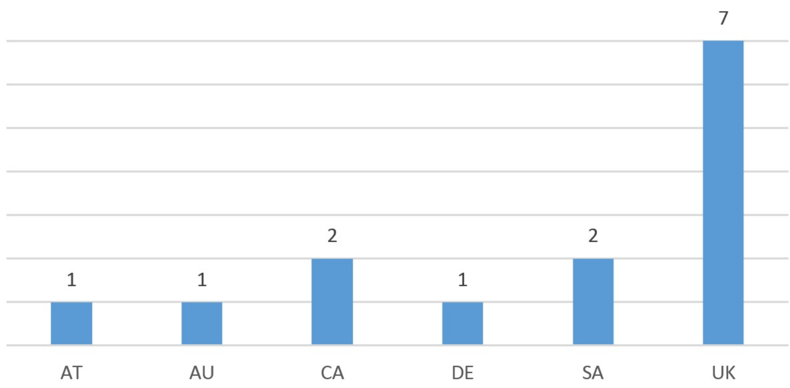

Figure 3.2: Number of relevant articles based on the country of publishing

3.3 Discussion

The performed review gave us insight into several approaches on how to valuate cloud using ROA. We became familiar with this issue from both customer's and provider's perspective. The majority of authors examine the secondly mentioned side and discuss the possibility of utilising the cloud resources provisioning through economies of scale. Important for us is the second group of articles, focused primarily on the customer's point of view. In these papers, authors use real options to valuate the added value which flexibility of cloud has on decisions regarding IT infrastructure investments. Cloud characteristics open many ways for options to valuate opportunities to grow, defer, switch or abandon an IT infrastructure, as stated in section 3.2. Before we conclude this review, let us look at the answers to questions set in the beginning.

1. Are there any attempts to valuate IT investments using Real Options Analysis?

   Yes, Real Options Analysis is mainly used in informatics and energetics. When performing the first pilot, we searched more than 100 eligible records.

2. If so, are there any attempts to valuate cloud computing investments with ROA?

   Yes, this issue is examined from both customer's and provider's perspective. We found 14 articles which consider this type of connection.

3. If so, what methodology and type of options are usually used for this purpose?

   When valuating investment into cloud or standard IT, authors use variations of ROA-adjusted NPV, described in detail in section 3.2. Not surprisingly, the option used for this matter is an option to switch and option to grow. In two papers, there is also contemplated an option to defer and option to abandon an investment.

4. Is there any methodology which uses the binomial model of real option and allows information to be passed from previous nodes to next ones? In other words, it allows determining the sequence of nodes which lead to the current one and the attached parameter (e.g. the amount of hardware purchased on the way).

   Up to our best knowledge, there is no methodology which would use an option with such capability.

The results of the review show us that our idea is relatively new because there are only a few researchers who discuss this kind of valuation. However, the existence of these articles also proves the idea and gives us a valuable inspiration for future work.

Summary of the chapter

In this chapter, we performed a systematic literature review of available articles on the usage of Real Options Theory on the valuation of IT investments, cloud computing in particular. Information learned from this review will serve as a cornerstone for the next chapter, where we will create the methodology comparing cloud and on-premises ourselves.

Chapter **4**

Methodology for valuation of cloud vs. on-premises

In the previous chapter, we performed a systematic literature review of existing papers describing the application of Real Options Analysis on cloud computing investment valuation. Special focus was on cloud vs. on-premises valuation. This chapter introduces a methodology for undertaking a qualified decision in this matter.

4.1 Methodology description

The comparison of the standard on-premises infrastructure and cloud will be made by subtracting the cost of cloud from the cost on-premises infrastructure. This subtraction will be managed in accordance with the ROA principles where the calculation will be performed in a binomial tree. As a result, we will be able to quantify the cost which the flexibility of cloud saved. Before we start with the description of the methodology itself, let us look at the necessary assumptions:

- The project is scheduled and valid for the period T, divided into n periods in which we can make an investment decision.
- The future cash flow (revenue generated by users) equals to the value S and is the same for both cloud computing and standard on-premises infrastructure.
- The expected value S constitutes a business requirement for which an appropriate IT investment is inevitable. The value of this investment for the cloud is C_i and for on-premises A_i.
- The volatility of the customer segment using the application is equal to the value σ.

- The risk-free rate of interest equals to the value r.

Having these assumptions, we can continue with the enumeration of all the steps. While describing the methodology, no specific calculations will be made since that is the objective of the next chapter 5. The methodology process consist of these steps:

1. Comparison of expected costs
2. Creation of revenue tree
3. Creation of intrinsic tree and transition table
4. Calculation of the final value

4.1.1 Step 1: Comparison of expected costs

In the first step, we calculate the expected cost of both cloud and on-premises infrastructure if we consider no change in demand during the whole period T. For given number of users and lifetime of purchased hardware, we get the cost of on-premises architecture. Similarly, for the cloud, we calculate its cost by changing the price of hardware for appropriate cost of lease. This is obviously quite simplified analysis, but a more or less complex analysis is something which every IT manager has to undertake at some point.[37][38] However, straightforward comparison of these two numbers might not lead to the best conclusion.

If the cost of cloud is higher than the cost of on-premises, it might be because the performed calculation did not consider the flexibility which cloud provides. Using our methodology, we can valuate this benefit and return the total savings cloud poses compared to on-premises. That enables us to make a more qualified decision.

On the other hand, if the cost of traditional infrastructure is higher than the cost of the cloud, we might be curious how big the difference truly is. Some managers may be sceptical towards cloud computing (e.g. because of security reasons), and an insignificant difference in cost might not change their opinion. Again, valuation of the flexibility could end up in a more significant difference in cost, and thus, change their mind.

As we can see, the first step of our methodology is not entirely a part of the calculation itself, but it is a calculation of Total Cost of Ownership which IT managers make when analysing both options. The result serves as a starting point with which we can later compare the flexibility savings of cloud (if there are any) and see the difference of these two methods.

4.1.2 Step 2: Creation of revenue tree

The second step is a traditional part of Real Options Analysis. Similarly to figure 1.4, we will create a revenue tree which represents the possible change in customer's demand over time. As stated in one of the assumptions, this revenue is the same for both considered options. To construct the tree we need to start with the current (or expected) revenue generated by our customers at the moment. This value will be obtained from the following equation 4.1.

$$S\ (revenue\ generated) = number\ of\ users \cdot revenue\ per\ user \tag{4.1}$$

Having the initial value S, the next step is to calculate the up and down factors u and d which symbolise the change of demand in time. We can get these factors from equations 1.3 and 1.4 but to do that we have to set the level of volatility. As we stated before, we will use the volatility based on the industrial market segmentation. Scholleová in her book *Investiční controlling*[39] contends that software falls within the highly volatile group of the Internet (e-commerce) and hi-tech products. The level of volatility for software is up to 1,09 while generally more than 0,6 is considered high. In the next chapter, we will use σ between 0,4 to 0,9 based on the number of competitors since that is a factor which influences the volatility significantly.

Once we have all the values needed we can create the revenue tree as depicted in figure 4.1. The picture comes as no surprise. The only addition is the description of levels of the tree which will come to use in the next step. The demand of customers is the same for every node of the same level. Towards this demand, appropriate IT investment, either in cloud or on-premises, will be realised.

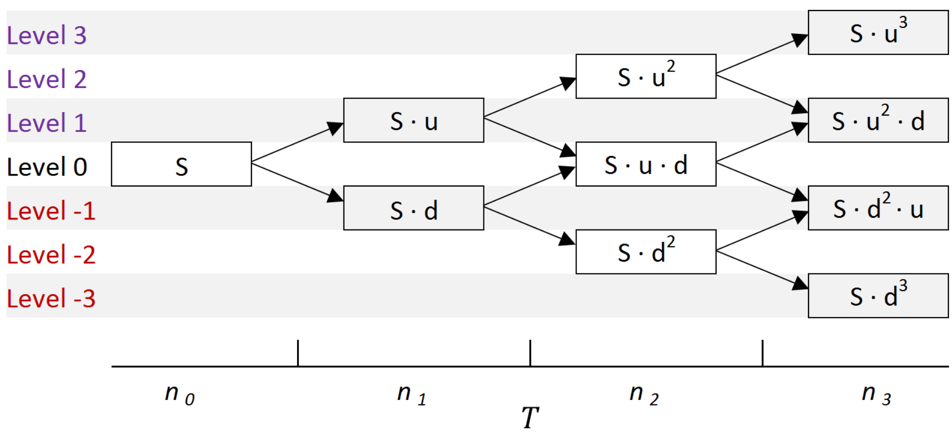

Figure 4.1: Revenue tree with corresponding levels of customers' demand (business requirements)

4.1.3 Step 3: Creation of intrinsic tree and transition table

The principle of the intrinsic tree is to compare the cost of cloud with the cost of on-premises at each node of the tree. By subtracting the cost of cloud from the cost of on-premises we get the value of expenses saved by cloud at any time during the lifetime of the investment. To follow the ROA paradigm, we will use the MAX function to compare the difference in price with a zero value, so if the cloud is more expensive, we will count with 0 instead. Let us look at how the cost can be generated in our methodology.

