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„Intra- and extra-organisational knowledge exchange within an agent based system from an option-theoretic point of view“

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Vienna, on 6 September 2010 *Michael G. Brinkman*

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List of abbreviations

ABS ...	Agent Based System
i.e. (id est) ...	namely, that is
e.g. ...	for example
et al ...	with other(s) (authors)
GBM ...	geometric Brownian motion
BTT ...	Business Transaction Theory
MAS ...	Multi-Agent-Systems
QMC ...	Quasi Monte Carlo
RJVs ...	Research Joint Ventures
VIM ...	Virtual Information Market

§ 57 DSG 2000: Linguistic non-discrimination

„Soweit in diesem Artikel auf natürliche Personen bezogene Bezeichnungen nur in männlicher Form angeführt sind, beziehen sie sich auf Frauen und Männer in gleicher Weise. Bei der Anwendung der Bezeichnungen auf bestimmte natürliche Personen ist die jeweils geschlechtsspezifische Form zu verwenden.“

1 Introduction

This diploma thesis represents a literature research on solutions and parameters in order to set up an Agent Based System (ABS), which provides a basis for a functioning knowledge/ information exchange between agents. The programming, testing and analysis of possible outcomes of the ABS would be beyond the objective of this diploma thesis and are therefore not included. The aim is to create a scenario with all necessary parameters that allow the exchange of information and more important, an evaluation possibility for judging the value of exchanged information. The ABS, if applied, would have two results: First, it would be the proof that the surrounding conditions, which are developed and explained in this diploma thesis, allow a functioning system and second, that the ABS states a possibility to also analyse unforeseen outcomes.

The way in which knowledge exchange is modelled, and how the value of information is judged by the agents, is defined through the Business Transaction Theory (BTT). This theory has been developed by Assoc. Prof. Dr. Barachini (Barachini, 2007) and represents the assumption that information exchange between humans is comparable to an American call option exchange situation. Due to this assumption, the value of exchanged information can be calculated by using option evaluation models from finance mathematics. To be precise, Barachini states: “The fair value of an option can be evaluated by the binomial option pricing model or the more modern method from Black-Scholes.” (Barachini, 2003, pp. 43-44)

The diploma thesis will, in the first step, take a look at the BTT. This model is presented in chapter two. The concept of the BTT is presented to explain this new model to the reader. In the second step the binomial model and the Black-Scholes model are analysed. This is done in chapters three and four. The binomial approach and the Black-Scholes model rely on almost the same assumptions, with the big difference that the binomial model is a discrete time model whereas the Black-Scholes model represents a continuous time model. As the Black-Scholes formula for option evaluation is of central concern for the BTT, the binomial approach is only briefly addressed.

A special focus is put on the very complex financial and mathematical theories of the Black-Scholes model, as they are inherent in the assumptions of the model. This is done for the following reason: The assumptions provide the framework under which the formula is stated to be true, and have to be explained in detail, because they are simplifying the situation on the financial markets. For a complete understanding of the model, it is essential to analyse the underlying assumptions of it in detail. It should be noted that the second step presents the Black-Scholes model as it is. The connection to the BTT and all occurring problems are addressed at a later stage. In this part, the reader should only be given enough information to allow the relevant understanding to be able to follow the ideas of the model and all financial economic requirements.

In the third step, the ABS is defined where specific characteristics of the agents are described, the way they interact, and how they find communication counterparts, etc. This description is done in chapter five. Basically, this chapter is divided into the two cases of the intra-organisational setup (personal exchange chapter 5.2) and the extra-organisational setup (impersonal exchange chapter 5.3). In the intra-organisational setup, the agents are limited to a department or a company and have social connections between each other. In this case, the knowledge exchange happens not on a monetary, but rather on an informal, basis. The ABS should contain at least two of these networks, which represent organisations, in order to provide an opportunity for the two organisations to exchange knowledge externally over a created virtual information market. This would represent the case of the extra-organisational information exchange. In this case, the exchange happens on a monetary basis and no social connections between the trading agents exist. In both cases, all necessary parameters are modelled in such a way that a problem-free knowledge exchange can take place. As both cases significantly differ from each other, all occurring problems and solutions are addressed in chapters 5.2.4 and 5.3.3 respectively.

2 Business Transaction Theory (BTT)

2.1 Option basics

To understand the BTT fully, it is necessary to be familiar with mathematical financial concepts and ideas, especially concerning call options. Due to the BTT, these types of options reflect the information exchange situation. An option represents a conditional forward contract. Two types of options exist: call and put options. The right to buy is referred to as call option; the right to sell is a put option. (Stoll & Whaley, 1993, p. 6) A call option gives the buyer the right (not the obligation) to buy a financial asset at a price, which is fixed when the contract is set up. (Chance, 1989, p. 3) The contract takes place between two parties: the buyer (holder) and the seller (writer) of the option. For the right to sign the option, the holder pays a premium to the writer. The buyer of a call option expects that the price of the underlying asset will rise. In this case, he can exercise the option and the writer is obliged to perform. (Edwards & Ma, 1992, p. 17) Due to these different rights and obligations, options are called unilateral contracts. With buying the underlying asset at the exercise price (which is the price at which the underlying asset can be bought at exercise point) and reselling it instantly at market price, the holder generates profits.

The difference between the market price (spot price) and the exercise price (strike price) is called the intrinsic value of an option. In the case of a call option, an intrinsic value is given when the market price exceeds the exercise price e.g. if the exercise price is €5 per underlying unit and the market price is €7 per unit, the intrinsic value is €2 per unit and can be realised as a profit. There can be no negative intrinsic value. (Gemmil, 1993, p. 31) If in the case of a call option the exercise price is above the market price at expiration date, the intrinsic value is considered to be zero. In this case, the option would not be exercised. The intrinsic value would only be negative if the option represents an obligation, which is not the case. (Winstone, 1995, p. 154) The intrinsic value for options can also be expressed differently: If the intrinsic value is positive, the option is called to be “in-the-money”, as it would lead to a profit, if exercised immediately. Analogous expressions are used if the intrinsic value is exactly zero: “at-the-money” and (theoretically) negative: “out-of-the-money”. (Summa & Lubow, 2002, p. 194)

Although there are a great variety of options e.g. “exotic options”, there are two major types of options: the “American option” and the “European option”, both distinguished by their exercise possibility. “An American call option gives its holder the right (but not the obligation) to purchase from the writer a prescribed asset for a prescribed price at any time between the start date and a prescribed expiry date in future.” (Higham, 2004, p. 173) European call options can only be exercised at expiry date, whereas American options can be exercised at any time until the expiry date. (Vine, 2005, p. 76) Furthermore, it can be distinguished between a *naked call* and a *covered call*. In the case of a naked call, the holder does not own the underlying asset, which is often done by small investors. In the case of a covered call the holder owns the underlying asset. (Dubowsky, 1992, pp. 12-13)

Let P_t denote the profit of an option, E_T denote the exercise price and let S_T denote the asset price all at exercise point T, then $P_T = (S_T - E_T)^+$ for call options. To buy the right for a option, the holder has to pay a premium p which leads to $P_T = (S_T - E_T)^+ - p$, with P_T denoting the total profit. (Jiang, 2005, p. 5) This can be demonstrated by a graph[1]:

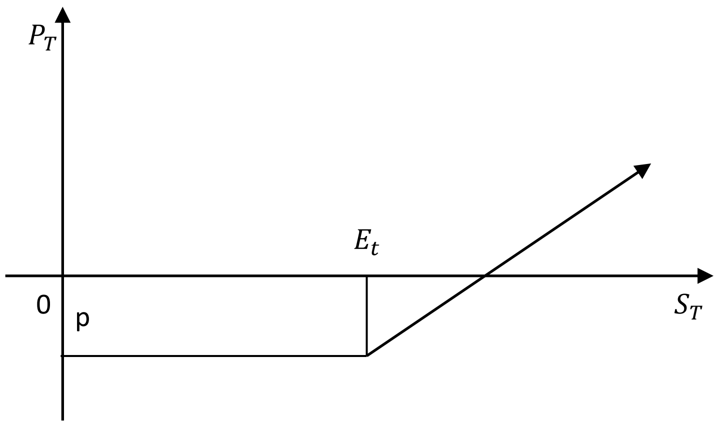

Figure 1 Profit development with buying a call option

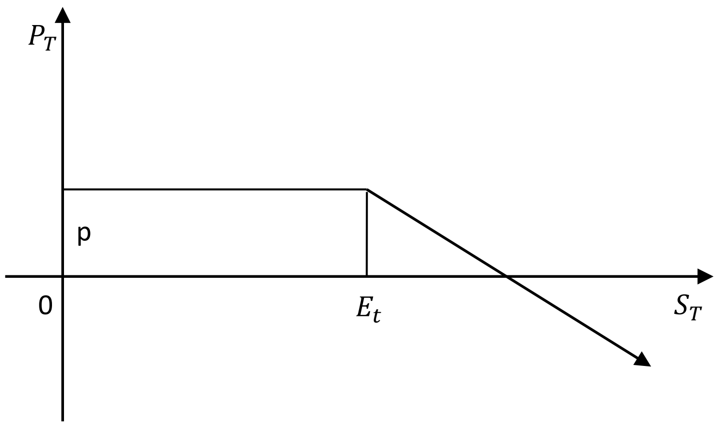

Figure 2 Profit development with writing a call option

The option buyer is said to have a *long position* in the option whereas the option seller has a *short position*. Combined with the two basic option types, four possible positions in options exist: a short/ long position in a call option and a short/ long position in a put option. Each of these positions has the inherent expectation that the price of the underlying is either going to rise or fall. Having e.g. a long position in a call option means that the investor expects the price of the underlying to rise, so the option will have a positive intrinsic value and vice versa. (Johnson, 2009, p. 4)

[1] Source: own illustrations on basis of Jiang (Jiang, 2005, p. 5)

2.2 Concept of the BTT

The Business Transaction Theory, which was been introduced by Barachini (Barachini, 2003), represents the idea that the human information exchange process is quantifiable by using finance mathematical option evaluation models like the Binomial model (Cox, Ross, & Rubinstein, 1979) or the Black-Scholes model (Black & Scholes, 1973). The emphasis of the BTT lies on the latter model. The basic idea behind the BTT can be separated into two parts: First, the assumption that the information exchange is comparable to an option-like situation and second, the resulting idea that the exchanged information is, due to this similarity, quantifiable by option evaluation models.

Human beings exchange information all the time. They exchange information immediately in both directions or, which is the more interesting case for the BTT, humans provide information with the hope to receive more valued information in the future. For example two scientific researchers in two different fields of science are assumed: One has reached the point where he is unable to solve a specific problem. To overcome this situation, he shares all information he has with another researcher. Although the other scientist might not be able to help instantly, there is a possibility that, due to his different approach and the different background, he will find a solution at some future point in time. If this case happens, the more valued information is passed back to the first scientist.

This situation is comparable to having an option on a stock. The holder of the option expects that at a certain point in the future, the stock price will exceed the option price and therefore will generate net earnings for him. This dynamic is similar to the information exchange situation, with the exception that not a stock is the underlying asset, but the piece of information itself. As in the stock option situation, it is likely that the receiver is unable to create additional value to the provided information. In this case, the information price (value) stays below the option price and will not be exercised. If additional value is created by the receiver, the information price (value) will exceed the option price and will be exercised to realise the intrinsic value.

Within the BTT two types of information exchange are defined: (Barachini, 2003, p. 43)

> *Type-1: Immediate information exchange*: Both individuals exchange information right away between each other. This is equal to “over-the-counter” business.
> *Type-2: Deferred unidirectional information exchange*: In this case, the information provider hopes, by providing information, to receive information of even greater value in the future. This setting can be compared to the trading situation of call options.

To be more precise the type-2 information exchange process is equal to the American call option situation. The reason that specifically the American call option is taken, is the fact that there are slight differences between the American and European call options, regarding the exercise possibility. For the purpose of this diploma thesis, it is more useful to assume an American call option situation, as with a complex trading situation, like information exchange and especially judging the value of knowledge, it would not be feasible to assume that the holder would already know at the time of setting up the contract at which point in time the assigned information will pay off. It is more likely that the holder is able to say when the additional piece of information is no longer of use for him. This point will be called the expiry date. Therefore, having the chance of exercising the option at any time, up to the expiry date, would make, for an information exchange situation, a lot more sense. Furthermore, only the call option situation is reviewed, as it is assumed that information is only passed if more value is expected in future. Therefore, the put options, that are an investment possibility at financial markets, are not transferable to an "information market". These are the reasons why the American call option is used.

Barachini himself identified many problems deriving the right values for the Black-Scholes formula, as no financial asset is valued, but exchanged information. (Barachini, 2003, p. 44) The value of the underlying asset is not known and represents unknown information, which might be offered in the future. Even if the objective value of information is tried to be ascertained, it must be accepted that the same piece of information is differently evaluated by each person. Therefore, no objective value exists and no statistics (e.g. for calculating historical volatilities) can be used, like on the financial market, as the current market price of the underlying asset, the exercise price of the option, the risk-free rate of return and the volatility are subjectively judged. According to Barachini even the running time of the option is not determinable as it is unclear when, or if, information can be offered in future. (Barachini, 2003, p. 44)

Barachini states: "Thus, a fair price for information cannot be calculated. Nevertheless, we argue that the P&L statement of a call option can be used as a thought model when we talk about information exchange between humans." (Barachini, 2003, p. 44) Barachini tried to find justification for the BTT through an empirical survey with 150 companies throughout Europe. (Barachini, 2007) The results supported the BTT and the idea of information exchange as a trading process. The employees interviewed stated that personal goals are only reachable through information exchange and these goals are of great personal importance. (Barachini, 2009)

The arguments by Barachini all come from the knowledge management point of view, which stress the fact of being unable to quantify knowledge, respectively the value of exchanged information, due to the dissimilarity of humans and the not quantifiable processes of knowledge exchange. This is not surprising, as he himself claims that his main research interest lies in the field of knowledge management and therefore e.g. he has been the chairman of the "International Conference of Knowledge Management" in Vienna 2007. Therefore, all publications about the BTT are placed in knowledge management journals like e.g. the “Journal of Knowledge Management” and the “Journal of Information and Knowledge Management”. The discussion in this diploma thesis shows a different point of view, namely the finance mathematic/ economic point of view. This seems a reasonable approach, as the BTT refers, besides to the knowledge management, heavily to this field of science. This approach therefore provides a good base to find further problems in addition to the already found issues.