4.1.3.1 Cost generation options

As said before, each level of the tree symbolises a change in customers' demand and a change of associated system requirements. For given IT solution, a variable will be assigned which will represent the monthly annuity payments necessary to cope with the demand change. The definition of the variable differs based on the infrastructure option chosen.

Investing in traditional infrastructure

In the case of on-premises, we will use variables A_i where i corresponds with the level of demand. Starting with A_0 as the annuity payment we would have to pay for the investment today, in the event of increased demand the additional investment would be counted to the sum of all purchased hardware. That means after the first period in level 1 the annuity payment would be $A_0 + A_1$. In the event of decreased demand, no additional investment is necessary since we have more capacity than we need. The continuously compounding formula for the annuity payment is in equation 4.3, where INV stands for investment cost, L for service life in years, Δt for lenght of one period in years, and annual rate of return r is adjusted based on formula 4.2. Due to this adjustment, the rate r_{cc} when continuously compounded gives us the original effective rate r.[40]

$$r_{cc} = ln(1 + r) \tag{4.2}$$

$$Annuity\ payment = INV \cdot \frac{e^{r_{cc}\Delta t} - 1}{1 - e^{-r_{cc}L}} \tag{4.3}$$

The evolution of annuity payments is depicted in figure 4.2. Paths through the tree follow binomial coefficients of Pascal's triangle, so the number of brackets in each node is equal to the number of possible combinations of reaching the node. As we can see, the payments in parentheses of a node differ based on from which node we reached it. If we came to the node from the upper level, then we have more computational capacity than we need and pay for the unused resources. If we came from the lower level, then we might need to buy an additional server to deal with the increased demand. There

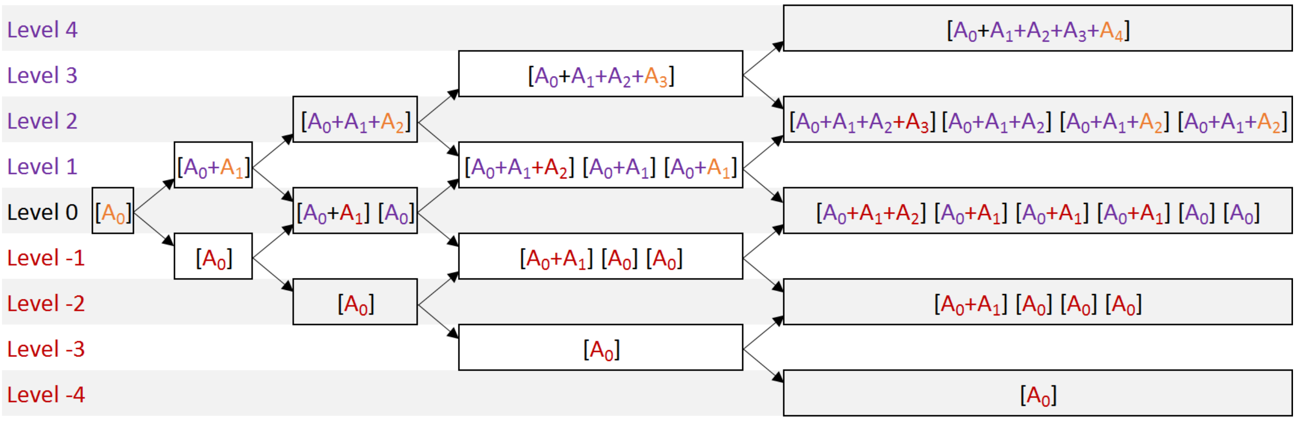

Figure 4.2: Tree mapping the evolution of annuity payments for purchased hardware

are more scenarios which might occur, described in section 4.1.3.2, but even from this simple example it is clear that the intrinsic value of the tree is not dependent solely on the level (demand) but on the sequence of nodes it went through as well. In this sense, we talk about a path-dependent option with strong memory.[41] Examples of this option include lookback options or Asian options used for unstable underlying assets. Payoffs of these options are not derived only from the final value of the underlying asset but also from the development of the price during the life of the option. There are numerous methods of how to calculate the price of path dependent option. One of the examples is the usage of reflection principle and combinatorics to estimate the probability of the option touching a barrier price.[42] Nevertheless, what all of them have in common is the use of some sort of estimation or average which is inconvenient for our purpose.

In response to the path dependency, we established a colour coding system to keep track of the particular routes through the tree. The meaning of these colours is following:

- Red is the purchased hardware which capacity is not used at the moment. The payment would not be necessary at this point if we had a cloud. There has been a decrease in demand.

- Purple marks the purchased hardware which is in use at the moment, with no need to buy more resources. At this point, we pay an adequate amount.

- Brown indicates the hardware we need to buy to keep up with the increased demand. Moreover, there is an issue with payments of this investment exceeding the termination date of the project.

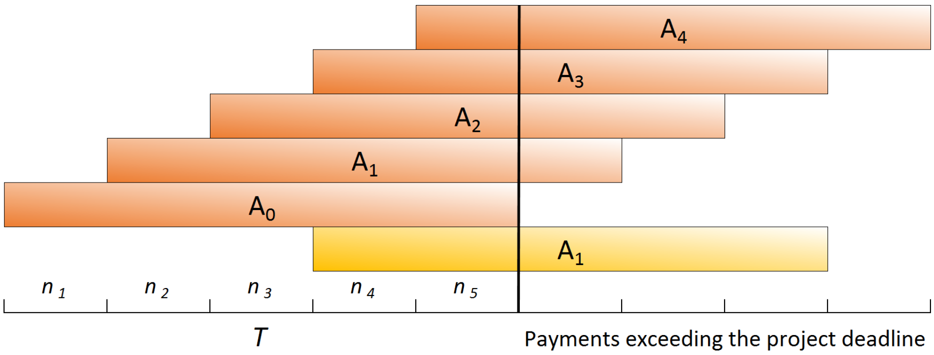

Figure 4.3: Annuity payments for purchased hardware paid during the project and after the deadline

In the last bullet point, we mentioned investments whose service life is longer than time left until the end of the project. This situation occurs whenever we reach a non-negative level for the first time, and we have to buy additional hardware. Since we consider a three-year service life we must take into account the payments which will be left to pay once the project is over. Picture 4.3 shows an example where payments of investment A_0 are fully spread during the lifetime of project T, with no need for any adjustments. However, this issue arises with the remaining payments of other investments. Since we do not consider reselling of idle hardware during the project nor at the end, depending on the project's success, two situations may occur.

If the project ends after the period T, remaining payments will constitute a loss. This loss can be calculated as a sum of these payments discounted to the end of the project T. Payments will be derived from the end nodes and weighted by the probability of reaching a node. For the purpose of discounting, we will apply the continuous compounding formula 4.4, where ΔT is the exceeding time in years and risk-free interest rate r is again adjusted by formula 4.2.[43]

$$Present\ value = Annuity\ payment \cdot \left(\frac{1 - e^{-r_{cc}\Delta T}}{r_{cc}}\right) \tag{4.4}$$

If the project continues after the period T, we can create another tree starting from the terminal node of the reached level. In that tree, we would have to take into account finishing service life of hardware purchased in the first tree and buy a substitute to keep demanded capacity. This, however, requires a deeper analysis, and it is not a part of this thesis.