3 Binomial model

Basically, the Black-Scholes model represents a limiting case of the binomial model. The biggest difference between the two models is that the binomial model represents a discrete model and Black-Scholes a continuous time model. To understand where the formula comes from, a short description of the binomial model is given and the connection to the Black-Scholes formula shown, before the B-S model and the corresponding assumptions are analysed. The binomial model was developed by Cox, Ross and Rubinstein (Cox, Ross, & Rubinstein, 1979) and has two assets: (Dana & Jeanblanc, 2007, p. 57)

1. *A riskless asset*: The rate of return r is independent of t and the state of the world, while $r = 1 + r_f$ (Cox, Ross, & Rubinstein, 1979, p. 232), with r_f denoting the riskless interest rate.
2. *A stock*: The price change factors for the stock between time n and time $n + 1$ can either be u or d. One dollar invested at time n will yield $1 + r_f$ dollars, respectively a debt of $1 + r_f$ dollars if borrowed, at time $n + 1$. To rule out arbitrage, it is assumed that $d < 1 + r_f < u$ and $0 < d$, as stock prices are positive. (Shreve, 2004, p. 2)

That the asset price either moves up by a factor u, or down by a factor d, is the central assumption of the binomial model. This movement happens with a complementary probability. Up-movements with a probability p, down-movements with a probability $1 - p$. $\delta n = \frac{N}{M}$ denotes the spacing between successive points in time, with N being the expiry date and M being the number of periods until expiration. The initial asset price S_0 is known. Therefore, the possible asset prices at time $n_1 = \delta n$ are uS_0 and dS_0. At time $n_2 = 2\delta n$ the possible asset prices are u^2S_0 , udS_0 and d^2S_0. (Higham, 2004, pp. 151-152) This can be also shown in a graph[2]:

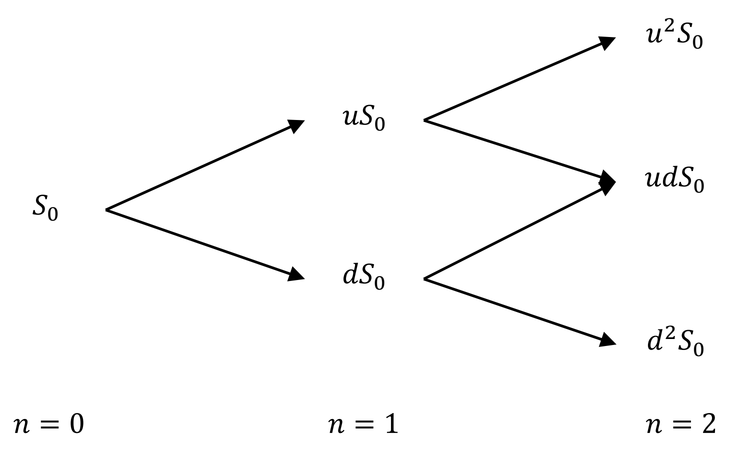

Figure 3 Stock price development in a three period binomial model

[2] Source: own illustration on basis of Hull (Hull, 2009, p. 245)

At time n there are 2^n nodes and for all nodes j and all n, $\Delta^n(j)$ has only two elements. As the price of the stock at time n depends only on the number of up-moves, S_n is a random variable with a binomial distribution dependent on parameters n and p and can be denoted as follows: (Dana & Jeanblanc, 2007, p. 59)

$$Q(S_n = u^j d^{n-j} S) = \binom{n}{j} p(1-p)^{n-j} \tag{3.1}$$

s.t.

$$\binom{n}{j} = \frac{n!}{j!\,(n-j)!}$$

$S \ldots current\ stock\ price$
$Q \ldots binomial\ distribution$
$n \ldots number\ of\ periods$
$j \ldots\ number\ of\ nodes$
$p \ldots probability\ of\ the\ stock\ price$
$u \ldots price\ factor\ for\ up - movements$
$d \ldots price\ factor\ for\ down - movements$

The value of a call on a stock in the binomial approach is denoted as follows: Let C denote the value of the call, C_u the value if the stock price falls to uS and C_d the value if the stock price rises to dS. The possibilities of up- or down-moves are again q respectively $1-q$. The values of the calls in analogy to figure 3 are[3]:

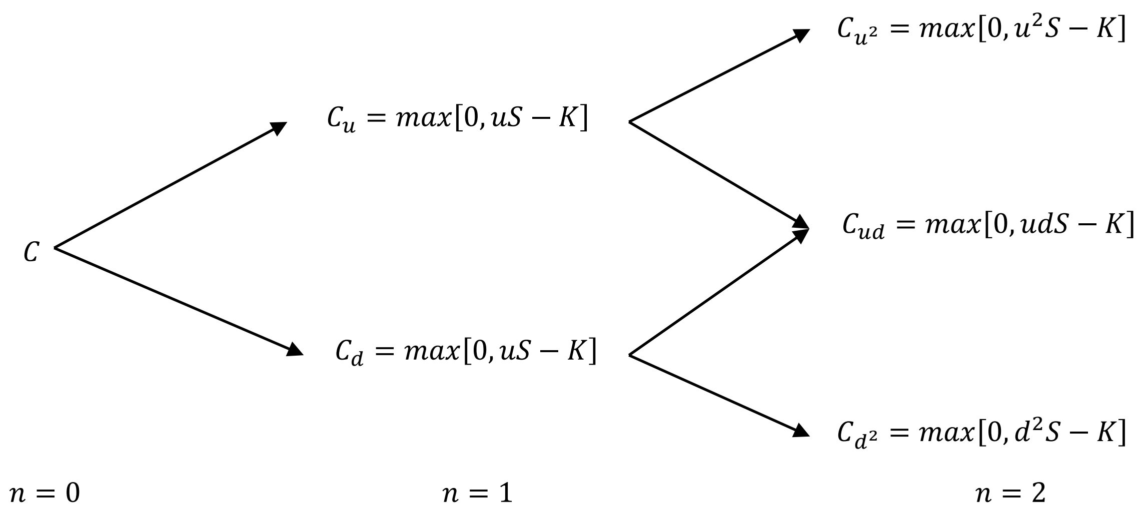

Figure 4 Call value development in a three period binomial model

[3] Source: own illustration on basis of Cox, Ross & Rubinstein (Cox, Ross, & Rubinstein, 1979, p. 236)

For the case of a multi-period binomial case the final option pricing formula looks as follows: (Cox, Ross, & Rubinstein, 1979, p. 239)

$$C = S\left[\sum_{j=a}^{n}\left(\frac{n!}{j!\,(n-j)!}\right)p^{j}(1-p)^{n-j}\left(\frac{u^{j}d^{n-j}}{r^{n}}\right)\right] - Kr^{-n}\left[\sum_{j=a}^{n}\left(\frac{n!}{j!\,(n-j)!}\right)p^{j}(1-p)^{n-j}\right] \quad (3.2)$$

$S \ldots current\ stock\ price$
$C \ldots value\ of\ the\ call\ on\ the\ stock$
$n \ldots number\ of\ periods$
$j \ldots\ number\ of\ nodes$
$a \ldots smallest\ non-negative\ integer\ greater\ than\ \frac{log\left(\frac{K}{Sd^{n}}\right)}{log\left(\frac{u}{d}\right)}$
$p \ldots probability\ of\ the\ stock\ price$
$r \ldots rate\ of\ return\ on\ the\ asset\ in\ terms\ of\ r = 1 + r_f$
$u \ldots price\ factor\ for\ up-movements$
$d \ldots price\ factor\ for\ down-movements$
$K \ldots strike\ price\ of\ the\ option$

The latter bracketed expression in formula 3.2 can be interpreted as a complementary binomial distribution function $\Phi[a;n,p]$ and the first bracketed expression as a complementary binomial distribution $\Phi[a;n,p']$ where $p' \equiv \left(\frac{u}{r}\right)p$ and $1-p' \equiv \left(\frac{d}{r}\right)(1-p)$, which leads to the binomial option pricing formula: (Cox, Ross, & Rubinstein, 1979, p. 239)

$$C = S\Phi[a;n,p'] - Kr^{-n}\Phi[a;n,p] \quad (3.3)$$

s.t.

$$p \equiv \frac{(r-d)}{(u-d)}$$

$$p' \equiv \left(\frac{u}{r}\right)p$$

$S \ldots\ stock\ price$
$C \ldots value\ of\ the\ call\ on\ the\ stock$
$n \ldots number\ of\ periods$
$a \ldots smallest\ non-negative\ integer\ greater\ than\ \frac{log\left(\frac{K}{Sd^{n}}\right)}{log\left(\frac{u}{d}\right)}$
$p \ldots probability\ of\ the\ stock\ price$
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$u \ldots price\ factor\ for\ up-movements$
$d \ldots price\ factor\ for\ down-movements$
$K \ldots strike\ price\ of\ the\ option$

In this case, if $a > n$ then C would be 0. Given the previously shown explanations the impression could arise that the binomial model is only dependent on the assumptions concerning the up- and down movements. But this is not the case. Cox et al took for the mathematical derivation of the binomial model assumptions such as no-arbitrage opportunities, no dividends, perfect hedge and the riskless asset into account[4]. (Cox, Ross, & Rubinstein, 1979, pp. 232-239) The binomial model therefore, cannot be seen apart from these assumptions, which are creating the *perfect financial market*. In total, the assumptions on which the binomial approach is based, are the following: (Deutsch, 2008, pp. 59-61;145)

- Market participants always prefer, given equal costs and risk, the strategy which provides more earnings. No participant resigns from earnings on purpose.
- There are no arbitrage possibilities on the market. If arbitrage possibilities would have existed, they would have already been used by arbitrage dealers. Markets are therefore always at equilibrium.
- The markets are infinitely liquid. Buying and selling financial instruments is possible with no restrictions on the amount and no effects on the price.
- No competition risk exists. The price of a financial instrument is only dependent on the market and not on the individual, who is selling the product.
- There are no transaction costs in buying or selling a financial instrument.
- Relative price changes are random walks, which implies that the course development is lognormal distributed.
- The risk-free rate is known and constant over time.
- Volatilities are not stochastic and constant.
- The underlying pays no dividends.

As for the B-S model, especially the building of a *replicating portfolio* and hedging positions is fundamental for the binomial model: ”...*an appropriately levered position in stock will replicate the future returns of a call*.”. (Cox, Ross, & Rubinstein, 1979, p. 232) The *replicating portfolio* is a tool from finance mathematics that is used to calculate the value of a financial derivative. It consist of Δ pieces of the underlying and a money amount g. Due to a risk-free interest rate r_f the money amount g charges interest. Δ and g are adjusted now in such a way that the portfolio performs exactly as the evaluated derivative. Therefore, it replicates the derivative, which led to the name *replicating portfolio*[5]. (Deutsch, 2008, pp. 145-146)

[4] For a detailed discussion on these assumptions please see chapter 4.2 concerning the Black-Scholes model. As the assumptions are the same for both models, but the Black-Scholes model is of central concern for the BTT, this model is discussed in detail, whereas the binomial approach is kept short.

[5] It should be noted that the replicating portfolio is only replicating the price development of the underlying financial derivative.

To illustrate the dynamics of the model a simple numerical example should be given: A stock is worth €20 and will be worth either €22 or €18 in three months. What is the value of a European call option that allows buying the stock in three months for €21? Under no arbitrage opportunities, a portfolio of a stock and an option is created in such a way that the risk is zero. If the stock is worth €22, the value of the option would be one. If the stock is worth €18, the option would be worthless with a value of 0. The risk-free rate of interest is 12% per annum. In a risk-free world, the return on the stock must be the risk-free rate. Therefore, $22p + 18(1-p) = 20e^{0,12x3/12}$ must be true and results in $p = 0,6523$. The call option has a $0,65$ probability of being worth 1 and as $q = 1 - p$, a $0,3477$ probability of being worth zero. The expected value is therefore $0,6523.1 + 0,3477.0 = 0,6523$. As this value has to be discounted to get the value today, the option is worth $0,6523e^{-0,12.3/12} = 0,633\$$. (Hull, 2009, pp. 241-242) This can be summed up as follows: "**The actual value of a derivative is equal the up today discounted expected value of it.**"[6]. (Deutsch, 2008, p. 153)

In order to approach a continuous-time model like the Black-Scholes model, one must take the limit of the call option price in the binomial model. The asset price movement is reflected by a discrete random walk, which converges to a continuous lognormal diffusion as the time interval between successive time steps tends to zero. (Kwok, 1998, p. 189) Let h represent the elapsed time between two successive stock price changes. Given a period t, and assuming n periods of length $h = \frac{t}{n}$, the continuous-time model is approached by letting n tend to infinity ($n \to \infty$) while t stays fixed. Cox et al proved in their article that continuous trading and lognormal distribution of returns are limiting cases of their binomial approach. (Cox, Ross, & Rubinstein, 1979, pp. 246-250) In fact, the geometric random walk assumed by the binomial model is the discrete pendant to the geometric Brownian motion that the Black-Scholes model assumes for the stock price development. (Franke, Härdle, & Hafner, 2004, p. 118)

Additionally to this configuration of the time interval, there have to be adoptions to other parameters of the binomial model in order to be compatible to the Black-Scholes model. The up- and down-movements have to be of the following form: $u = e^{\sigma\sqrt{t/n}}$ and $d = \frac{1}{u}$. Furthermore, the interest rate has to be adapted in order to be compatible to the infinite small period lengths. The relation of the interest rate of the binomial model r_{bin} and the Black-Scholes interest rate r_{bs} can be shown as follows: $r_{bin} = (r_{bs})^{t/n}$. If the parameters are chosen in this way, the binomial model is asymptotic approximating the Black-Scholes call price. (Weßels, 1992, p. 53)

[6] Own translation from German source

4 Black-Scholes model

4.1 Option evaluation formula

The relationship between the stock price and the option price has to be clarified. The simplest call option is the right to buy one piece of stock at a future point T. In general, it is clear that the higher the price of the stock, the higher the value of the option. As the stock price exceeds the exercise price, the option will be exercised to realise profits. On the other hand, if the stock price is beneath the exercise price, the option will not be exercised and the holder will lose money in the amount of the premium. A major factor for the relationship between option and stock price is the length of period until the expiry date. If the expiry date is far in the future, the option price will approximately equal the share price. If the expiry date is imminent, the option price will equal the stock price minus the premium, or, has a value of zero should the stock price be beneath the exercise price. (Black & Scholes, 1973, p. 638) The dynamics can be illustrated as follows[7]:

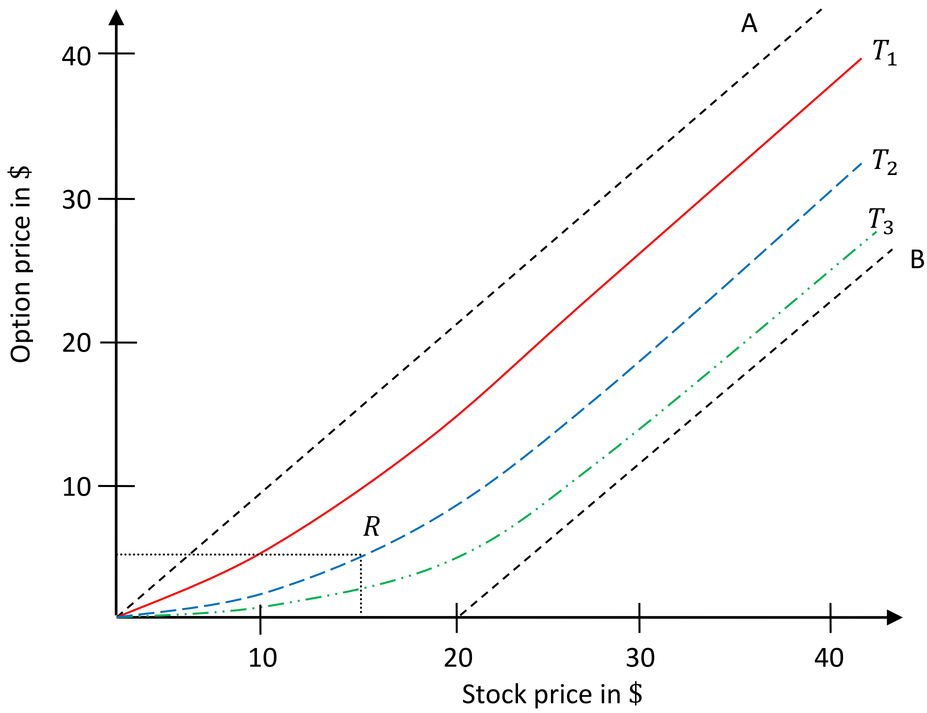

Figure 5 Relationship between stock and option prices

Line A represents the maximum possible value of the option, as it can never be worth more than the stock. Line B represents the minimum value, as the option cannot be negatively valued or below the stock price minus the exercise price. The curves T_1, T_2 and T_3 represent the possible relationships regarding the running time of the option, with T_1 having the longest run time (and therefore greatest value) and T_3 having the shortest life span. Since all three curves are below the Line A, the option price has a higher volatility than the stock price. Holding the maturity constant, a change of the stock

[7] Source: own illustration on basis of Black & Scholes (Black & Scholes, 1973, p. 638)

price leads to a higher change in the option value. Therefore, the volatility of the stock is not constant, but dependent on the stock price and the maturity. (Black & Scholes, 1973, pp. 638-639)

Under the previous described assumptions, the only values that the option price is dependent on are the price of the stock and the time (the remaining variables are constant). This leads to the central idea that a hedged position can be created consisting of a long position in the stock and a short position in the option, whose value is only dependent on time and constant variables, not on the stock price. The ratio between the option that must be sold short to hedge one share of stock long is $\frac{1}{w_1(x,t)}$ with $w(x,t)$ denoting the value of the option as a function of stock price x and time t and $w_1(x,t)$ referring to the partial derivative of $w(x,t)$ with respect to its first argument. (Black & Scholes, 1973, p. 641)

Referring to point R in figure 5, the price of the stock is at $\$15$ with the resulting value for the option of $\$5$. Assuming that the slope at that point is ½, the hedged position is now created by buying one share of the stock and selling two options leading to an equity of $5. This equity has to be kept constant as stock prices change, which makes continuous rebalancing of the portfolio necessary. Thus, the risk in the hedged position is zero if the short position in the stock is adjusted continuously. If the stock price follows a random walk (what is assumed) and the return has a constant variance rate, the covariance between the return on the equity and the return on the stock is zero. If this is true, the price of the stock and the "market portfolio" follow a joint random walk where the covariance between the two is zero too. (Black & Scholes, 1973, p. 642)

The Black-Scholes formula for estimating the fair value of an option is denoted as follows: (Black & Scholes, 1973, p. 644)

$$w(x,t) = xN(d_1) - ce^{r_f(t-t^*)}N(d_2) \tag{4.1}$$

where

$$d_1 = \frac{\ln\left(\frac{x}{c}\right) + (\ln r + 0{,}5\sigma^2)(t^* - t)}{\sigma\sqrt{t^* - t}}$$

$$d_2 = \frac{\ln\left(\frac{x}{c}\right) + (\ln r - 0{,}5\sigma^2)(t^* - t)}{\sigma\sqrt{t^* - t}} = d_1 - \sigma\sqrt{t^* - t}$$

$\mathrm{x} = current\ market\ price\ of\ underlying\ stock$
$c = exercise\ price\ of\ the\ option$
$r = 1 + r_f = cont.compounded\ risk - free\ rate\ of\ return\ expressed\ on\ annual\ basis$
$t^* - t = time\ remaining\ before\ expiration\ expressed\ as\ a\ fraction\ of\ a\ year$
$\sigma = risk\ of\ the\ underlying\ common\ stock, measured\ by\ the\ standard\ deviation\ of$
$the\ continuously\ compounded\ annual\ rate\ of\ return\ on\ the\ stock$

For the present value of the exercise price $ce^{r_f(t-t^*)}$, a continuous discount rate is used. $N(d_1)$ and $N(d_2)$ denote the probabilities of outcomes, less than the values of d_1 and d_2 will occur in a normal distribution with a mean of 0 and a standard deviation of 1. Assuming a call option with expiring date in three months, the exercise price is \$40 ($c = 40$). As $t^* - t$ is seen in fractions of a year $t^* - t = 0{,}25$. The current price x is \$36 and the underlying stock has a risk of 50% ($\sigma = 0{,}5$). The risk-free rate r_f is 5%. Putting the values into the formula d_1 and d_2 are denoted as follows: (Sharpe, Alexander, & Bailey, 1995, p. 690)

$$d_1 = \frac{\ln(\frac{36}{40}) + [\ln(1 + 0{,}05) + 0{,}5(0{,}5)^2]0{,}25}{0{,}5\sqrt{0{,}25}} = -0{,}25$$

$$d_2 = -0{,}25 - 0{,}5\sqrt{0{,}25} = -0{,}5$$

The probabilities $N(d_1)$ and $N(d_2)$ can be looked up in a table or be solved graphically[8]:

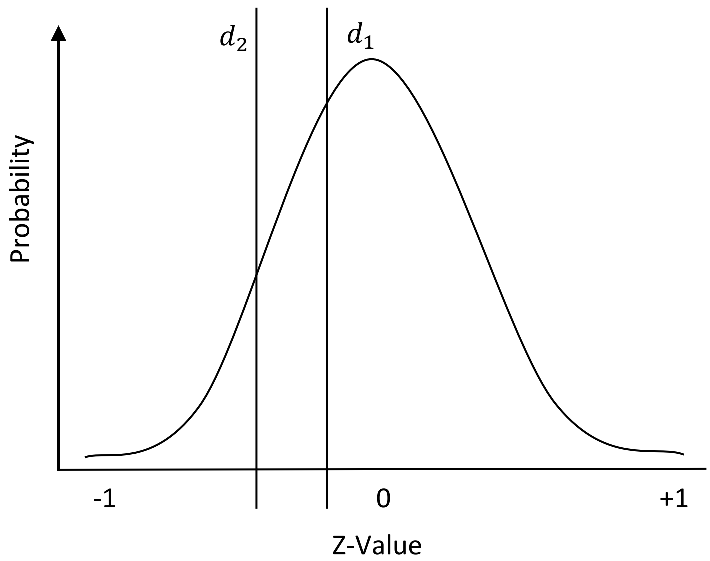

Figure 6 Values of d_1 and d_2 on the standard deviation graph

The values for $N(d_1)$ and $N(d_2)$ are below zero which means the probabilities are below 0,5. Next the integrals $N(d_1) = N(-0{,}25) = 0{,}4013$ and $N(d_2) = N(-0{,}5) = 0{,}3085$ are calculated, which leads to the fair value of the option: (Sharpe, Alexander, & Bailey, 1995, p. 690)

$$w(x,t) = (0{,}4013 \times \$36) - \left(\frac{\$40}{e^{0{,}05\times 0{,}25}} \times 0{,}3085\right) = \$2{,}26$$

The Black-Scholes formula depends on five variables: $x, c, r, t^* - t$ and σ. The stock price at the financial market is observable at trading terminals or can be traced over the press. The exercise price

[8] Source: own illustration on basis of Kolb & Overdahl (Kolb & Overdahl, 2007, p. 450)

and the time until expiration are known, as they are fixed between the writer and the holder. But how are the risk-free rate and the volatility estimated?

4.1.1 Estimating the risk-free rate of interest

For calculating the risk-free rate, Kolb & Overdahl (Kolb & Overdahl, 2007, p. 452) give a very descriptive explanation which will be reviewed in the following paragraphs. As Black-Scholes are using a risk-free interest rate, the Treasury bill (T-bill) rate is taken into account. Usually, the T-bill that expires closest to the option expiry date is taken. This could be e.g. a T-bill that expires in 84 days, has a bid yield of 8,83 and an asking yield of 8,77. The following formula gives the price of the T-bill in percentage of its face value: (Kolb & Overdahl, 2007, p. 452)

$$P_{TB} = 1 - 0{,}01 \times \left(\frac{BID + ASK}{2}\right)\left(\frac{days\ until\ maturity}{360}\right) \tag{4.2}$$

$$= 1 - 0{,}01 \times \left(\frac{8{,}83 + 8{,}77}{2}\right)\left(\frac{84}{360}\right) = 0{,}97947$$

In this example, the T-bill is priced 97,95% of its face value. The bid and ask yields are averaged to estimate the unobservable true yield that lies between the observable bid and ask yields. To find the corresponding continuously compounded rate, the following equation has to be solved for r_f: (Kolb & Overdahl, 2007, p. 452)

$$e^{r_f(T-t)} = \frac{1}{P_{TB}} \tag{4.3}$$

$$e^{r_f(0{,}23)} = \frac{1}{0{,}97947}$$

$$r_f = \frac{\ln(\frac{1}{0{,}97947})}{0{,}23} = 0{,}0902$$

It should be noted that $T - t = 0{,}23$ because 84 days are 23% of a year, as the risk-free rate is expressed on an annual basis. With this procedure, it is very easy to calculate the risk-free rate for the Black-Scholes formula.

4.1.2 Estimating the stock´s standard deviation

Price volatility measures the amount and intensity of price fluctuation. It is inversely proportional to the amount of information about the future stock´s price and therefore the higher the volatility is, the less predictable the future development of the stock. (Chriss, 1997, p. 94) There are basically two ways to calculate the volatility: Either one takes the *historic volatility* data or uses the *implied volatility* for the estimates. Ideally, the two possibilities should lead to the same results, but this is rarely the case. (Benth, 2004, p. 72)

The *implied volatility*: In this case, it is assumed that the option is priced at fair value (w) in the information market. Therefore, $w = x$, while x denotes the actual price of the derivative. By plugging in all other known parameters into the formula and reformulating it, the risk rate of the information is calculated. (Ho & Lee, 2004, p. 105)

As σ cannot be observed directly, one approach is to deduce the volatility from market data. In the historical volatility approach, the price relatives, logarithmic price relatives and the mean and standard deviation of the logarithmic price relatives, are calculated based on historical data. Letting PR_t denote the price relative for day t so that $PR_t = \frac{P_t}{P_{t-1}}$ the formulas for the mean and variance of the logarithmic price relatives is denoted as follows: (Kolb & Overdahl, 2007)

$$E(PR) = \overline{PR} = \frac{1}{T}\sum_{t=1}^{T} \ln PR_t \tag{4.4}$$

$$VAR(PR) = \frac{1}{T-1}\sum_{t=1}^{T} (\ln PR_t - \overline{PR})^2 \tag{4.5}$$

In literature, it is often criticised that many models weight historical volatilities equally which means that the volatility value one year ago is just as important as the volatility value one day ago, which simply does not reflect the reality due to the permanent changes that happen in the financial markets. Special attention should be, therefore, put on methods like the *exponential smoothing* method and the *exponentially weighted moving average* method. In these models, smoothing parameters are used to give more weight to actual volatility values. (Poon, 2005, pp. 32-35) But, there are also other e.g. stochastic approaches to estimate the *historical volatility* e.g. with a Monte Carlo calculation to estimate the mean and variance, or a “maximum likelihood estimate”, etc. (Higham, 2004, pp. 203-211)

4.2 Black-Scholes assumptions

After having explained the option evaluation formula itself, a close look at the assumptions of the model is taken. The assumptions are very specific and are the major factor why the option evaluation formula is simple and easy to calculate. Black-Scholes defined the following assumptions: (Black & Scholes, 1973, p. 640)

(1) For constant μ and σ, $dS = \mu S dt + \sigma S dz$
(2) There are no penalties to short selling.
(3) There are no transaction costs in buying or selling the stock or option.
(4) The stock pays no dividends or other distributions.
(5) The short-term interest rate is known and constant through time.

(6) The option is “European” and can, therefore, only be exercised at maturity.

(7) It is possible to borrow any fraction of the price of a security, to buy it or to hold it, at the short-term interest rate.

In addition to these original assumptions of the model, some general assumptions of mathematical finance, which are defining the *perfect financial market* are stated true. For example assumptions like no arbitrage (i.e. market is at equilibrium), lending rates equal borrow rates and securities are infinitely divisible, continuous trading (rebalancing of portfolio is done instantaneously),... Basically, the assumptions are equal to the assumptions on which the binomial model is based[9], with the exception that the stock price follows a *geometric Brownian motion*. Are all these assumptions, designed to meet the needs of a financial market, useful and applicable to an information exchange situation, like in the planned ABS simulation? Therefore, all assumptions have to be reviewed in detail, especially in very complex cases, like the first assumption concerning the stock price movement in order to judge their usability.

4.2.1 For constant μ and σ, $dS_t = \mu S_t dt + \sigma S dz$

The assumption that the price of the underlying asset follows a *geometric Brownian motion* (GBM), is the most complex assumption and needs further explanation. It is assumed that the stock price follows a random walk in continuous time with a variance rate proportional to the square of the stock price. Therefore, the distribution of possible stock prices at the end of a finite time interval is lognormal. (Black & Scholes, 1973, p. 640)

The ideas for modelling the prices of stocks came from very different areas of the applied sciences and have a remarkable history. The point of origin is called the *Brownian motion* concept. The model was introduced by the botanist Robert Brown (Brown, 1828) who examined the movement of small particles in a fluid, which performed under rapid stochastic collisions very anomalous movements. Explanation for that observation was given by Albert Einstein (Einstein, 1905), who proved mathematically that the *Brownian motion* is a result of the continuous bombardment of the particles with molecules from their surrounding medium. Later, the applied mathematician Norbert Wiener (Wiener, 1921) further extended the theory. Since then, the *Brownian motion* is also known as *Wiener process*. (Ross S. M., 2003, p. 35)

It should be noted that the stock price is seen as a continuous-variable as well as continuous-time stochastic process. That means that the stock price can take any value within a certain range and the price, seen as a variable, can change its value at any point in time. (Hull, 2009, p. 259) This is contrary to reality: Here stocks can only be traded when the stock market is opened and price changes can

[9] see chapter 3

only happen in this period, which represents a discrete process. Therefore, volatility calculations are based on a year that consists out of 250 days where the stock exchange is open.