Lease of cloud computing service

In the case of cloud computing, we will use variables C_i where i again corresponds with the level of demand. The value of C_i is simply the amount we have

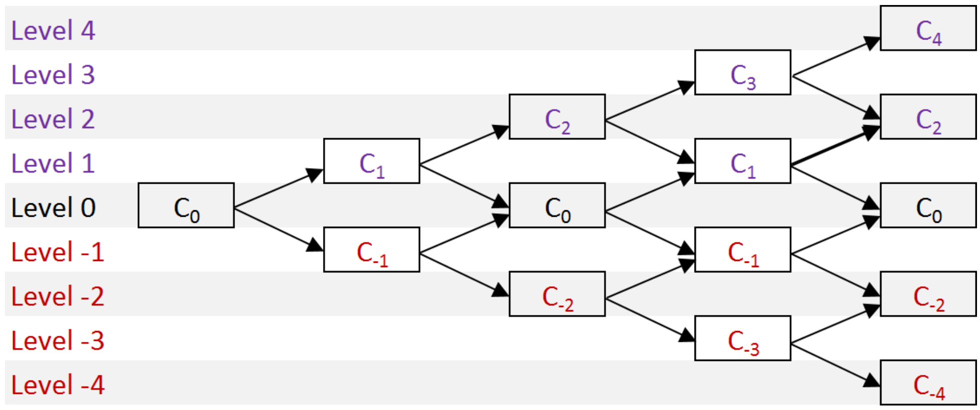

Figure 4.4: Tree displaying the cost/lease of cloud for given level

to pay for provision of the cloud infrastructure for one month in level i. Unlike the traditional infrastructure where the investments and thus payments A_i add up, with cloud we always pay only for what we use. The cost tree is then quite straightforward to create since the value of every node equals to C_i. Such tree is shown in figure 4.4.

4.1.3.2 Final cost tree

The cost tree depicted in figure 4.5 is a combination of both trees presented so far. As mentioned before, the probability of reaching a node follows Pascal's triangle pattern, so the number of paths leading to a node is equal to its binomial coefficient. We will use variable p for the probability of an increase in demand and variable e for the probability of a decrease in demand, obtained from formulas 1.7 and 1.8 respectively. This probability will weight the payments based on the node of occurrence. Although the weight is the same for all expressions[4] (variables bounded by a square bracket) of a node, we write the sequence of probabilities to keep track of the possible paths and thus corresponding hardware changes. For that purpose, we again introduce a colour coding system.

- Purple marks the sequence of probabilities and the difference in cost of both solutions in case of moving up. Purchased hardware is brought from the previous lower node.

- Red stands for the sequence of probabilities and the difference in cost of both solutions in case of moving down. Purchased hardware is brought from the previous upper node.

[4] From now on, we will use the word "expression" to reference the variables and operators in a node which are bounded by a square bracket.

- Brown indicates the hardware we need to buy to keep up with the increased demand. As discussed before, payments of this investment may exceed the termination date of the project.

Even with the colour coding system, the schema might look a bit complicated, and even more so with rising number of time periods. There are however just a few situations which may occur.

Without any additional hardware

Expressions with no additional hardware exist only in the bottom part of the tree, from level 0 down. This situation happens only when demand starts to go down from the beginning and never reaches a positive level. In accordance with the philosophy of the tree, we subtract the lease of cloud from the annuity payment of the initial investment. That way get the money cloud saves us. **Expressions:** $[A_0 - C_i]$ for $i \leq 0$

Purchasing of additional hardware

On the contrary, expressions, where we purchase additional hardware, occur only in the positive levels of the tree. Whenever we go to a positive level for the first time, we buy hardware to meet the higher requirements. We add the payment of newly purchased hardware to the sum of payments incurred by previously bought hardware. From this sum, we subtract the cost of cloud, so we again get the net savings of cloud. **Expressions:** $[(A_0 + \ldots + A_i)–C_i]$ for $i > 0$

With already purchased additional hardware

The most frequent are expressions where we have some additional hardware already, but there is no need to buy another one. This situation can happen in the whole tree except for the outer nodes which are extreme cases of permanent increase or decrease in demand. The value of nodes is calculated the same way as in the previous two groups. **Expressions:** $[(A_0 + \ldots + A_i)–C_i]$ for any i

The nodes from the last group most evidently depict the primary feature of this option. The fact, that we stack hardware payments on the way in contrast with the lease of the cloud where we always pay the adequate amount. Whenever we go down in the tree, we are left with unused hardware for which we have to pay. The same can happen if the demand rises, but we still possess hardware capacity from a higher level than the current one. So the only time we use all our capacity is when we buy new hardware or move up to a level for which we already have the appropriate on-premises infrastructure. This tree thus monetizes the advantage of cloud's flexibility.

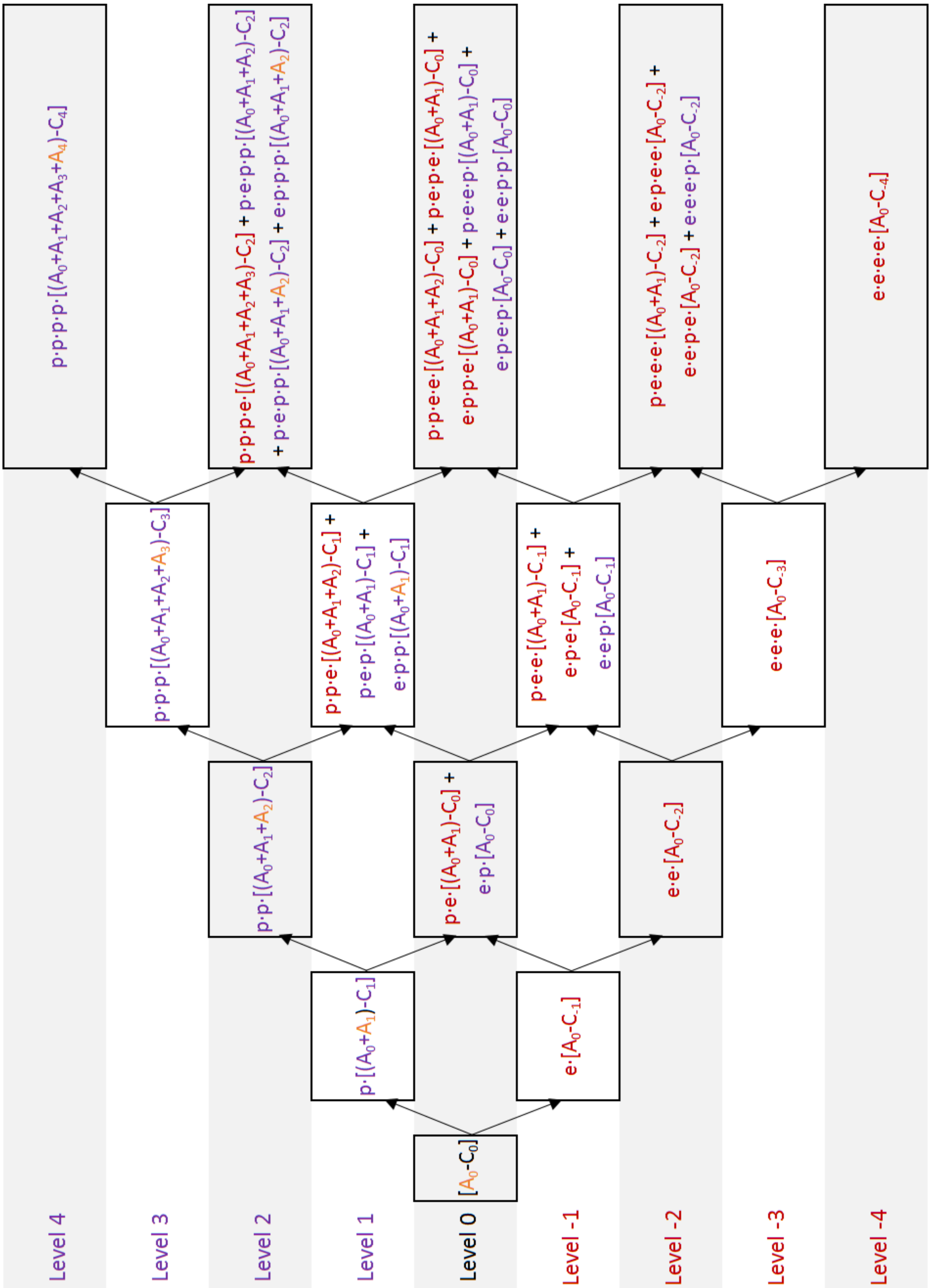

Figure 4.5: Tree consisting of the amount of money saved by the cloud

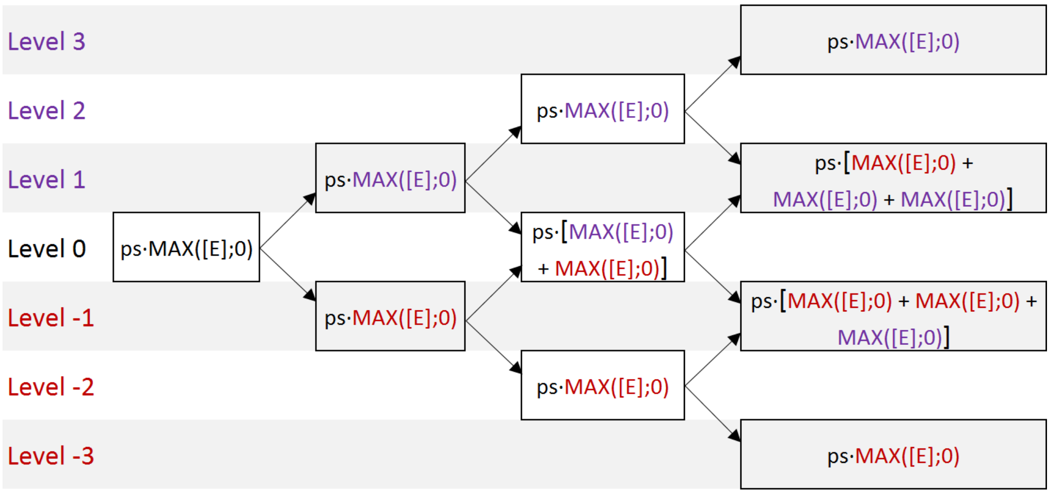

Figure 4.6: Tree holding the intrinsic value of the option

To complete the cost tree, we must not forget that the value of any expression may be negative at this point, signalising that the cloud is more expensive than standard infrastructure. Since we calculate the option from a cloud perspective, we would not choose the cloud option at that point. In accordance with the Real Options Analysis, we will use MAX function to round up these values to zero. In order to save some space, we will use symbol E as a substitute for any expression and symbol ps as a substitute for any sequence of probabilities as shown in equation 4.5. The final cost tree is then displayed in figure 4.6.

$$probability\ sequence \cdot MAX([any\ expression]; 0) = ps \cdot MAX([E]; 0) \quad (4.5)$$

Each node of the tree holds the amount of money saved by cloud compared to on-premises infrastructure. That means the tree constitutes the intrinsic value of our "cloud saving option". In the next step, we will add the time value and thus calculate the final value of the option. To do so, we need to determine the costs A_i and C_i first. For this purpose we will create the transition table.

4.1.3.3 Transition table

The transition table relates to the transition between expected revenues and appropriate infrastructure investment. In other words, it is a connection between the revenue tree and the cost tree. We need to configure the reaction to a change of the number of users for both cloud and on-premises infrastructure. In the case of cloud and its pay-per-use model, the situation

Level i	**Revenue S [MU]**	**Annuity A_i [MU/per.]**	**Lease C_i [MU/per.]**
3	183 348	996	11 200
2	149 802	0	10 800
1	122 394	996	10 400
0	100 000	10 083	10 000
-1	81 704	0	9 600
-2	66 755	0	9 200
-3	54 541	0	8 800

Table 4.1: Transition table with payments per period for A_i and C_i in monetary units (MU)

is quite simple, and we just follow available offers of vendors. In the case of on-premises, however, we can choose how powerful computational capacity do we want to buy and if we even need to buy some. For example, we can overestimate the investment A_1 and then have no need to buy A_2 even if the demand increases. In that case, we would just use 0 for the payment of A_2, as shown in table 4.1. We can alter the table however we like and analyse the outcome values to get the best results. Set values will then be used to compute the intrinsic value of the option.

4.1.4 Step 4: Calculation of the final value

The last step is identical to its equivalent in the binomial pricing model. We add the time value of the option using the probability of an increase in demand and decrease in demand which are based on equations 1.7 and 1.8, respectively. Starting from the second to last nodes, we use the formula 4.6 to perform a backward induction towards the root node. Since we are using American option, we have to compare the weighted sum of possible future values with the current intrinsic value at each node of the tree. The process of calculating the option value (OP) from the intrinsic values (IV) is depicted in figure 4.7.

$$node\ value = MAX\Big[\frac{p \cdot node\ value_{up} + (1-p) \cdot node\ value_{down}}{1+r}; ps \cdot \sum MAX([E];0)\Big] \tag{4.6}$$

At this point, we calculated the value of our “cloud saving option”, and that means we are at the end of the methodology itself. All is left to do is to analyse and interpret the result. The value of the root node says how much

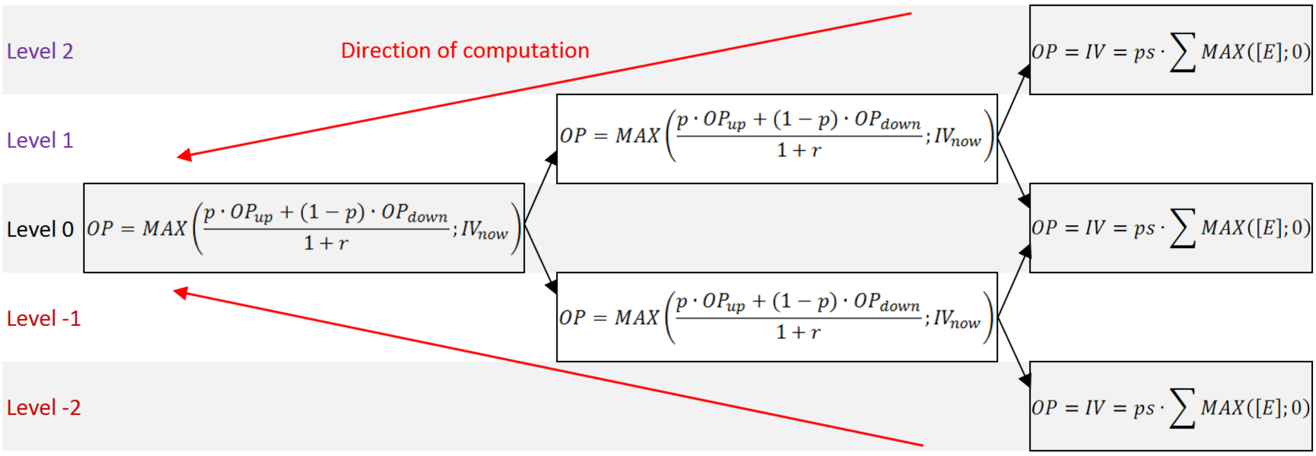

Figure 4.7: Backward induction process when calculating the option value

is this option worth to us right now. In our case, it is the amount of money we can save by choosing the cloud service over on-premises infrastructure. If the value is zero, cloud costs either the same or more and in that case, we should consider investing in our own infrastructure. On the other hand, a positive option value suggests that cloud computing is cheaper, hence it is a recommended solution. A deeper analysis will be performed during a practical application in the next chapter. We will use different inputs and analyse their impact on the result. Before we proceed to that chapter, however, let us look at the algorithmization of our methodology.

4.2 Algorithmization of the methodology

Although most of the methodology follows standard binomial pricing model which has been algorithmized many times, the most interesting part, generation of the intrinsic tree, is unique in this matter. The tree gets quite complicated with the increasing number of periods, primarily because of its path dependency. For that reason, in this section, we will focus on algorithmization of this tree.

To validate the accuracy of presented algorithm, we created a program which goes through the whole methodology and calculates the value of our option. The outcomes of all steps were compared with results from manual computations, so the correctness is guaranteed. (In detail in section 5.1.) The application was programmed in C++ language using GCC compiler 5.4.0, Microsoft Visual Studio Community 2017 IDE, Windows 8.1 platform. The program will also serve in chapter 5 when performing use case computations.