4.2.1.1 The Brownian motion

The x-coordinate $w(t)$ of the particle is irregularly dependent on Time t. Therefore, $w(t)$ follows a stochastic process. From point t_1 to t_2 the position of the particle changes from $w(t_{i-1})$ to $w(t_i)$. The model has the following underlying assumptions: (Nguyen, 2002, pp. 25-26)

$$w(0) = 0 \; with\; the\; probability\; 1 \qquad (4.6)$$

The first condition means that the stochastic process has a fixed starting point with 0. Converted into a stock scenario, this would be the introduction of the stock at the stock exchange with the company going public.

$$P(w(t_i) - w(t_{i-1}) \in [a_i, b_i], i \leq n) = \prod_{i \leq n} P(w(t_i) - w(t_{i-1}) \in [a_i, b_i]) \qquad (4.7)$$

$$[a_i, b_i] \subset \mathbb{R}, i = 1,2, \dots, n \; and \; n \in \mathbb{N}$$

The second condition explains that the increases in the variables $w(t_1) - w(t_0), \dots, w(t_n) - w(t_{n-1})$ are independent from each other. (Seydl, 2004, p. 26) This effect is known as the Markov characteristic. Seen in a stock price context, the Markov property simply assumes that the price is not dependent on any historic development, but that only the present value is relevant for predicting future values. (Isaacson & Madsen, 1976, p. 229)

$$P(w(t_i) - w(t_{i-1}) \in [a, b]) = \frac{1}{\sqrt{2\pi(t_i - t_{i-1})}} \int_a^b \mathrm{e}^{\left(-\frac{x^2}{2(t_i - t_{i-1})}\right)} dx \qquad (4.8)$$

The third condition states that the increase of the variables $w(t_i) - w(t_{i-1})$ with $i \in [1, \dots, n]$ is normally distributed with a mean of 0 and variance of $\sqrt{t_i - t_{i-1}}$. The last condition says that every $w(t)$is continuous in t for $t \geq 0$. If a random process is satisfying all four conditions, it is called *Brownian motion* or *Wiener process*. (Jiang, 2005, p. 58)

If w follows a *Brownian motion* process and has the value 25 ($n = 1 \; year$), at the end of the first year the variable would be distributed normally with a mean of 25 and a standard deviation of 1. At the end of five years w would still have a mean of 25, but a standard deviation of $\sqrt{5}$. As the standard deviation increases with time, the uncertainty about the value of the variable in future is reflected. The further away in time, the bigger the uncertainty about the value of w. (Hull, 2009, p. 263)

If a variable $w(t)$ follows a *Brownian motion* process, and all four conditions of the model are therefore stated true, then $\Delta w = z\sqrt{\Delta t}$ with z being distributed according $\varphi(0,1)$, the standard normal distribution (abbreviated $z \sim \varphi(0,1)$); this implies that $\Delta w \sim \varphi\left(0, \sqrt{\Delta t}\right)$. Summing up the changes of the variable from 0 to T the following result is received: (Nguyen, 2002, pp. 28-30)

$$w(T) - w(0) = \sum_{i=1}^{n} z_i \sqrt{\Delta t} \tag{4.9}$$

To be able to observe a long period of time, the interval 0 to T has to be split up in $n = \frac{T}{\Delta t}$ parts, while $n \in \mathbb{N}$. Therefore, one can say $w(T) - w(0) \sim \varphi(0, \sqrt{T} = \sqrt{n\Delta t})$. This means future values of w are equal to the present value and course changes either up or down are equally likely. This fact constitutes a problem, as with long term observations a positive trend of stock prices can be observed. (Nguyen, 2002, pp. 28-30)

Apart from this problem, the *Brownian motion* process to model stock prices has further flaws: First, the price of a stock is a normal random variable (it can therefore become negative) and second, "...the assumption that a price *difference* over an interval of fixed length has the same normal distribution no matter what the price at the beginning of the interval [is], does not seem totally reasonable.". (Ross S. M., 2003, p. 36) This assumption implies only a consideration of an absolute change in stock prices, which presumes that the probability of an increase of a stock price from \$5 to \$10 is just as high as the probability of a stock price going from \$250 to \$255.

4.2.1.2 The geometric Brownian motion

The *geometric Brownian motion* has neither of these problems. Contrary to *Brownian particles,* stock prices change in proportion to their size (a so called *geometric* change). They therefore have no absolute change in value, but a percentage change based on their actual value. Furthermore, the model implies that the future return on a stock is normally distributed with $\varphi(\mu\Delta t, \sigma\sqrt{\Delta t})$. Therefore, future prices are lognormal distributed. (Chriss, 1997, pp. 97-111)

As the logarithm of the price of stock is now the normal random variable, no negative values are allowed and the percentage change in price (not the absolute change) is taken. (Ross S. M., 2003, p. 36) These advantages make the *geometric Brownian motion* model a major factor within the Black-Scholes formula, as it is taken to determine the price development of stocks.

The *geometric Brownian motion* has another advantage: If stock price changes are observed over a long period, a positive trend can be recognized. To integrate this observation into the *Brownian motion* process, a drift variable is introduced. The drift rate indicates the mean change per time unit for a stochastic process, while the variance rate indicates the variance per time unit. (Hull, 2009, p. 263)

$$\Delta x = \mu\Delta t + \sigma\Delta w \tag{4.10}$$

This *geometric Brownian motion* has two components: The deterministic and the stochastic component. μ is the instantaneous rate of return and the term $\mu\Delta t$ describes the expected development over the period Δt, while Δx is positively linear correlated to μ. This term is the deterministic part of the *geometric Brownian motion* model. The second term $\sigma\Delta w$ reflects the variability or noise around the expected development and therefore represents the stochastic component. σ is called the volatility of the stock and is normally distributed with an expected value of 0. (Chriss, 1997, p. 101)

The following example may be considered: The cash position of a company follows a generalized Wiener process with a drift of 20 per year and a variance rate of 900. If the initial value of the cash position is 50, the value at the end of one year (as it is normally distributed) would have a mean of 70 and a deviation of 30 ($\sqrt{900}$). After half a year, it would have a mean of 60 and a standard deviation of $30\sqrt{0{,}5}$. Still, the linear correlation between time and uncertainty is given. (Hull, 2009, p. 265)

4.2.1.3 Itô process

The *geometric Brownian motion* can now be further developed, where μ and σ are not constant but dependent on the variables x and t. When μ and σ are functions of the underlying variables x and t the stochastic process is called an *Itô process* (Itô, 1942) and can be denoted as follows: (Nguyen, 2002, p. 30)

$$dx = \mu(x,t)dt + \sigma(x,t)dz \tag{4.11}$$

In this case, dz denotes the *Wiener process*. The Itô formula is a stochastic version of the classical chain rule of differentiation and describes how a *Brownian motion* function changes stochastically as time progresses. (Benth, 2004, p. 38) As a precise description of the lemma would go far beyond this diploma thesis, one can look up the mathematical proof of the Itô formulas at Itô (Itô, 1951) or e.g. Korn (Korn & Korn, 2001, p. 51). Basically, two important conclusions can be drawn from the lemma: First, Itô showed that a function G of x and t follows a specific process: (Hull, 2009, p. 270)

$$dG = \left(\frac{\partial G}{\partial x}\mu + \frac{\partial G}{\partial t} + \frac{1}{2}\frac{\partial^2 G}{\partial x^2}\sigma^2\right)dt + \frac{\partial G}{\partial x}\sigma dz \tag{4.12}$$

where dz is the same *Wiener process* as in the previous formula. Therefore, G follows an Itô process with a drift rate of $\frac{\partial G}{\partial x}\mu + \frac{\partial G}{\partial t} + \frac{1}{2}\frac{\partial^2 G}{\partial x^2}\sigma^2$ and a variance of $\left(\frac{\partial G}{\partial x}\right)^2\sigma^2$. This is the proof that both processes, the stock price development as well as the derivative price development, are affected by the same source of uncertainty and therefore follow a joint stochastic process, which is one central concern in the derivation of the Black-Scholes model. (Hull, 2009, pp. 269-270) Second, Itô´s lemma shows that the logarithm of the stock price is denoted as follows: (Poon, 2005, p. 77)

$$d \ln S = \left(\mu - \frac{1}{2}\sigma^2\right) dt + \sigma dz \quad (4.13)$$

which means that the stock price has a lognormal distribution or the logarithm of the stock price has a normal distribution.

In order to sum up, all these findings have led to the famous Black-Scholes formula: For constant μ and σ, $dS_t = \mu S_t dt + \sigma S dz$. With μ being the expected return rate, σ being the volatility and dz defining the Wiener process. As μ and σ being constant, this formula is often written as $\frac{dS_t}{S_t} = \mu dt + \sigma dz$ defining the growth rate and $E(dz) = 0$ and $Var(dz) = dt$. (Jiang, 2005, p. 74)

4.2.2 There are no penalties to short selling

This implies that short selling is allowed (permitted) with full use of proceeds. In the original paper of Black-Scholes it is stated that: "A seller who does not own the security will simply accept the price of a security from a buyer and will agree to settle with the buyer on some future date by paying him an amount equal to the price of the security on that date." (Black & Scholes, 1973, p. 640)

If the underlying asset is a stock, then selling the stock short means that the investor borrows the stock (usually from a broker) and sells it immediately (in one transaction). By doing this, the investor receives an amount equal to the current price of the stock and must return the stock (not the money) to the lender. (Roman, 2004, p. 85) If an investor short-sells a stock, he gains from a fall in the stock and loses from a rise. (Ross, Westerfield, & Jaffe, 2005, p. 354)

An example: The price of a share of IBM is expected to fall from $\$120$ to $\$100$ in the next month. If the stock is short sold a gain of $\$120$ is made on the account and the liability of one share of IBM. The cash can be invested immediately and can earn interest, while the short sale position is in hold. If the price drops to $\$100$, one share of IBM is bought to cover the short position. The net gain is $\$120$ plus interest rate minus the $\$100$. (Whaley, 2006, p. 53)

For the Black-Scholes model, this assumption is relevant for the building of the hedged portfolio. The portfolio consists of two positions: the stocks and the options; the stocks could be owned or short sold. (Weßels, 1992, p. 23) Should short sells be punished, it would be more complicated to construct a portfolio out of short sold shares. This makes short selling penalties even worse than e.g. borrowing penalties, because an investor is unable to sell stocks short with falling prices. Furthermore, penalties on short selling stocks lead to a mispricing in the option, as buying put options is equal to selling stocks short. Penalties on short selling, therefore, may lead to an increase in the price of put options. (Black, 1992b, p. 54)

4.2.3 There are no transaction costs in buying or selling the stock or option.

Trading at stock exchange triggers a number of costs and taxes connected to trading options. Commission costs are paid to the broker, fees are taken by the option clearing company (OCC), etc. and of course the investor has to pay taxes for his earnings, according to the laws of the country. (Johnson, 2009, pp. 36-40) Taxes are influencing the option value. In which way taxes are influencing the price of options is difficult to determine, as there are many aspects to the influence of taxes on the trading behaviour of investors. E.g. individuals are taxed differently compared to companies. Simply for this fact their investing behaviour is diversified. (Black, 1992b, p. 55)

In relation to potential profits from mispriced options transaction, costs are often substantial. "Because of transaction costs, it is not possible to maintain a neutral hedge continuously, changing the ratio of your option position to your stock position as the stock price and other factors change." (Black, 1992b, p. 55) Transaction costs are not the only reason for being unable to sustain a perfect hedge at every point in time. To keep them as low as possible Black is suggesting building a portfolio out of long positions in underpriced options and short positions in overpriced options. By doing this, the risk stays low even if the portfolio is not rebalanced continuously. (Black, 1992b, p. 55)

4.2.4 The stock pays no dividends or other distributions

Dividends are payments by a company, which are either reinvested into business or paid to the shareholders. In the case of a dividend paying stock, the stock holder receives at certain dates, called ex-dividend dates, a certain amount out of the option. At this ex-dividend date, the stock´s price goes down by a certain amount, equal to the dividend paid per share. (Hull, 1995, p. 273) Thus, dividends have basically one effect: They reduce the stock price on the ex-dividend date. The values of call options are therefore negatively related to the size of anticipated dividends, whereas put options are positively correlated. (Hull, 1995, p. 200) Dividends, therefore, make early exercises of call options more likely and early exercises of put options less likely. (Black, 1992b, p. 55) As the Black-Scholes model does not take dividends into account, these dynamics and the effects on the stock price have not to be taken into account.

4.2.5 The short-term interest rate is known and constant through time

The constant risk-free interest rate is another basic assumption of financial mathematics. In practice the short-term interest rate is set equal to the risk-free interest rate on an investment that lasts for time T. (Hull, 1995, p. 268) Usually, investments such as government bonds, US Treasury bills or savings accounts are taken to evaluate the risk-free rate. These investments grow according to a continuously compounding interest rate and increases an amount D_0 by $e^{r_f t}$ over time t. Usually, the value of the risk-free rate is between 1% - 10%. The assumption that the interest rate stays constant over time, does not reflect reality. In fact, the rate changes over the life time of an option and depends on the invested amount. (Higham, 2004, p. 12) But this assumption is not critical, as empirical findings have come to the conclusion, that option pricing is not sensitive to the assumption of a constant interest rate. (Poon, 2005, p. 72)

For the Black and Scholes model, this risk-free rate is essential as the hedged portfolio is always constructed in such a way that the return is equal to the return of a risk-free investment. Therefore, the risk-free rate is the benchmark, which must be exceeded by the portfolio. At first sight, the assumption that the interest rate has to be constant seems to be redundant, as the price which is derived from the Black-Scholes model is equal to the value of the perfect hedge portfolio at maturity, discounted with the actual rate of the risk-free investment. But, when the value of the perfect hedge is measured at the actual interest rate, an unpredictably changing interest rate would lead to unpredictable final values of the perfect hedge portfolio and therefore, not calculable call prices. (Weßels, 1992, p. 33)

4.2.6 The option is "European" and can therefore only be exercised at maturity

Under this assumption, it is guaranteed that the option is not executed before maturity. As already previously described within the BTT, the information exchange process is better reflected by an American call option, rather than a European call option. It is not likely that the holder of an option already knows the perfect execution date in advance. At this point, one major problem arises. The Black-Scholes formula is unable to calculate the value of an American option. The formula has been designed to calculate values for European options only, as the current assumption of Black-Scholes states that the investor is not allowed to exercise the option before maturity. (Black, 1992a, p. 52) Therefore, usually binominal models are used for valuing American options, where these characteristic can be taken into account.

Two years after the presentation of the Black-Scholes formula Black proposed an approximation method (Black, 1975), which enables the Black-Scholes formula to calculate the value of an American option. However, this approximation does not work with the same degree of preciseness in all cases. It leads to different values compared to binominal models. This deviation has two reasons: (Hull, 2009, p. 301)

1. *Timing of the early exercise* – Black`s approximation implies that the decision maker has to decide, in advance, whether he will exercise the option before expiry date and at which point in time. In binominal models, the decision maker can take this decision on the specific day, based on the stock price. Therefore, binominal models tend to have greater values than Black`s approximation values.

2. *How volatility is applied* – In a portfolio with for example two ex-dividend dates, the need for estimating the exercise point in time is influencing the volatility, as it is either applied to the stock price, less than the present value of the first dividend, if exercised early, or two dividends, if exercised at expiry date. In this case, Black´s approximation values tend to be greater than the values of the binominal models.

As Black´s approximation would in most cases lead to different values, it is inadequate for the purpose of this diploma thesis. However, calculating the value of an American option with the Black-Scholes formula is still feasible. In finance mathematics the special case of American options with underlying stocks that pay no dividend over the life-time, is mentioned. In this case, it can be proven that it is never optimal to exercise an American call option on a non-dividend paying stock before the expiry date. Therefore, the opportunity to do so is worthless[10]. (Sharpe, Alexander, & Bailey, 1995, p. 688)

This conclusion has also been stated by Merton (Merton, 1973), who contributed substantially to the Black-Scholes model. Let $S_{(t)}$ denote the asset price and $E_{(T)}$ denote the exercise price. Assuming that the holder wishes to exercise the option for a specific price E, at some point t before the expiry date T, $t < T$ is true. Of course, as he wants to gain profit the following has to be true $S_{(t)} - E > 0$ at time t. But instead of doing this, he has another possibility: he could sell the asset short at market price at time t and then purchase the asset at time $t = T$. In this way he does best by exercising the option at $t = T$ and buying at the market price at time T. The holder has gained amount $S_{(t)} > E$ at time t and paid out an amount less or equal to E at time T, which is better than gaining $S_{(t)} - E$ at time t. (Higham, 2004, p. 174)

To demonstrate the dynamics, the following example is provided: A stock with the current price of $\$110$ has a call option with an exercise price of $\$100$ that is selling for $\$14$. The intrinsic value (if exercised immediately) and time values (excess of the option´s price over its intrinsic value) are $\$10$ $(= \$110 - \$100)$ and $\$4$ $(= \$14 - \$10)$. The owner of the option could exercise it by spending $\$100$, but would always have less additional costs by selling the call option and buying the share of stock at the stock exchange, as this would only cost him $\$96$ $(= \$110 - \$14)$. (Sharpe, Alexander, & Bailey, 1995, p. 689)

[10] It should be noted that there is a difference between being unable to exercise the option before the expiry date and the mathematical proof that this is not reasonable.