4.2.1 Data structure

To understand the code better let us briefly look at the data structure depicted in figure 4.8. Its base is a two-dimensional array of `Node` objects (highlighted in blue) which are indexed by `column` and `row`. Columns start at index 0 and end at the index equal to the number of periods n. Rows (indexes located under nodes) also start at index 0 but end at the index equal to the index of a column. The level of each node then can be obtained from formula 4.7.

$$node\ level = 2 \cdot row - column \tag{4.7}$$

$$number\ of\ expressions = \binom{column}{row} \tag{4.8}$$

Each node includes a certain number of `expressions` (highlighted in red). Its number follows binomial coefficients so in our case we can derive it from formula 4.8. The value in each cell of `expressions` array indicates the number of hardware pieces the expression consists of.

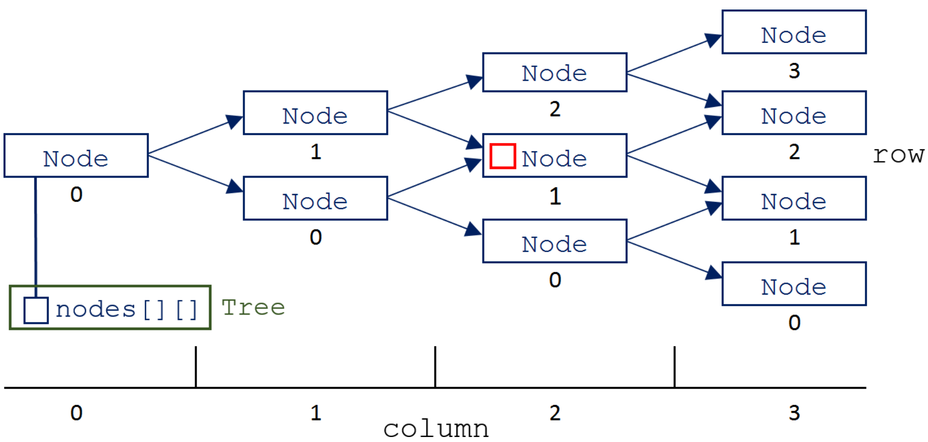

Figure 4.8: Structure of the tree with nodes' indexes

In given example in figure 4.9, the node (marked by red square in figure 4.8) has the first expression (`expressions[0]`) consisting of hardware A_0, and the second expression (`expressions[1]`) of hardware A_0 and A_1.

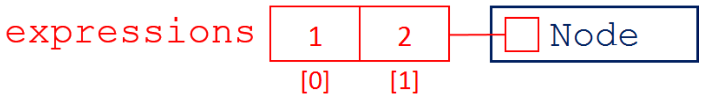

Figure 4.9: Detail of a node structure

Finally, there are three arrays held in a `Tree` object (highlighted in green) - `hwPay`, `cloudPay` and `hwSums`. The first two mentioned represent annuity/lease payments from a transition table. The third one includes sums of hardware payments up to the index of the array. For example `hwSums[0]` contains value A_0, `hwSums[1]` value $A_0 + A_1$, etc. Considering that, following equations are valid:

$$hwPay[i] = annuity\ A_i$$

$$hwSums[i] = \sum_{j=0}^{i} hwPay[j]$$

Then for any expression i:

$$expression[i] = number\ of\ \text{“}hardwares\text{”}\ in\ expression$$

$$total\ annuity\ of\ expression = hwSums\big[expressions[i] - 1\big]$$

4.2.2 Algorithm for computing the intrinsic value

Having all the necessary information, we can proceed to the algorithm itself. Listing 4.1 shows the computation of the intrinsic value of the option. The two for cycles iterate all nodes upon which appropriate methods are executed. The iteration starts at the root node and continues with the next columns, going through the nodes from bottom up. In the root node, we need to set up the initial hardware to enable following nodes to copy it. The three following if statements in the code represent positions in which a node may appear.

```
void Tree::createIntrinsicTree() {
  for (int column = 0; column < columns; column++) {
    for (int row = 0; row <= column; row++) {
      /*Root node - purchase hardware A0 so other nodes can copy*/
      if (row == 0 && column == 0)
        nodes[column][row].purchaseHW(hwPay, T, n, r, serviceLife);
      /*First node of a column - copy from the upper node only*/
      else if (row == 0)
        nodes[column][row].copyHardware(nodes[column-1][row]);
      /*Last node of a column - copy from the lower node only*/
      else if (row == column)
        nodes[column][row].copyHardware(nodes[column-1][row-1]);
      /*Middle node - copy from both upper nad lower node*/
      else {
        nodes[column][row].copyHardware(nodes[column-1][row]);
        nodes[column][row].copyHardware(nodes[column-1][row-1]);
      }
      /*Check for purchase and calculate node's intrinsic value*/
      nodes[column][row].purchaseHW(hwPay, T, n, r, serviceLife);
      nodes[column][row].calculateIntValue(hwSums, cloudPay, n);
} } }
```

Listing 4.1: Algorithm for computing the intrinsic value of the option

In the outer nodes, we copy already bought hardware only from one previous node depending on the side of the tree. In the case of middle nodes, we obtain hardware from both previous nodes. Afterwards, we check all nodes whether or not is it necessary to purchase another piece of hardware.[5] Last, we compute the intrinsic value of each node.

As we can see, except for the root node the algorithm is following. First, pass on any existing hardware, then check for a necessary upgrade and last compute the intrinsic value. Now let us look at the implementation of methods called in the algorithm. All three are procedures of a `Node` object, on the contrary to `createIntrinsicTree` method of the `Tree` object. That means we will work with variables on a node level.

Method responsible for hardware acquisition is displayed in listing 4.2. It goes through all expressions of a node and for each compares its size (number of bought pieces of hardware) with node's level. If the level is lower, we have sufficient capacity and no purchase is needed. Otherwise, we have just entered a non-negative level for the first time, and we increment the number in expression. We can observe that two calls of this function in root node result in the first one adding new expression with hardware A_0 and the second one stopping at both if statements since `expressions.size()` and `expressions[i]` are equal to 1 at that point.

```
void Node::purchaseHW(double*hwPay,double T,int n,double r,double serviceLife){
  double delta_T = max(serviceLife - ((n - column) * T/n), 0);
  /* Root node */
  if (expressions.size() == 0) {
    expressions.push_back(1);
    nodeLoss += hwPay[0] * ((1 - exp((-1)*log(1+r)*delta_T)) / log(1+r));
  }
  for (int i = 0; i < expressions.size(); i++) {
    if (expressions[i] <= level) {
      expressions[i]++;
      nodeLoss += hwPay[level] * ((1 - exp((-1)*log(1+r)*delta_T)) / log(1+r));
    }
}
```

Listing 4.2: Method checking the need of hardware acquisition

When adding new hardware, we also calculate its potential loss according to formula 4.4. The number of exceeding years ΔT is derived from set `serviceLife` reduced by the time spent in the tree which is based on the `column` of purchase. The result is then added to the value of node's loss.

The second mentioned method copies acquired architecture from a source node to the current one. Reference (&) to the source node is passed as the input parameter. Code of this method is available in listing 4.3. The loop

[5] This call is redundant for the root node, but in the run, it is executed only once. The reason of this solution is clearer code.

again iterates every expression of the source node and creates identical one in the current node. (Method `push_back` adds a new item/number to the end of the array `expressions`.) Besides that, we also take over predecessor's potential loss.

```
void Node::copyHardware(Node & source) {
  nodeLoss += source.nodeLoss;

  for (int i = 0; i < source.expressions.size(); i++)
    expressions.push_back(source.expressions[i]);
}
```

Listing 4.3: Method to copy hardware from source node to current one

The last method called in the algorithm is calculateIntValue, shown in listing 4.4. Its job is to compute the intrinsic value of the node. Similarly with the previous procedure, it runs through all expressions, but this time, for each obtains its sum of annuity payments as we showed before. This sum is then reduced by the cost of the cloud for the particular level and then compared to zero in a max statement. The result of the max function is then added to the intrinsic value of the node. Finally, intrinsic value is weighted by node's probability.