4.2.7 It is possible to borrow any fraction of the price of a security to buy it or to hold it, at the short-term interest rate

Basically, this assumption is made to guarantee that, at any point in time, the perfect hedge position can be created. The type of hedging used in the B-S model is called *dynamic hedging*, contrary to the *static hedging*, where the hedged position is created once and never rebalanced. To be precise, the hedging within the Black-Scholes model is called *delta (Δ) hedging*. It is defined as the change in the option price with respect to the price of the underlying asset: (Hull, 2009, pp. 360-361)

$$\Delta = \frac{\partial f}{\partial S} \tag{4.14}$$

A delta of a call option on a stock of 0,6 would mean that, if the stock price changes by a small amount, the call price changes by 60% of that amount. The investor must now create a position where the delta of the stock position offsets the delta of the call position. If this is the case, this position is called *delta neutral*. Out of this position every loss in the option value is equalized with a gain in the stock value and vice versa, which keeps the portfolio risk free. This position must be sustained by constant rebalancing. Black-Scholes set up a riskless portfolio consisting of -1 option and $+\Delta$ shares of the stock. In this way they created a delta neutral position and argued that the return on the position should be the risk-free interest rate. (Hull, 2009, pp. 361-362)

In reality, investors are forced to hold only an integer amount of stocks, respectively options. For the model, this would mathematically mean that it is possible that at some point, no perfect hedge could be created. To avoid this it is assumed that it is for example possible to create a long position in three quarters of a stock. By this assumption financial derivatives become infinitely divisible. At first sight, this assumption is strangely formulated, as it does not state that borrowing of a part of the security is possible, but that only borrowing fractions of a price is possible. What is meant, is that the correlation between the buying of a part of a security and the price paid, must be constant. Buying three quarters of a stock therefore means paying only three quarters of the price. This analogy must, of course, be true for selling too. The expression “hold it” concerns the creation of short positions for which this infinite division must also hold. Being in a hold position with a short sale allows therefore, also gaining interest rate with these fractions of the price of the security.

4.2.8 Finance mathematic inherent assumptions

For creating and designing the models e.g. of option evaluation, such as the Black-Scholes model, assumptions are made that are necessary for the models. One example is that lending rates equal borrowing rates and securities are infinitely divisible. This is not the case for real world markets, but is assumed to be able to create a perfect hedge portfolio. These assumptions are often summed up in literature as a definition of the so called *frictionless market*, which is an idealised version of the reality.

The above is a further assumption of the model that does not meet reality. Usually, borrowing rates are higher than lending rates. Additionally, margin requirements or restrictions put on by lenders, usually limit the possible borrowing amount. These limitations and high borrowing rates increase the value of an option, as options provide leverage that can substitute for borrowing. In this case, limited traders want to buy more options, but traders, who can borrow freely at a rate close to the lending rate, are more interested in getting leverage through borrowing rather than buying options. (Black, 1992b, p. 54) Although not explicitly taken into account by the Black-Scholes assumptions that have been discussed, the following assumptions are not less important, as they are inherently contained in the model.

4.2.8.1 No arbitrage (i.e. market is at equilibrium)

One of the key principles of the option evaluation theory and mathematical finance is that there is no arbitrage. Arbitrage refers to the financial strategy that, on the one hand, allows no possibility of a loss and, on the other hand, allows the possibility of a gain. The risk for the investor must be truly zero and not just small and, if money is spent, there must be no chance of a net outflow at any time. (Vaaler & Daniel, 2007, p. 324) “There is never an opportunity to make a risk-free profit that gives a greater return than that provided by the interest from a bank deposit.” (Higham, 2004, p. 13)

The most obvious arbitrage is given when different financial (e.g. geographically separated) markets are not at equilibrium. This leads to the following situation: As a company can be denoted at different stock exchanges, one stock of the same company can have different values at different stock exchanges. It is therefore possible for the trader to make money without any risk by buying the stocks at the out-of-equilibrium market and selling them with profit at the market which is at equilibrium. It should be noted that the arbitrage opportunity is always short lived, as these transactions will trigger the price level of the not-at-equilibrium market to reach the price level of the market, which is at equilibrium. It is therefore assumed that there is no arbitrage at all. (Joshi, 2003, p. 19)

One example: One share of a company is worth $US\$1$ at the NY stock exchange. However, the company is also written at the Singapore stock exchange, where the company´s share is worth $S\$1{,}8$, indicating that the market is not at equilibrium. If the conversion rate is $US\$1 = S\$1{,}7$, a broker could sell 100 shares at the NY stock exchange and sell them instantly at the Singapore stock exchange making a profit of $S\$10$. Big broker houses make such transactions, as they have virtually zero transaction costs. (Baaquie, 2004, p. 17)

Furthermore, out of the no arbitrage assumption upper- and lower-bounds for standard option (*plain vanilla*) prices can be derived. Let $c_S(t,T,K)$ and $p_S(t,T,K)$ denote the value of a European call, respectively put, option at time t with expiry date T and strike price K and the spot price $S(t)$. If $C_S(t,T,K)$ and $P_S(t,T,K)$ denote the values of an American call respectively put option, the boundaries can be drawn as follows[11]: (Deutsch, 2008, pp. 81-82)

	European options
Call	$max\{0, S(t) - K\} \leq c_S(t,T,K) \leq C_S(t,T,K)$
Put	$max\{0, K - S(t)\} \leq p_S(t,T,K) \leq P_S(t,T,K)$
	American options
Call	$max\{0, S(t) - K\} \leq C_S(t,T,K) \leq S(t)$
Put	$max\{0, K - S(t)\} \leq P_S(t,T,K) \leq K$

Table 1 The upper and lower boundaries of option prices drawn from the no-arbitrage assumption

If one of these rules is violated, arbitrage is possible. It would e.g. then be possible that a call is worth more than the underlying asset. In this case, the call could be sold, one piece of the underlying bought and the rest of the money can be kept. (Deutsch, 2008, p. 82)

Why are these findings important? The main reason is that it can be used to determine the unknown value of a financial derivative. A portfolio A is constructed where under investigation an instrument, with known price along with one unit of the derivative, can be observed. The second portfolio B, the duplicate portfolio, contains exclusively instruments with known prices and is constructed to have at T the same value as portfolio A. As before from the no-arbitrage assumption, it can be assumed that both portfolios must have the same value at prior time $t < T$ as well. Therefore, the value of the financial derivative can be calculated for any time $t < T$. (Franke, Härdle, & Hafner, 2004, pp. 12, 68)

4.2.8.2 Continuous trading (rebalancing of portfolio is done instantaneously)

Continuous trading is one of the most essential assumptions of the Black-Scholes model as it guarantees that at any point in time, it is possible to create the perfect hedge portfolio. Due to the fact that stock prices change constantly, the rebalancing of the portfolio has to be performed constantly after every price change to guarantee that the ratio, between option and security within the portfolio, is kept constant.

The assumption of the continuous trading can be for example violated by takeovers. If company A takes over company B by buying up stocks, it also takes over the regarding options. But now, the volatility of company A must be considered for the evaluation of these options. The effects on the option value are very complex and dependent on the modality of the takeover and the likely

[11] Source: own table on basis of Deutsch (Deutsch, 2008, p. 82)

premium. Therefore, Black sees the Black-Scholes model rather as an approximation to a model that includes all these effects which has, so far, not been formulated. (Black, 1992b, p. 56)

Black-Scholes summed up this central assumption in the partial differential equation (PDE) which should, due to its importance, be pointed out explicitly. The basic assumption of the partial differential derivation is that the stock price and the option price depend on the same underlying source of uncertainty, which has already been shown before with the Itô`s lemma. Therefore, a portfolio consisting of the stock and the option can be created, which would eliminate this source of uncertainty. As the portfolio is now seen as riskless, it can earn the risk-free rate of return, which can be denoted as follows: (Poon, 2005, pp. 77-78)

$$\Delta S = \mu S \Delta t + \sigma S \Delta z \tag{4.15}$$

$$\Delta v = \left[\frac{\partial v}{\partial S}\mu S + \frac{\partial v}{\partial t} + \frac{1}{2}\frac{\partial^2 v}{\partial S^2}\sigma^2 S^2\right]\Delta t + \frac{\partial v}{\partial S}\sigma S \Delta z \tag{4.16}$$

$\mu \ldots premium\ for\ risk\ (return\ on\ S)$
$\sigma \ldots volatility$
$v \ldots value\ of\ the\ derivative$
$S \ldots value\ of\ the\ underlying\ asset$
$t \ldots time$

It should be noted that formula 4.16 represents the discrete notation of Itô´s lemma as now Δt, Δv and Δz are used. In analogy to the arguments of the Itô´s lemma Δz is the same for both processes and can be eliminated by choosing a portfolio of the stock and the derivative. The hedging portfolio, Π, is created, which consists of $\frac{\partial v}{\partial S}$ number of shares and short one unit of the derivative security denoted as follows: (Hull, 2009, p. 287)

$$\Pi = -v + \frac{\partial v}{\partial S}\mathrm{S} \tag{4.17}$$

The change in the value of the portfolio $\Delta\Pi$ in the period Δt is denoted as follows: (Hull, 2009, p. 288)

$$\Delta\Pi = -\Delta v + \frac{\partial v}{\partial S}\Delta \mathrm{S} \tag{4.18}$$

Substituting equation 4.15 and 4.16 into formula 4.18 results in: (Hull, 2009, p. 288)

$$\Delta\Pi = \left(-\frac{\partial v}{\partial t} - \frac{1}{2}\frac{\partial^2 v}{\partial S^2}\sigma^2 S^2\right)\Delta t \tag{4.19}$$

As one can see, this formula does not include Δz. The portfolio must therefore be riskless during the period Δt. As already stated, the portfolio must earn the risk-free rate of return r_f, which leads to $\Delta\Pi = \mathrm{r_f}\Pi\Delta t$. Substituting formula 4.17 and 4.18 into formula 4.19 results in: (Hull, 2009, p. 288)

$$\left(\frac{\partial v}{\partial t}+\frac{1}{2}\frac{\partial^2 v}{\partial S^2}\sigma^2 S^2\right)\Delta t = r_f\left(v-\frac{\partial v}{\partial S}\mathrm{S}\right)\Delta t \qquad (4.20)$$

which can be reformulated to the partial differential equation (PDE) of the Black-Scholes model (Poon, 2005, p. 78)

$$r_f v = r_f S\frac{\partial v}{\partial S}+\frac{\partial v}{\partial t}+\frac{1}{2}\frac{\partial^2 v}{\partial S^2}\sigma^2 S^2 \qquad (4.21)$$

This independency of the model from the investor´s risk preferences is one major advantage compared to other approaches.

4.3 Criticism about the Black-Scholes formula

In the Black-Scholes model, the central assumption exists that certain factors are normally distributed with known mean and variance. Investors want to maximize expected return and to minimize the variance of return. This central assumption can be questioned, as it is for example questioned by Benoît Mandelbrot (Mandelbrot, 1963), who is the pioneer in questioning the normal distribution at the financial markets. (Fama, 1963) He stated that the normal distribution leads to an underestimation of the risk and an overestimation of the expected return on the financial markets. (Mandelbrot & Hudson, The (Mis)Behaviour of Markets, 2004)

Within the Black-Scholes formula, the assumption of normally distributed returns arises out of the *geometric Brownian motion model* that is used to predict stock price developments. As the return is assumed to be normally distributed, small changes in price are much more likely than big changes. In fact, statistically there is a leptokurtosis ("fat tails"): The likelihood of returns near the mean and the variance is bigger than the *Brownian model* would predict. (Chriss, 1997, p. 115) In the following graph the red line represents an example of such a leptokurtosis, which can be shown as follows[12]:

[12] Source: own illustration

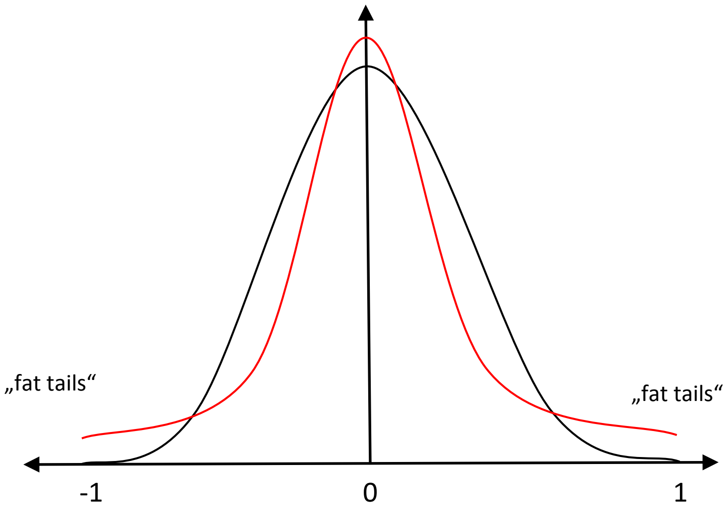

Figure 7 Comparison of the standardised normal distribution and a leptokurtosis

It appears that the wrong assumption of the normally distributed returns had its origin with Markowitz. (Markowitz, 1952) His use of the normal distribution function combined with the following popularity of his work, led to the embedding in the recent literature of portfolio selection, although he himself never constituted the assumption of normally distributed returns as the only possibility. (Markowitz, 1952, p. 80)

Further criticism refers to the assumptions of the model: In reality, transaction costs are not negligible - especially as the portfolio has to be constantly adapted to changes in stock prices and option prices. The constant rebalancing of the portfolio is not given, as neither stocks nor options are treaded continuously. Furthermore, stocks and options are, in reality, not infinitely divisible. Short selling of stocks is prohibited and the short selling of options underlies the margin-rules. The risk-free rate is not determinable for sure on real world financial markets and is not constant. (Kohler, 1992, p. 90)

Several empirical studies have been made, since the introduction of the Black-Scholes model, in order to prove the ability of the model to reflect the reality of option pricing. The following results have been found: (Pape & Merk, 2003, pp. 14-15)

1. The Black-Scholes formula overvalues options with a probability of 81,2%.
2. The longer the run-time of the option and the more the option is “out-of-the-money”, the higher the probability of a mispricing.
3. The assumptions of the Black-Scholes model are, in reality, not given and there are hints that the option market is not fully efficient.

Due to Pape & Merk these findings are congruent with other empirical studies of e.g. Mac Beth/ Merville (MacBeth & Merville, 1980) and Rubinstein (Rubinstein, 1985). However, Black himself has tried to prove the model empirically (Black, 1975) and came to the conclusion that highly “in-the-money” options are overvalued and highly “out-the-money” options are under-priced. Empirical studies, which compare the Black-Scholes model with other alternatives like e.g. Cox`s “constant elasticity of variance” (CEV) model (Cox, 1975) came to the conclusion that the Black-Scholes model has been outperformed. (Lauterbach & Schultz, 1990) A very good overview of option evaluation models and their applications can be found at Broadie and Detemple. (Broadie & Detemple, 2004)

Black was surprised that the model had become so popular, although there are shortcomings that he was well aware of. He pointed out that the assumptions behind the model are very simple. Therefore, the model is not considered perfect and should only be seen as an approximation. Black realised that the success of the model was founded in its simplicity. He stated: “Because the formula is so popular, because so many traders and investors use it, option prices tend to fit the model even when they shouldn´t” (Black, 1992a, p. 21) He expressed his surprise that, concerning the multitude of variables, option formulae get even close to reality. (Black, 1992a, p. 51)

Recent works on the Black &Scholes model have brought several extensions to the model itself and enervate some of the criticised points. It is for example not necessary that the volatility is constant. The model also holds, for instance, with a volatility, which is dependent on t (Ankudinova & Ehrhardt, 2008) or also a stochastic volatility (Ingber & Wilson, 2000). Merton (Merton, 1994) e.g. has gathered some developments of research regarding the violation or extension of the Black-Scholes model: The model even remains valid, when the stock pays dividends, the interest rate is stochastic and the option is exercisable before maturity. (Merton, 1994, p. 310) Furthermore, the model is valid when the proceedings of the short sale are not used. (Thorp, 1973) Also the introduction of differential taxes, dividends or interest payments does not influence the validity of the model. (Ingersoll, 1976) Nevertheless, the model assumptions should be analysed in their base form, as Black-Scholes proposed them.

5 Parameters for the Agent Based System (ABS)

Agents within the ABS must be able to improve their knowledge and must have the ability to transfer pieces of information between each other. For this purpose, the agent based model introduced by Günther (Günther, 2007) is referred to. The model by Günther focuses on the intra-organisational knowledge transfer between employees and the effects on creating innovations. (Günther, 2007, p. 159) It provides ideas for solving certain problems that arise from the desired knowledge exchange process. Although this diploma thesis does in no way deal with the subject of innovation, the characteristics of the agents and also the modelling of the social network by Günther, could be perfectly used for this work.

For the knowledge exchange, one must distinguish between the case of the personal knowledge exchange and the impersonal information exchange. In the case of the personal exchange, one can think of company employees, who meet informally to exchange knowledge. In addition to this internal knowledge transfer possibility, the employees are able to buy external information on an anonymous information market. Both transfer types allow the following exchange possibilities:

1. <u>Personal knowledge exchange</u>:
    a. *Unidirectional (asymmetric) knowledge exchange*: The provider hopes that he will obtain even more valued knowledge in the future. This exchange situation is referred to as the Type-2 information exchange situation from the BTT. In this case, a special attribute of the personal knowledge exchange is assumed: Knowledge that has been passed on personally can only be given back personally. There is no chance of mixing the personal knowledge exchange with the impersonal information exchange situation.
    b. *Mutual knowledge exchange*: Knowledge is exchanged immediately at the same point in time in both directions. This type refers to the previous defined Type-1 information exchange situation of the BTT.
    c. *No knowledge exchange*: This scenario is reflecting “real world” situations such as informal meetings for socializing needs, where only private topics are discussed. It is assumed such meetings play a significant role in reality, because meetings purely for socialising needs often take place between humans.
2. <u>Impersonal information exchange</u>:

    In this scenario, the information exchange happens via an information market. No personal meetings between the agents are necessary. The pieces of information are traded like at the stock exchange, where the value of information can be observed such as stock prices. Contrary to the personal knowledge exchange, it is possible to exercise the option at any point in time, not only at personal meetings. The agents have no social connection and do not know each other in advance of their trading actions. Therefore, all influencing effects that arise out of social connections can be neglected.

The following chapters describe first the agent characteristics; second, the social networks that influence the personal knowledge exchange; and third, the virtual information market for the impersonal information exchange. It should be noted that the terms “agent” and “employee” are used equivalently in the following chapters. The term “knowledge exchange” is chosen on purpose and should be understood as the only possibility at personal meetings. Due to the personal character of the face-to-face communication, it is possible to not only provide information, but to provide it together with the background of the information provider and to immediately correct eventual misunderstandings. This is different from impersonal exchange where, due to missing personal contact, only information without the previously named attributes is exchanged. This distinction between knowledge and information may vary from definitions of other authors: see e.g. (Barachini, 2009, p. 99). They are of the opinion that knowledge itself cannot be transferred directly, as it is embedded in the person itself. The distinction used in this diploma thesis should not be seen as a contribution to the on-going discussion of knowledge management about the difference of knowledge and information. In this diploma thesis, the distinction is used to clearly separate the two types of the impersonal and the personal exchange from each other. Whenever information is exchanged, it is performed within the impersonal exchange setup, while on the contrary, knowledge transfers only happen within the personal exchange setup.

5.1 Trading agents

For the simulation, a finite number of agents {1,...,N) is defined. With respect to the setup and the specific characteristic of the traded good knowledge/ information, their first level priority is to maximize their knowledge level by either exchanging (intra-organisational) or buying (extra-organisational) pieces of information. The second level priority is to maximize their profits by trading options on the virtual information market. The agents are both: provider and buyer of information. Due to the idea of the BTT, the trading agents are able to evaluate the options by using the options evaluation formula by Black-Scholes. These priorities may seem to have conflicting goals, but as having exemplary knowledge is financially rewarded on the virtual information market, the two goals are complementary.

The modelling of the agent´s characteristics has to focus on the knowledge/ information transfer process. According to the model by Günther, certain characteristics of the agents are therefore defined to make it possible to perform such an exchange process (Günther, 2007, pp. 161-162): These are the absolute communication frequency, the knowledge level, the knowledge development and exchange as well as the knowledge loss. These characteristics will be explained in detail in the following chapters.

5.1.1 Absolute communication frequency

It is assumed that employees have different knowledge levels as well as different communication skills. They vary due to personal abilities or work load of projects, they are involved in. The absolute communication frequency (acf) reflects the individual ability, respectively the possibility of a single agent to be part of the knowledge/ information exchange process. The acf represents the likelihood that an agent communicates with other agents and is constant over time. The absolute communication frequency can be denoted as follows: (Günther, 2007, p. 164)

$$acf_i \in]0,1]$$

$acf_i \ldots absolute\ communication\ frequency$
$i \ldots agent\ index$

The value of 0, as it would represent an agent who is unable to interact with his neighbourhood, is of no use for the simulation and is therefore not included in the range of values for the acf in order to guarantee a minimum communication frequency. An acf value of 0,8 would mean a 80% probability that the agent is participating in the communication process. If we think of modelling the point $t = 0$ for the agent based simulation, it is necessary to define a distribution function, which determines the acf values for the whole number of agents within the system. This function is monotonically increasing, continuous and looks as follows[13]:

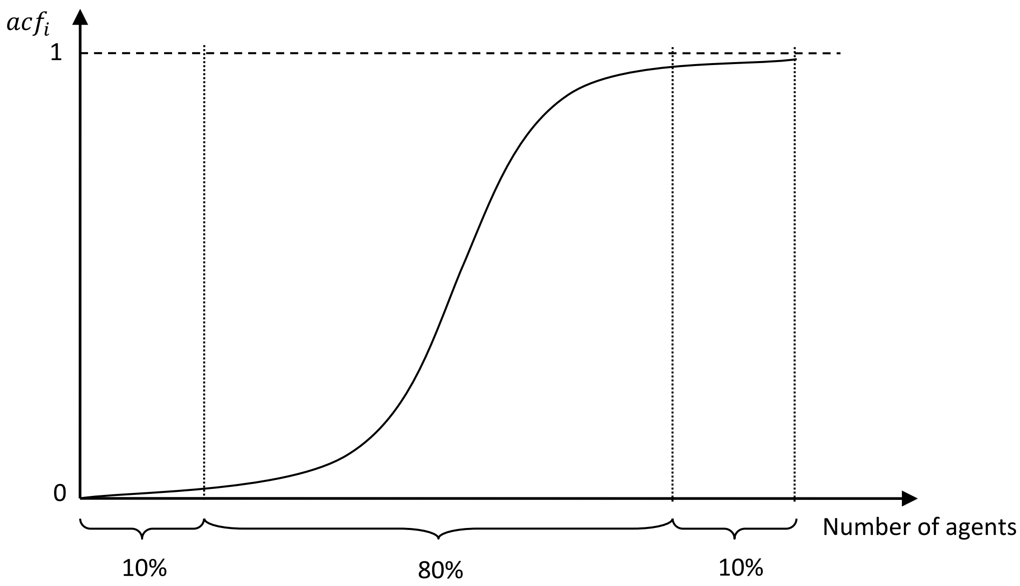

Figure 8 Distribution function of acf values across the agents

[13] Source: own illustration

According to this distribution, 10% of the agents are either almost unable to communicate or, are totally overloaded with other aspects of their work $(acf < 0{,}1)$. On the upper side of the distribution, 10% have a lot of spare time, which they can use to improve their knowledge level $(acf > 0{,}9)$. The majority of agents are placed between both extremes, which should perfectly reflect reality. After the allocation of the acf values to the single agents, they are randomly split up into the social networks, which are representing the different companies. As the agents are placed along the x-axis in a sequential order (e.g. from 1 to 50, if $N = 50$), there can be an inference drawn from the number of the agent and the acf level, as agent one would always be the one with the lowest acf level.

A possible extension to the model by Günther would be to model the acf dynamically. In this case, the acf represents the "normal" level, which reflects the effort for routine or daily tasks. This value is kept constant. On top of this daily workload employees can be part of projects. Due to the degree of involvement in other projects of the company, it is feasible to assume that this workload changes as projects are brought to an end, or new projects are started. This would lead to "more-periodic" changes over time. E.g. a five week project that an agent is involved in lowers the acf frequency from 0,6 to 0,3 for five time periods. With the end of the project, the acf falls back to the "normal" level. It is concluded that several possible outcomes can arise out of this setting as agents must not be limited to one project at one time. If, for instance, three projects are handled simultaneously in one period, they reduce the acf value by their cumulated workload values.

5.1.2 Knowledge level

The varying knowledge levels k of different agents i in different knowledge fields f at a certain point in time t can take a value between 0 and 1, where $k_{i,f,t} = 0$ would mean no knowledge of the specific agent in this specific field at all and $k_{i,f,t} = 1$ would represent perfect knowledge of the agent in this area. As there is a need for the group of agents to be modelled heterogeneously, to reflect that humans are not equally gifted, it is necessary to introduce an immutable maximum boundary $k_{i,f}^{max}$ for the knowledge level of an agent who is set in the beginning of the simulation and can be denoted as follows: (Günther, 2007, p. 162)

$$k_{i,f}^{max} \in [0{,}1]$$

According to this, the knowledge level is denoted as follows: (Günther, 2007, p. 163)

$$k_{i,f,t} \in [0, k_{i,f}^{max}]$$

$i \ldots agent\ index$
$f \ldots knowledge\ field\ index$
$t \ldots time\ index$

$k_{i,f,t}$ ... $knowledge\ level\ of\ agent\ i\ in\ field\ f\ at\ point\ t$
$k_{i,f}^{max}$ ... $maximum\ boundary\ of\ the\ knowledge\ level$

The distribution function of $k_{i,f}^{max}$ is the same as with the acf distribution, but yet slightly modified. First, there has to be one distribution function for each knowledge field. Second, the ranking of the agents along the x-axis is no longer chronological but random, as a chronological order would again mean agent 1 is the most ungifted agent in every knowledge field. This would be especially precarious, as due to the former acf value allocation, he would not only be the lowest gifted, but also the one who has the fewest time for improving his knowledge. After the $k_{i,f}^{max}$ levels are set for each agent, the agents get actual knowledge levels assigned randomly due to previous defined restrictions ($k_{i,f,t} \leq k_{i,f}^{max}$).

5.1.3 Knowledge development

In this chapter the question how the knowledge development is modelled, is answered. Günther is referring to the concept of the S-shaped learning curve, which can be denoted as follows: (Günther, 2007, p. 169)

$$f(itc, i) = k_{i,f}\left(itc; \alpha_{i,f}, \beta_{i,f}, k_{i,f}^{max}\right) = \frac{k_{i,f}^{max}}{1 + \beta_{i,f} e^{-\alpha_{i,f} itc}}$$

$k_{i,f}$ ... $observable\ variable$
$k_{i,f}^{max}$ ... $saturation\ limit$
itc ... $information\ transfer\ through\ communication$
$\alpha_{i,f}, \beta_{i,f}$ ... $factors\ which\ determine\ the\ shape\ of\ the\ learning\ curve$

If $\alpha_{i,w} > 0$, the learning curve has the typical S-shaped form. (Günther, 2007, p. 169) The S-shaped form of the knowledge development can be interpreted as a possibility to take network effects of knowledge into account. Entering a new research topic, without any prior knowledge, means to first study the basics and gather knowledge. This process is very time and resource intensive with no rapid improvement of the knowledge level. At the point, where the knowledge within a specific research field has reached a level, where cross-references can be drawn and the correlation between the gathered knowledge appears, the gathering and further learning process increases rapidly in efficiency. This would be the rising part of the S-curve. This process continues until the saturation limit, when all available information has been gathered, is reached and the curve flattens out.

In the best case, the agent has a reachable knowledge level close to one. But, the model should also reflect the fact that agents are not equally gifted in their learning abilities and have, in respect to their knowledge fields, different potential for the personal knowledge development. This is modelled by configuring the previously introduced saturation limit $k_{i,f}^{max}$ and is shown as follows[14]:

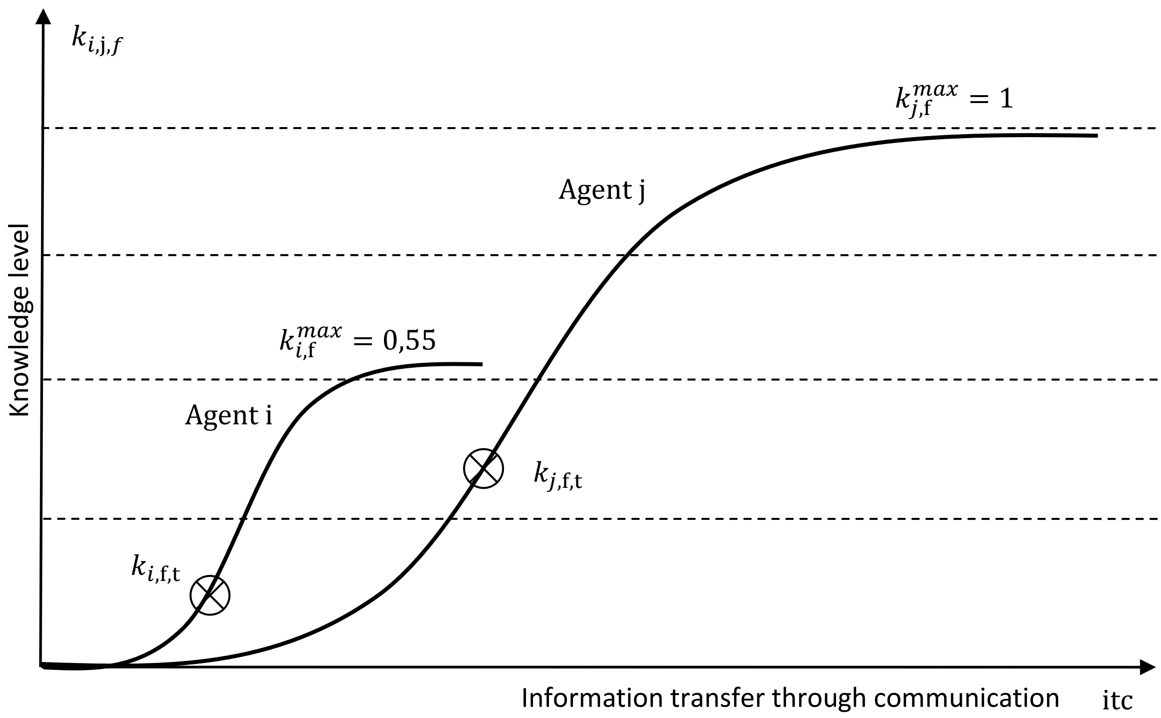

Figure 9 Example of agents with S-shaped learning curves and different saturation limits

Figure 9 shows the learning curve of two different agents who are differently gifted[15] in the same knowledge field. The cross on the curve denotes the actual knowledge level of the agents in the current period.