The rest of the program is the same as normal binomial pricing method, so there's no point in analysing it here. The only exception is the calculation of potential loss due to exceeding payments which we are going to discuss now.

```
void Node::calculateIntValue(double * hwSums, double * cloudPay, int n) {

  for (int i = 0; i < expressions.size(); i++)
    intrinsicValue += max((hwSums[expressions[i]-1]-cloudPay[n+level]),0);

  intrinsicValue *= probability;
}
```

Listing 4.4: Method for calculation of node's intrinsic value

4.2.3 Algorithm for calculation of the potential loss

In section 4.1.3.1 we discussed the problem of payments scheduled after the project deadline. We also mentioned two ways of handling it. Although it is not the key objective of this work, we decided to simulate the case where the project ends at time T, and we calculate incurred loss. The result will be used as another factor influencing the architectural decision. Due to scale and complexity of the second scenario, we do not consider continuing the project in this thesis.

As we could see, the loss is continuously calculated during the creation of the intrinsic tree and passed from the root node up to terminal nodes. To get the total potential loss, we just make a weighted sum of end node's values. Such method is in listing 4.5. In the end, we are left the total loss discounted to the project termination date.

```
void Tree::calculateCorrectionLoss() {

  for (int row = 0; row < rows; row++)
    correctionLoss += nodes[columns-1][row].getCorrectionLoss()
                      * nodes[columns-1][row].getProbability();
}
```

Listing 4.5: Method calculating the sum of exceeding payments

Before we conclude this chapter allow the author an important note. Presented code samples were slightly modified for better readability. The real implementation is more optimised, although there is still room for improvement. The bottom line is the application meets the requirements of this thesis completely.

Summary of the chapter

In this chapter, we introduced a methodology for valuation of benefits which cloud possess compared with traditional on-premises infrastructure. We started with a description of individual steps and followed with the question of algorithmization. In the next and last chapter, we will apply this methodology to use cases and analyse the result.

Chapter **5**

Practical application of the methodology

This chapter applies methodology described in the previous chapter to several use cases. Its structure is based on equivalent chapter included in simultaneously written diploma thesis on similar topic.[44] When performing the testing, we stumbled on a difficulty with mapping revenue S (customers' demand) in a particular level to associated architecture cost. Since the definition of the transition table is project specific, we leave this assignment to the reader. In other words, we will calculate the value of the option (steps 3 and 4) with no relation to the revenue tree (step 2). Moreover, set values will be in monetary units and convenient scale. All this will allow us to discuss the results regardless of the concrete project.

At the beginning of this chapter, we will verify the correctness of programmed application on two small examples. Afterwards, we will proceed to various scenarios of hardware acquisition. In the end, we will discuss the usability of the methodology.

The application takes input values from an excel file and generates the output into the same file. The information is read from *Input* sheet which is static. The output is printed dynamically into three sheets – *Revenue tree*, *Intrinsic tree* and *Option tree*. Excel (input/output) files for all performed tests and scenarios are available in folder *excel_files* of attached CD under specified name. All use cases can be re-run or modified with the use of the program *cloudOption* located in folder *application*.

5.1 Verification of the program

We executed two tests to check the output of the application. The purpose of these tests is not to analyse any specific scenario, so there is no need to examine the input values in detail. Computed results of both were compared

test_six_periods		
T	σ	r
2	0,7	0,05
Level	**Annuity A_i**	**Lease C_i**
6	100	220
5	250	215
4	300	210
3	220	205
2	150	200
1	50	195
0	300	190
-1	0	185
-2	0	180
-3	0	175
-4	0	170
-5	0	165
-6	0	160

Table 5.1: Input values of the first test case with six periods

to manual calculation in Microsoft Excel. These files can be found in folder *excel_files\tests*.

The first test checks the option tree generated for six periods. Input data are available in table 5.1. Generated option tree is shown in figure 5.1. As we can see in attached file, the output is correct for every tree.

The second test verifies not only the option tree itself but also the calcula-

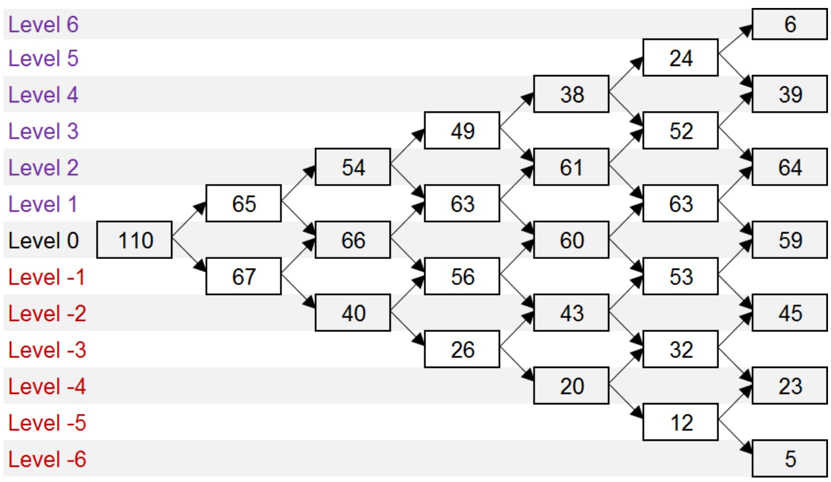

Figure 5.1: Option tree from the first test case with six periods

		test_three_periods	
$\boldsymbol{T}$	2	**Service life**	3
$\boldsymbol{\sigma}$	0,5	$\boldsymbol{r}$	0,04
Level	**Annuity** $\boldsymbol{A_i}$		**Lease** $\boldsymbol{C_i}$
3	0		1500
2	1800		1000
1	0		660
0	640		400
-1	0		300
-2	0		250
-3	0		225

Table 5.2: Input values of the second test case with three periods

tion of potential loss. Due to the complexity of manual calculation, the option is scheduled only for three periods. In this example, we consider three-year service life and only two-year lasting project. That means even investment A_0 brings potential loss and therefore we expect its high value. All input values are in table 5.2, option tree in figure 5.2. As with the previous example, each tree is generated correctly. The value of potential loss also fits and is calculated to 1 373 MU.

The result of both tests is identical with the manual calculation performed in Microsoft Excel. Moreover, other tests (all up to six periods) have been executed throughout the development with the same result. Although six (three for calculation of the loss) periods seem small compared with 24 which we will use in the next section, they are big enough to test all possible situations which might occur in the tree. With that in mind, we can conclude the application works correctly.

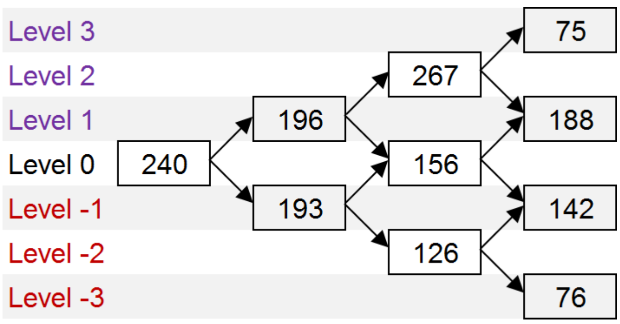

Figure 5.2: Option tree from the second test case with three periods

5.2 Scenarios performance

In this section, we cover various scenarios of infrastructure decision-making represented by different input values. Scenarios are by default scheduled for 2 years divided into 24 periods thus we work with monthly payments. Consequently, in this text, we present only general input parameters and final option value. The potential loss (computed for two-year service life) is presented as well as one of the factors influencing the decision. However, its purpose is merely informative. Annuity/lease payments together with all generated trees are due to space reason located only in folder *excel_files\scenarios* of attached CD. Summary of all scenarios can be found in file *overview* of the same folder.

All experiments are performed from a position of an ICT startup which has been on the market for some time (two years for example). Over this period it successfully developed and acquired a certain number of customers. To address their need, it used cloud service for its economic convenience and flexibility. Since the idea of the startup proved itself, the owners are now considering the future of IT infrastructure. At this point, they might do the TCO analysis and decide whether to continue with cloud or change to on-premises. However, this method would not incorporate the possible change in demand which is probable in this industry. That is why this situation is perfect for usage of our methodology.

Input values such as volatility, risk-free interest rate and service life are based on real values. The only exception are monthly payments which are set in general. This makes no difference from the testing perspective because even these values allow us to valuate the flexibility of the cloud, regardless of the specific project. What matters is the relation between the lease of cloud and annuity of on-premises which we will test in a separate set of scenarios.