5.1.4 Knowledge exchange

The knowledge exchange process is always seen as an asymmetric unidirectional transfer of knowledge. Even the previously defined mutual information exchange consists of two separated asymmetric unidirectional information exchanges between the same agents, as the information cannot be exchanged at the same time in both directions. The increase in the knowledge level of agent i, which happens through the information transfer by agent j can be denoted as follows: (Günther, 2007, p. 170)

$$\Delta k_{i,f,t}(\mathrm{j}) = f_i\left(f^{-1}(k_{i,f,t-1}) + \Delta\mathrm{itc}(\mathrm{i},\mathrm{j},\mathrm{f})\right) - k_{i,f,t-1}$$

$f(itc, i)$ defined the shape of the S-curve for agent i. $\Delta\mathrm{itc}(\mathrm{i},\mathrm{j},\mathrm{f})$ now determines the increase in the knowledge field f of agent i through the transferred knowledge from agent j. The increase in the knowledge level is ascertained by adding the acquired knowledge $\Delta\mathrm{itc}(\mathrm{i},\mathrm{j},\mathrm{f})$ to the actual position of

[14] Source: own illustration on basis of Günther (Günther, 2007, p. 170)
[15] Denoted by the different k_{f}^{max} levels.

the agent on the S-curve and by then subtracting the knowledge level of the former period. The actual knowledge level is therefore calculated as follows: (Günther, 2007, p. 171)

$$k_{i,f,t} = k_{i,f,t-1} + \Delta k_{i,f,t}(\mathrm{j})$$

which can be rewritten as (Günther, 2007, p. 171)

$$k_{i,f,t} = f\left(itc\left(f^{-1}\left(k_{i,f,t-1}\right) + \Delta itc(i,j,f)\right), i\right)$$

It is assumed that, only if the knowledge level of the emitter (j) is higher than the knowledge level of the receiver (i), a learning effect that leads to an increase of the knowledge level of the receiver takes place. The maximum boundary for this increase would be the knowledge level of the emitter. This can be denoted as follows: (Günther, 2007, pp. 171-172)

$$\Delta\mathrm{itc(i,j,f)} = \begin{cases} \min\left(P_{itc}; \left(f^{-1}\left(k_{j,f,t}\right) - f^{-1}\left(k_{i,f,t}\right)\right) \times h_{i,t}^{itc}\right) & k_{j,f,t} < k_{i,f}^{max} \\ P_{itc} & k_{j,f,t} \geq k_{i,f}^{max} \end{cases}$$

s.t.

$$k_{j,f,t} - k_{i,f,t} \leq h_{i,t}^{itc} \leq k_{j,f,t} - k_{i,f,t} + 1$$

$$h_{i,t}^{itc} \in \{0; 1\}$$

P_{itc} ... *learning increase parameter*
$h_{i,t}^{itc}$ ... *auxiliary variable which determines the value range*

If $k_{j,f,t} < k_{i,f}^{max}$, then the second part of the minimum function determines the upper boundary to avoid that more knowledge than the emitter possesses is transferred. This is done via the auxiliary variable $h_{i,t}^{itc}$, which is 1 if $k_{i,f,t} < k_{j,f,t}$ and 0 if $k_{i,f,t} \geq k_{j,f,t}$. (Stummer & Heidenberger, 2003) Assuming that the actual knowledge level of the emitter is above the maximum reachable boundary of the receiver $\left(k_{j,f,t} > k_{i,f}^{max}\right)$, the increase by P_{itc} is only possible to the value of $k_{i,f}^{max}$. (Günther, 2007, p. 172)

Graphically, the knowledge exchange can be drawn as follows[16]:

[16] Source: own illustration

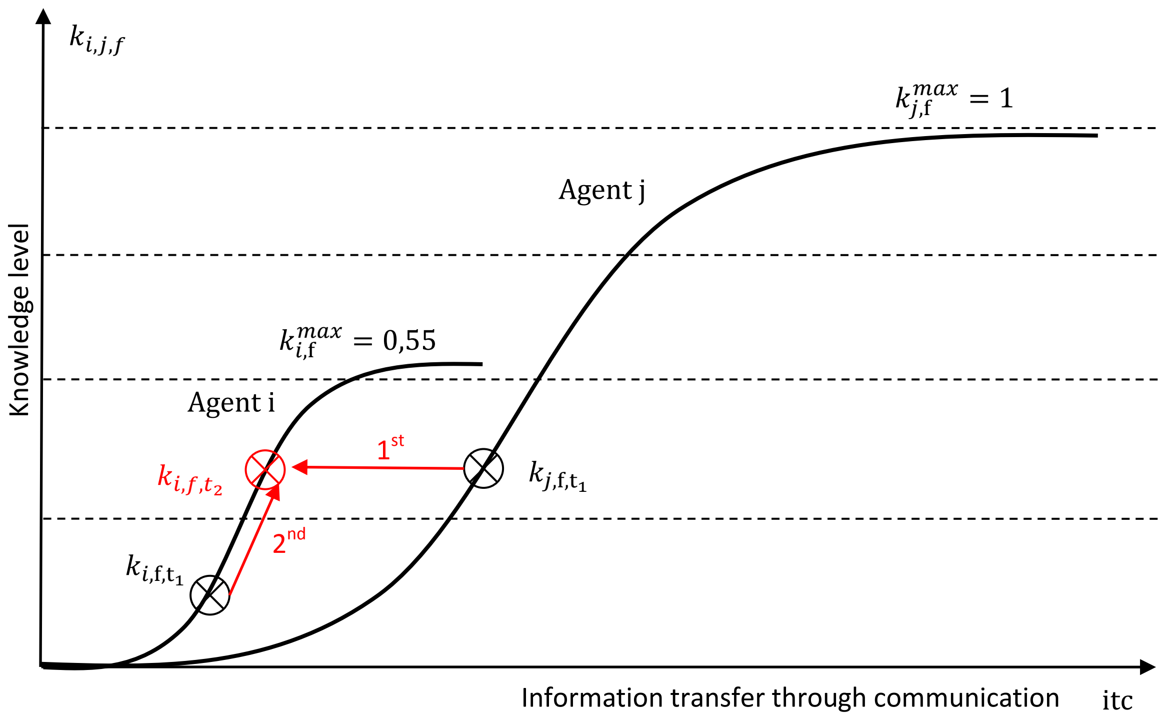

Figure 10 Knowledge exchange between two agents

As one can see in figure 10, agent j passes his knowledge to agent i. Assuming a complete transfer of the knowledge, agent j increases through the exchange, the actual knowledge level of agent i (k_{i,f,t_1}) to his own actual knowledge level, resulting in $k_{i,f,t_2} = k_{j,f,t_1}$. As $\Delta itc(i,j,f)$ can never exceed $k_{i,f}^{max}$, it is, in the first place, always a theoretic possible maximum increase $\Delta itc^T(i,j,f)$. Only if it does not exceed $k_{i,f}^{max}$, it is added to k_{i,f,t_1} with the full amount. (Günther, 2007, p. 172)

5.1.5 Distance in knowledge levels

With the information transfer, another effect should be taken into account: If the knowledge levels of the trading agents are significantly apart, it is assumed that the agent with the lower knowledge level will have problems understanding the complexity of the provided knowledge/ information. Therefore, the learning effect would be diminished. On the other hand, if both agents are on nearly the same knowledge level, as $k_{i,f}^{max}$ is the upper boundary of the learning increase, the total increase would be quite small. The best learning effect is achieved if the knowledge levels of the agents are settled between both possibilities. (Günther, 2007, pp. 197-199) This effect can be modelled as follows: (Günther, 2007, p. 198)

$$\delta_{i,j,f,t} = k_{j,f,t} - k_{i,f,t}$$

First, the distance of the knowledge levels of the two trading agents is calculated. Second, the ratio between the knowledge level of the receiver and the difference in the knowledge levels between the receiver and the emitter is calculated: (Günther, 2007, p. 198)

$$\psi_{i,j,f,t} = \frac{k_{j,f,t}}{\delta_{i,j,f,t}}$$

Then the information transfer through communication is calculated: (Günther, 2007, p. 198)

$$\Delta itc(i,j,f) = \max\left(\min\left(\psi_{i,j,f,t}, \delta_{i,j,f,t}\right), 0\right)$$

$\delta_{i,j,f,t}$ *… distance in the knowledge levels in knowledge field f between agent i and agent j at time t*
$\psi_{i,j,f,t}$ *… ratio between the knowledge level of agent i and the distance in the knowledge levels*
itc *… information transfer through communication*
$k_{i,f,t}$ *… knowledge level of agent i in field f at point t*
$k_{j,f,t}$ *… knowledge level of agent j in field f at point t*
i, j *… agent index*
f *… knowledge field index*
t *… time index*

The information transfer process, taking the difference in knowledge fields into consideration, can be graphically shown as follows[17]:

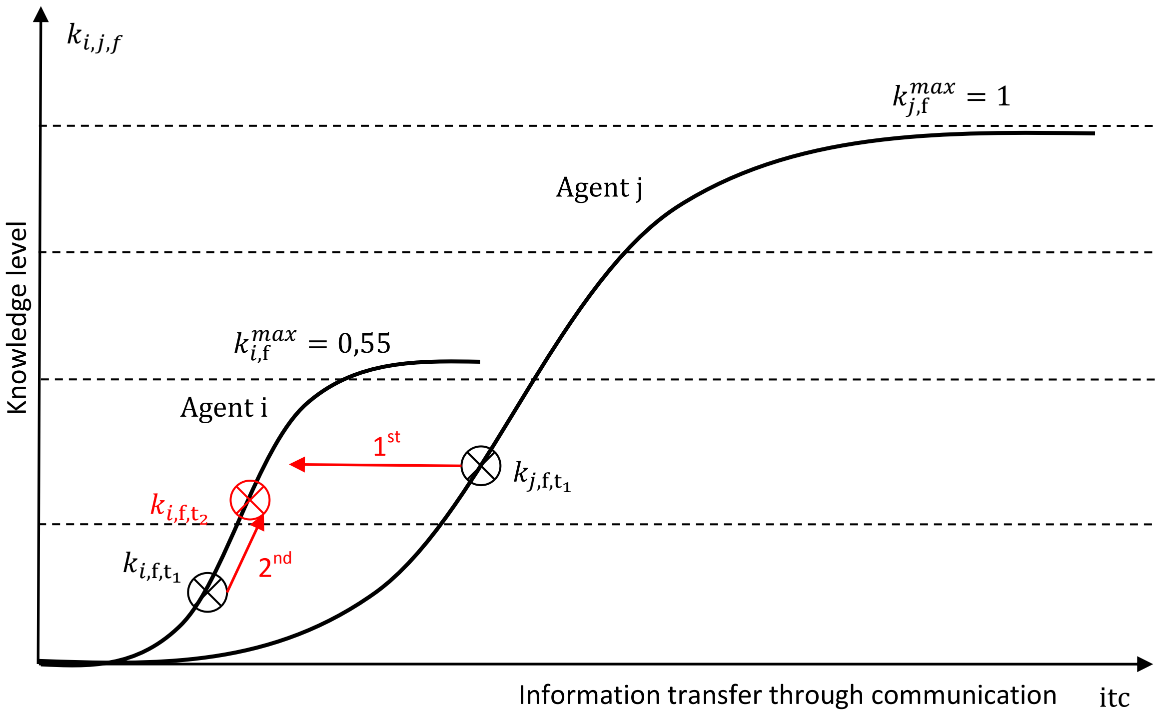

Figure 11 Knowledge exchange taking into consideration the difference in knowledge fields

As one can see in figure 11 agent j passes his knowledge to agent i. But this time a difference in knowledge fields leads to a diminishing factor. The transfer of the knowledge is not leading to an increase up to the knowledge level of the emitter. Agent j increases through the exchange the actual

[17] Source: own illustration

knowledge level of agent i $k_{i,\mathrm{f},\mathrm{t}_1}$ not to his own actual knowledge level $k_{j,\mathrm{f},\mathrm{t}_1}$, but to by the diminishing factor lowered level[18] $k_{i,\mathrm{f},\mathrm{t}_2}$.

5.1.6 Knowledge loss

The last characteristic of the agents is the knowledge loss. If the agents do not constantly access their own knowledge, they keep forgetting what they have learned. This characteristic also guarantees a maximum relation to reality of the ABS. A time factor for each knowledge field is introduced, which defines the time period in which the knowledge level is decreasing, should it not be accessed repeatedly. Knowledge is accessed, when information is passed to or received from another agent and is defined as follows: (Günther, 2007, pp. 173-174)

$$k_{i,f,t} = k_{i,f,t-1} - h_{i,f,t}^{forget} k_f^{forget,amount}$$

s.t.

$$h_{i,f,t}^{forget} = \begin{cases} 1 & \left(t - k_{i,f}^{last\ active}\right) \geq k_{i,f}^{forget,time} \\ 0 & \left(t - k_{i,f}^{last\ active}\right) < k_{i,f}^{forget,time} \end{cases}$$

$k_{i,f,t}$ ... $knowledge\ field\ f\ of\ agent\ i\ at\ time\ t$
$h_{i,f,t}^{forget}$ ... $auxiliary\ variable$
$k_f^{forget,amount}$ ... $knowledge\ loss\ in\ knowledge\ field\ f$
$k_{i,f}^{last\ active}$ ... $time\ of\ last\ activation\ of\ the\ knowledge$
i ... $agent\ index$
f ... $knowledge\ field\ index$
t ... $time\ index$

The formula provides motivation for agents to share their knowledge and to participate actively in the information exchange process. Furthermore, this aspect of the knowledge loss brings volatility into the knowledge development of the single agents. If no knowledge loss would take place, the knowledge levels of the agents would be constantly increasing. Setting the knowledge loss to a level at which the agents have to access their knowledge every period, in order not to forget, would result in a highly volatile knowledge development, which can be seen as an equivalent to highly volatile stock price developments.