5.2.1 Various volatility

The first set of scenarios tests the influence of volatility on the option value. The level of volatility relates primarily to the market stability. Low volatility implies stable market. On the other hand, high volatility is present in changeable and risky markets which bring the opportunity of high profit. Although we mentioned that Internet and ICT, in general, belongs to the highly volatile industry, we will test the methodology for various levels of volatility independently on the market. Set levels for each test are in table 5.3 as well as other input values.

The risk-free interest rate is derived from the interest rate of government bonds.[45] Since the startup has accumulated customers and associated infrastructure cost over the period of its existence, the initial hardware investment has to catch up with current demand. Its value is estimated to 240 000 MU, and with the use of formula 4.3, we calculate the annuity to 10 083 MU. A reg-

1_various_volatility

Scenario	1	2	3	4	5	6
$\boldsymbol{T}$	2					
$\boldsymbol{n}$	24					
$\boldsymbol{r}$	0,008					
$\boldsymbol{\sigma}$	0,1	0,3	0,5	0,7	0,9	1,1
Annuity initial (A_0)	10 083					
Annuity regular	483					
Annuity large	903					
Lease initial (C_0)	10 000					
Change in lease	400					
Potential loss	1 375	1 109	942	802	682	578
Option value	**209**	**222**	**232**	**243**	**256**	**272**

Table 5.3: Input/output values of scenarios with various volatility

ular additional investment in the case of increased demand is estimated to 11 500 MU with the annuity of 483 MU. After every tenth enhancement of the on-premises infrastructure, we expect a special investment due to the reorganisation of hardware capacity. (Purchase of additional slots etc.) Its cost is estimated to 10 000 MU. Together with the regular investment, we are going to call it a large investment – 21 500 MU with the annuity of 903 MU. Lease of the cloud is set to 10 000 MU in the level zero. The difference between adjacent levels is estimated to 400 MU. The prices are set in a way, so the development of both options is similar.

5.2.1.1 Analysis of results

Since this is the first real test, let us look at the option tree and review the patterns of this methodology. They are common for all trees and visible even in figures 5.1 and 5.2. Due to the probability adjustment, the values of outer nodes are getting significantly smaller and in the end are close to zero values. The largest values are around zero level since the probability of getting there is the highest. As a consequence, the most expressions are calculated in central nodes and for example difference $A_0 - C_0$ is present there multiple times.

Although it might seem odd that the lowest path (decrease in demand from the start on) does not possess high values even though the cloud is way more convenient at that point way, the pattern makes sense. The methodology prioritises the more probable developments of demand. The highest values are located around level zero, and in our case, even a bit lower - those end nodes represent the paths where there is an increase in demand first, and then the demand goes down. In these nodes, the benefit of cloud is the highest due to the idle hardware.

The option tree is at first sight quite difficult to read. However, when reviewing it, we must take the tree as a whole. Therefore, the values in the tree should be looked at as subtotals of the final option value.

If we return to the volatility test, we see that with increasing volatility the option value rises as well. This is with analogy with option theory where higher volatility brings higher possible profit. In our case, it represents higher possible savings of the cloud. However, for us, this trend has a different reason. Since the relation between revenues and payments is not set, the volatility does not affect the computation through factors u and d but only through changed probabilities. Specifically, higher volatility implies a higher probability of decrease $(1 - p)$. As a result, values under level zero are multiplied by higher probability and therefore grow. This makes the option value higher with increased volatility.

The same reason also causes the potential loss to go down with increasing volatility. In accordance with section 4.1.3.1 and listing 4.5 the loss of end nodes is weighted by the nodes' probability. Since the highest loss is in the upper half of the tree where the probability of an increase in demand p is present more often than its opposite the potential loss is less likely to happen and therefore gets lower.

5.2.2 Various expiration date

The second set of scenarios tests the influence of length of the project on the option value. We perform five scenarios with different expiration date T, but we keep the same length of a period – one month. Volatility is set high as it should be for this industry.[19] Other parameters are kept the same as in the previous set of scenarios. Summary of all runs is in table 5.4.

5.2.2.1 Analysis of results

As we expected, option calculated for longer time period has a higher value. Long term options give cloud more time to demonstrate its flexibility, for example, in the case of decreased demand where we pay more unnecessary annuity payments of on-premises. With cloud service, we only pay for what we use.

The potential loss goes up dramatically with shortening project. That is because we keep the same service life of two years for all scenarios. (As it is in reality.) As a result, the initial investment A_0 has 21 exceeding payments in the first scenario, 18 in the second, 12 in the third, etc. If we had wanted to set the payback period equal to the project length, the potential loss would have decreased significantly (in scenarios 1-4) since there would be fewer payments exceeding the project. Moreover, the option value would have changed in the

2_various_expiration_date

Scenario	1	2	3	4	5
T	0,25	0,5	1	1,5	2
n	3	6	12	18	24
r	0,008				
σ	0,7				
Annuity initial (A_0)	10 083				
Annuity regular	483				
Annuity large	903				
Lease initial (C_0)	10 000				
Change in lease	400				
Potential loss	18 302	16 075	11 234	6 108	802
Option value	**206**	**221**	**233**	**239**	**243**

Table 5.4: Input/output values of scenarios with various expiration date

other direction. That is because the multiplied on-premises annuities would have put the cloud in favour significantly.

5.2.3 Regular overinvestment

Following series of tests examines scenarios where the owner deliberately overestimates the investment into hardware infrastructure. This investment is carried out at regular intervals during the lifetime of the option. This strategy is likely to happen in reality because it allows us to update the on-premises infrastructure only sometimes, not every time the demand increases to a level we have never reached before.

We have identified two approaches to this strategy. The first one (A) starts with standard initial investment. If the demand increases to level 1, we purchase the over dimensioned hardware, so we do not have to enhance our capacity again when reaching next level. The second approach (B) is similar. The only difference is that we over dimension even the initial investment. The rest of payments is the same.

Input data are the same as in the previous section. The length of the project is set to original two years. The difference is in annuities which are calculated based on the interval between two investments. This interval (number of periods) is in table 5.5 in the row labelled *Interval*. The first scenario is computed with an interval of one period which means we make an investment every period – just as we did in the previous section. In the second scenario, we invest every second period, in third every third and so on. The value of a regular investment is multiplied by the interval since it has to be that times larger to make up for the idle periods. The reorganisation cost does not change

3_regular_expiration_date

Scenario	1	2	3	4	5
T	2				
n	24				
r	0,008				
σ	0,7				
Annuity initial (A_0) A	10 083				
Annuity initial (A_0) B	10 083	11 050	11 533	12 016	12 499
Annuity regular	483	966	1 449	1 933	2 416
Annuity large	903	1 386	1 870	2 353	2 836
Lease initial (C_0)	10 000				
Change in lease	400				
Interval	1	2	3	4	5
Potential loss A	802	825	870	877	968
Potential loss B		614	554	456	441
Option value A	**243**	**297**	**436**	**580**	**725**
Option value B		**1 050**	**1 533**	**2 016**	**2 499**

Table 5.5: Input/output values of scenarios with regular overinvestment

and is added to a regular investment which would normally include the tenth upgrade. (For an interval of 2 it is the 5th and 10th regular investment.) This large investment is necessary twice in the 24 periods. The value of the initial investment does not change as well. Only in approach B is increased by the first regular annuity.

5.2.3.1 Analysis of results

Results show that both options A and B make the cloud more convenient with the increasing interval. The reason for this is the overestimated cost of investments which we make very early on although there is no need for such capacity at that point. Interval of one period (used in scenario 1) shows the best result for on-premises because its development is the most similar to the flexible lease of the cloud. The massive difference between option A and B is due to the overestimated investment A_0. In option B, its annuity is paid even in the lower half of the tree where no additional investment is necessary.

In the case of the loss development, the explanation is not that simple. For the approach B, the loss decreases with rising interval. This comes as no surprise because the overestimated annuity A_0 is always paid whole in the tree leaving no payments left after time T. The increase of this annuity by an interval makes the bottom rows (its number equal to the interval) of the tree have no potential loss. This phenomenon together with all loss development

4_various_payments

Scenario	1	2	3	4	5	6	7
$\boldsymbol{T}$	2						
$\boldsymbol{n}$	24						
$\boldsymbol{r}$	0,008						
$\boldsymbol{\sigma}$	0,7						
Annuity initial ($\boldsymbol{A_0}$)	15 041						
Annuity regular	338	387	435	483			
Annuity large	632	723	813	903			
Lease initial ($\boldsymbol{C_0}$)	15 000						
Change in lease	400				440	480	520
Potential loss	562	642	722	802			
Option value	**215**	**219**	**225**	**233**	**247**	**262**	**278**

Table 5.6: Input/output values of scenarios various payments

trees is available in specially generated file *loss_development* located in folder *3_regular_overinvestment*.

In the approach A the loss changes in the opposite direction. If we compare the loss development of interval one with other developments of approach A, we see the reason why. Although the upper nodes where we invest frequently are slightly smaller because we pay more payments in the tree, the loss of the bottom nodes is higher. That is due to the increased investment A_1 which propagates itself to the bottom part of the tree and makes a more significant impact on the loss of end nodes. In the end, the potential loss of approach A slowly increases with rising interval.

5.2.4 Various payments

In the last group of scenarios, we separately change the payments of on-premises and cloud and check the influence of this relation on the option value. In total, we perform seven scenarios. The middle one (4th) uses almost the same values as we do when testing 24 periods, and we take it as a base. The only change are the initial investments which are increased for both alternatives to a value around 15 000 MU.

From the fourth scenario to the left we lower the on-premises investments every time by 10 % of the base one's. That means the second scenario has regular and large investments 20 % cheaper than the 4th scenario. On the way to the right, we keep on-premises costs the same, but we increase the lease of cloud every time by 10 % of the base scenario. Therefore the 7th scenario has the change of lease 30 % higher. The rest of the input values are the same for each scenario, available in table 5.6.

5.2.4.1 Analysis of results

Let us divide the results into two parts as we were preparing in. In scenarios 3-1, we lower on-premises payments which make the standard infrastructure more competitive. The scenario one is almost at the point where the on-premises becomes the preferred choice. This outcome comes as no surprise.

Conversely, opposite progress can be seen in scenarios 5-7 where we increase the change of lease. This change makes the difference between on-premises and cloud lower, thus makes the standard infrastructure more convenient. However, the cloud is not only more expensive in positive levels, but it is also cheaper in negative levels, thus generates more savings. The effect of the change has a bigger impact in the lower half which results in a gradual increase in the option value. It is, of course, arguable that the lease of cloud would change by the same amount in both ways in reality. Either way, it is a nice demonstration of the importance of the input values.

The results of the potential loss are quite straight forward. In scenarios 5-7 we change only the cloud payments, so the loss does not change at all. On the other side, in scenarios 3-1 we lower the on-premises annuities, and the loss goes down accordingly.

5.3 Discussion of the methodology

The methodology can capture and monetize the benefits which cloud represents. The use of annuity payments enables us to compare the one-time investments into standard infrastructure with rental payments of the cloud. That way we can valuate the flexibility of cloud and determine how much cheaper it is compared with infrastructure on our premises. Although the methodology works as required, there is still a lot to work on.

First, there is the problem with setting up the transition table. At the moment, there is no method which would directly map computation power to its cost. We have already mentioned that this task is not easy even for experienced IT managers.[37][38] This question is arguably yet more complicated in the case of standard infrastructure. A simple method which would estimate needed infrastructure and its cost based on a number of users is essential for adoption of this methodology.

Apart from that, during the testing, we noticed that the value of initial payments has a huge impact in the current version of our method. If the initial payment of on-premises is significantly higher than the cloud one's, the option price might become inert to change of volatility. Since the intrinsic value is adjusted by the probability from the first period (not zero period) onwards, the values are decreasing quite fast. Then when performing the backwards induction, the values in the first period are not big enough to change to the value of the root node, no matter the level of volatility. We work around this issue by setting both payments evenly. However, there are more solutions available.

Last, there is the question of exceeding payments which has been discussed in detail in the body of this work. As with initial payments, there exist more solutions. One could be re-selling of spare hardware. Another would be not buying additional hardware in the very top levels and count the lost revenue as a benefit of cloud. Last but not least we could keep it as it is and expect the project to continue.

As a counterpart of the loss might be the economic differences between both solutions. For example, on-premises investments can be depreciated and this amount used as a tax shield. This saved money puts in favour the traditional infrastructure.

As we can see, there is a lot to think about. With all the question stated it might look that the methodology is not a right way to go. The opposite is true. The literature review showed us that real options are already considered as a convenient method for valuation of IT investments. The analogy of option and cloud characteristics pointed out by the supervisor of this thesis is also indisputable. The valuation of cloud's benefits is worth dealing with since it is a question raised by many people. Although the use of the methodology will be at the moment primarily academic, it has potential to be used by startup owners and IT managers once some of the mentioned obstacles are solved.

Conclusion

The thesis met all objectives. In the beginning, we got ourselves familiar with terms startup and cloud computing. Afterwards, we described the real option principles, option value and finally binomial pricing method. All this gave us necessary theoretical background for explaining the idea of this work. Its basis is an interconnection of cloud principles with real option theory. We started with a discussion about the convenience of cloud characteristics for startups. Then we extended this analogy to real options and mapped their features to cloud one's. Thanks to their similarities real options seemed good for valuation of cloud services. This thought was examined during the systematic literature review. We looked for available papers concerned with this problematics, and found out there has been no research in this area so far. With this in mind, we moved to the practical part of the thesis.

There we defined steps of the newly created methodology which was built on the principle of binomial option tree. Its intrinsic value was created by subtracting the cost of cloud from the cost of standard infrastructure. That way the result gave us the amount of money by which the cloud is cheaper than on-premises.

At the end of the same chapter, the question of algorithmization was contemplated, and for the purpose of verifying the algorithm, an application was created. Although the application was not one of the objectives, it came to use during testing of the methodology. We first tested the correctness of the outcome. Afterwards, we performed and analysed several scenarios from a startup environment. Among other things, we identified the importance of input values for the proper functioning of the methodology.

Although there are still some questions considering the infrastructure payments, the concept of the methodology proved itself. The outcome of research to follow, such as the dissertation thesis of supervisor of this work[46], will decide the application of the methodology in real situations.

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Appendix A

List of Abbreviations

CB-SOA Cloud-based Service-Oriented Architecture

CC Cloud computing

CEO Chief Executive Officer

IaaS Infrastructure-as-a-Service

ICT Inforamtion Communication Technology

IDE Integrated Development Environment

IoT Internet of Things

IT Inforamtion technology

MU monetary unit

NIST National Institute of Standards and Technology

QoS Quality of Service

PaaS Platform-as-a-Service

PraaS Process-as-a-Service

R&D Research and Development

ROA Real Options Analysis

ROT Real Options Theory

SaaS Software-as-a-Service

SeaaS Security-as-a-Service

TCO Total Cost of Ownership

XaaS Everything-as-a-Service

Appendix **B**

List of reviewed articles

1. Alzaghoul, E.; Bahsoon, R. Evaluating Technical Debt in Cloud-Based Architectures Using Real Options. In *2014 23rd Australian Software Engineering Conference*, 2014, ISSN 1530-0803, pp. 1–10, doi: 10.1109/ASWEC.2014.27

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12. Jede, A.; Teuteberg, F. Valuing the Advantage of Early Termination: Adopting Real Options Theory for SaaS. In *2016 49th Hawaii International Conference on System Science (HICSS)*, Kaola: IEEE, jan 2016, ISBN 978-0-7695-5670-3, pp. 4880–4889, doi: 10.1109/HICSS.2016.605

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Appendix C

Content of attached CD

```
description.txt ........................ brief description of attached CD
├── text ................................ electronic version of the thesis
│   ├── DP_Mastny_Martin_2017.pdf ........ text of the thesis
│   └── assignment.pdf ................... thesis assignment
├── excel_files .......................... excel files generated in the last chapter
│   ├── scenarios ........................ input/output files of performed scenarios
│   │   ├── 1_various_volatility .........
│   │   ├── 2_various_expiration_date ....
│   │   ├── 3_regular_overinvestment .....
│   │   ├── 4_various_payments ...........
│   │   └── overview.xlsx ................ inputs and results of all scenarios
│   └── tests ............................ input/output files of performed tests
│       ├── test_six_periods.xls .........
│       └── test_three_periods.xls .......
└── application .......................... application for cloud option calculation
    ├── cloudOption.exe .................. executable file
    ├── libxl.dll ........................ application extension
    ├── option.xls ....................... example of input/output excel file
    └── README.txt ....................... application manual
```