A possible extension of the knowledge loss characteristic would be, to assume a knowledge loss function that is dependent on the actual knowledge level of the agent. In this case, it is assumed that basic knowledge, like e.g. multiplying or adding, is not as easily forgotten, as highly complex

[18] It should be noted that due to the personal relation and the face-to-face transfer of the personal exchange situation, the diminishing factor could be modelled smaller than with the impersonal exchange.

knowledge of quantum mechanics, which is owned at the latter end of the knowledge level S-curve. Therefore, the knowledge loss period decreases, the further the agent improves in his knowledge level, leading to the result that exemplary knowledge can only be sustained, if repeatedly accessed within very short periods. This extension would also lead to an increased interest of agents with profound knowledge to be part of teaching processes, in order to sustain their knowledge level.

5.2 Personal knowledge exchange through a social network

In this chapter the modelling of the intra-organisational knowledge transfer (personal exchange) is described. As the personal exchange is only possible in face-to-face communication, the employees must be located in the same spot. Therefore, they should be e.g. part of the same department, located in the same building, having several contacts per day or week, in order that a social connection can develop. The main question is how the social connection between the agents is influencing their knowledge exchange process. As outlined previously a successive learning function is assumed. The knowledge is transferred in the form of a conversation, in which the superior agent is teaching his counterpart everything he knows in a certain knowledge field.

5.2.1 Network structure

Analyses have shown that companies can be modelled as a group of information processing agents. (DeCanio & Watkins, 1998) The biggest problem in an intra-organisational setup is the difference between the hierarchical network and the social (personal) network. Numerous publications have addressed the problem of the coexistence of formal and informal structures in organisations like e.g. Watson & Weaver (Watson & Weaver, 2003), Guimera et al (Guimerà, Danon, Díaz-Guilera, Giralt, & Arenas, 2006) etc. These researches focus on the embedding of knowledge transfer and knowledge flow within the structural characteristics of organisations. (Tang, Mu, & MacLachlan, 2008, p. 1109)

Empirical studies show that formal organisation of processes has a great influence on the patterns of interaction, including affective relations. (Johanson, 2000) Generally, it can be stated that: "There is considerable consensus among scientists and practitioners that organisational actors use both formal and informal coordination devices side by side in order to achieve their targets." (Rank, 2008, p. 145) However, there are differences in the approaches to transfer organisational setups into agent based systems. One approach is the agent-oriented approach, where the design focuses on the single actions of the agents. In this approach agents have a common goal and cooperate, which makes it suitable for closed systems, but they are neglecting the organisational structure. Out of this disadvantage the organization-oriented multi-agent-systems (MAS) arose, which focus on the organisational concept. (Argente, Julian, & Botti, 2006, pp. 56-57) The organization-oriented approach is used for open MAS, where also malevolent agents can enter the network. In this case, goals are not common and agents do not cooperate by implication. (Carabelea & Boissier, 2006, p. 73) In order to model the organisational network and the actors as close to reality as possible, factors like agents leaving/ entering the company and malevolent agents must be considered. However, this diploma thesis only represents a basis, which enables agents to exchange knowledge with an option like procedure. Changes in the network structure caused by leaving or entering agents should therefore, in the first step, not be taken into account. The focus of this chapter lies on the knowledge exchange within an informal network. Agents are cooperating and have a common goal. This makes the approach of this diploma thesis classifiable as an agent-orientated approach.

The organisational structure on the other hand is too important to be neglected, especially as it directly influences the knowledge diffusion process. (Cowan & Jonard, 2004) There have been e.g. findings that knowledge transfer in a scale-free structure is more effective than in a hierarchy structure. (Tang, Xi, & Ma, 2006) Furthermore, even in organisations, which call themselves post-bureaucratic and non-hierarchical, the intra-organisational communication process of the employees persistently reproduced hierarchical structures and official channels, even if this was not the original purpose. (Oberg & Walgenbach, 2008) Therefore, the network structure of the ABS should contain hierarchical, as well as informal communication channels.

A good approach to combine the informal and formal communication channels is describing the network as a graph. "The organization itself is defined by the pattern of information exchange among the agents." (DeCanio & Watkins, 1998, p. 278) The modelling of the network by graph theory allows great flexibility, as the network can have any form ranging from complete interconnectedness to hierarchical tree structures. In this case, informal channels can exist alongside formal communication structures. (DeCanio & Watkins, 1998, p. 278)

A graph G is a pair $G = (V, E)$ consisting of a (in)finite set $V \neq \emptyset$ and a set E of two-element subsets of V. The elements of V are called *vertices* and an element $e = \{a, b\}$ of E is called an *edge* with *end vertices* a and b. a and b are *neighbours* of each other or *adjacent* and write $e = ab$. The complete graph K_n has n vertices and all two-element subsets of V as edges. (Jungnickel, 2005, p. 2) This can be shown as follows[19]:

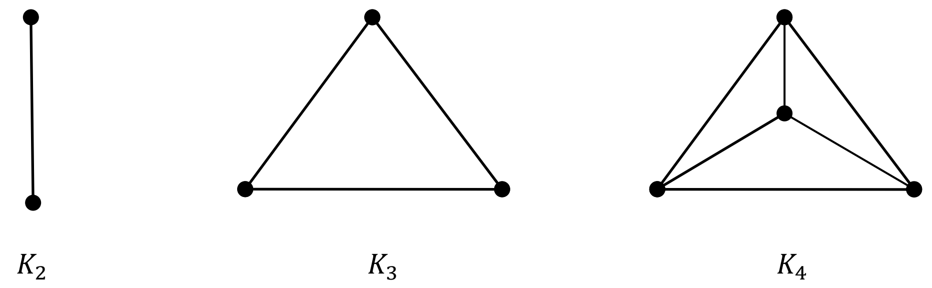

Figure 12 Illustration of some exemplary graphs

This possibility of illustration makes graphs especially easy to apply on the organisational chart of the companies, as these are reflecting the formal structure of the company. Especially, the possibility of arranging the graph as a tree, given that the graph is connected, acyclic and has n-1 edges, (Jungnickel, 2005, p. 7) is matching the organisational chart. Informal networks can be found by

[19] Source: own illustration on basis of Jungnickel (Jungnickel, 2005, p. 3)

questioning employees and illustrating the results in addition to the existing formal chart. Furthermore, graphs can be noted as matrices, which are called *adjacency matrices*. The adjacency matrix $A = (a_{ij})_{n \times n}$ of G is defined by: (Diestel, 2005, p. 28)

$$a_{ij} := \begin{cases} 1 & if\ \{v_i, v_j\} \in E \\ 0 & otherwise \end{cases}$$

The recently most popular idea within the graph theory is the "small-world" idea[20], which has been established by Milgram (Milgram, 1967). It is based on the assumption of coexistence of high local clustering and short global separation. Based on the idea by Milgram, Watts and Strogatz (Watts & Strogatz, 1998) developed the small world model. They criticised that "Ordinarily, the connection topology is assumed to be either completely regular or completely random.**".** (Watts & Strogatz, 1998, p. 440) In reality, networks are placed somewhere between both extremes and the small world model is one possibility to reflect this fact. The small world has four properties: (Watts, 1999, pp. 495-496)

1. A network has a number $n >> 1$ people.
2. The network is sparse. Every person within the network is only connected to an average of k other people.
3. The network is decentralized. The average degree k, as well as the maximal degree k_{max}, over all vertices must be much less than n.
4. The network is highly clustered, which means that most friendship circles are overlapping.

Graphically, this can be shown by a ring lattice with n vertices and k edges per vertex, where p denotes the probability, with which the edges are rewired randomly[21]: (Watts & Strogatz, 1998, p. 440)

[20] For a structured overview see e.g. Schnettler (Schnettler, 2009b)
[21] Source: Watts & Strogatz (Watts & Strogatz, 1998, p. 441)

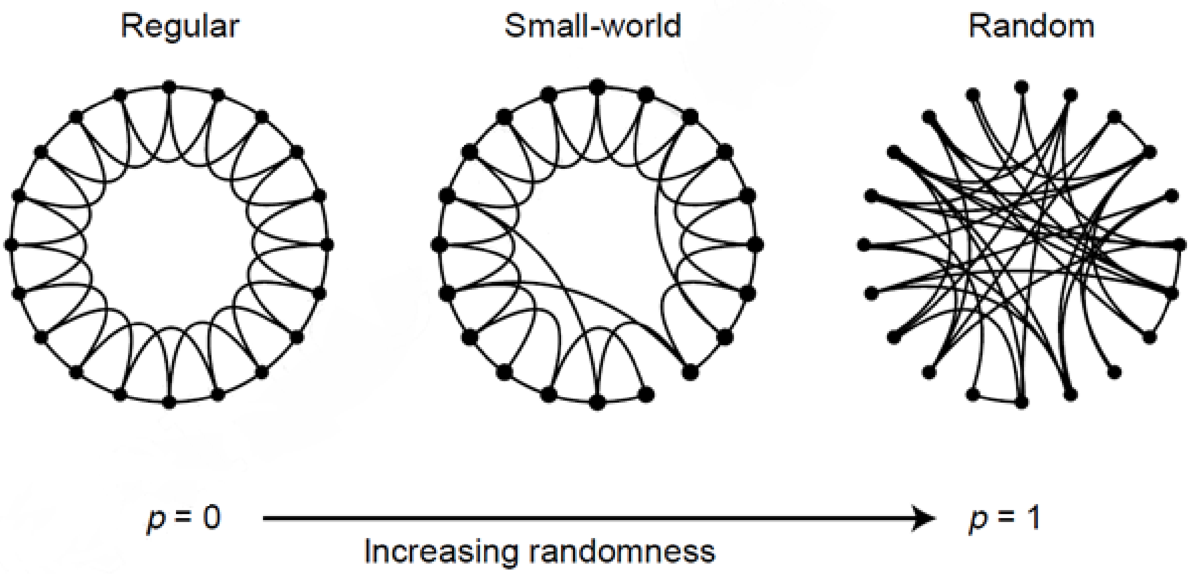

Figure 13 Small world networks with different levels of randomness

Is this small world model now applicable for an organisational setup? Milgram has later tried to find justification for this idea through an empirical study. (Travers & Milgram, 1969) This study and also following empirical studies concerning the small world phenomenon have been strongly criticised by researchers for having methodological weaknesses that bias their results like e.g. by Schnettler (Schnettler, 2009a). A recent study on small organisational networks came to the conclusion that a discrepancy between the perception of employees of the connectivity of their social network and the reality exists. (Killworth, McCarty, Bernard, & House, 2006) Employees seem to use the small world idea in order to keep track of their relations. In reality it seems "...that small worlds may be more prevalent in people's cognitions than in reality." (Kilduff, Crossland, Tsai, & Krackhardt, 2008, p. 26) Nevertheless, until more researchers have come to this conclusion the small world principle represents a suitable model for the network structure of a company and should be used.

5.2.2 Relative communication frequency

Referring to the model by Günther the social connection is reflected by the relative communication frequency $rcf_{i,j}$. (Günther, 2007, pp. 165-168)

$$rcf_{i,j} \in [0, 1]$$

$rcf_{i,j}$ ... $relative\ communication\ frequency\ between\ agent\ i\ and\ j$
i ... $index\ of\ the\ agent\ communicating\ with\ j$
j ... $index\ of\ the\ agent\ whose\ communication\ is\ defined\ by\ i$

In principal a weighted network[22] is assumed with unidirectional, asymmetric and dynamic relationships. The following figure shows an example for a social network of three agents. The higher the value of $rcf_{i,j}$, the closer the social connection between the agents[23]: (Günther, 2007, p. 192)

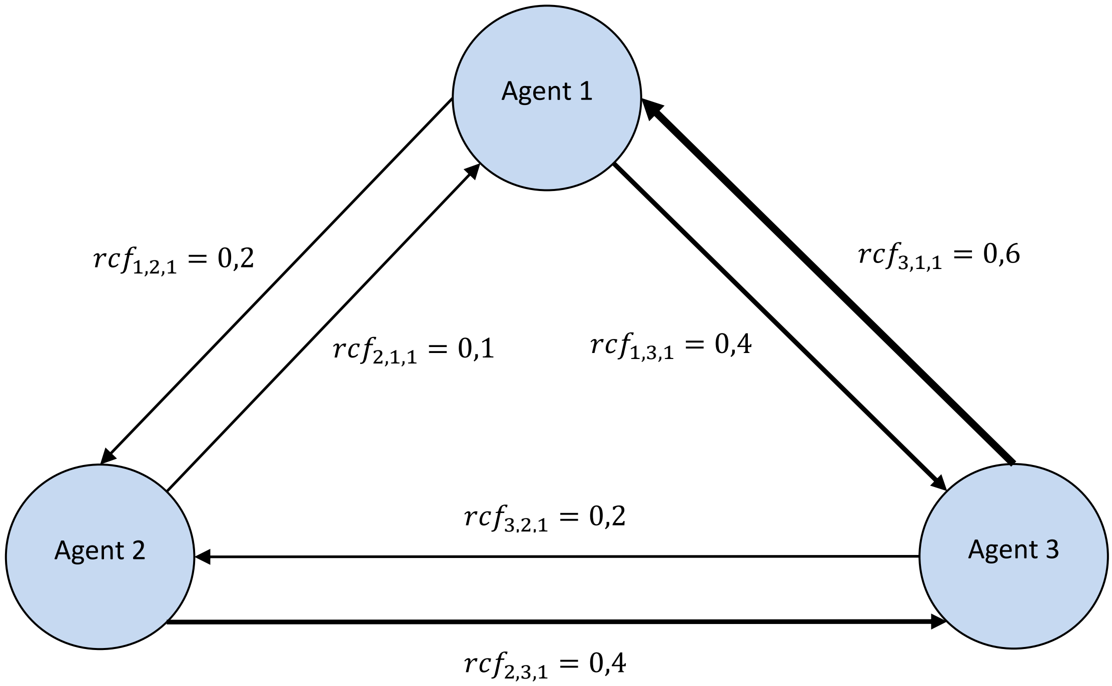

Figure 14 Relative communication frequency

This weighted network can be denoted in a matrix and leads through reformulation to the adjacency matrix, which reflects the social network structure: (Günther, 2007, pp. 166-167)

$$RCF = \begin{pmatrix} 0 & 0{,}2 & 0{,}4 \\ 0{,}1 & 0 & 0{,}4 \\ 0{,}6 & 0{,}2 & 0 \end{pmatrix} \therefore A = \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix}$$

Contrary to the approach by Günter, where the agents are brought together randomly, the agents should search for a perfect counterpart. In this case, the rcf values should be seen as probabilities. If $rcf_{i,j} = 0{,}3$, then the probability that the agents communicate with each other is 30%. The reason for different values in the social connection between employees can be either that the subjective impression about the relationship diverges, or e.g. the hierarchical position within the company. In this case, the subsidiary agent is judging the relationship not as well as the superior agent due to the fact that he has a different social status compared to the counterpart.

5.2.3 Communication process

First, the acf_i of an agent is determining, if he is participating in the communication process. If this value is positive for the actual period, the search for a counterpart is initiated. In the communication

[22] For literature on weighted small world networks see e.g. Li et al (Li, Lin, & Liu, 2007)
[23] Source: own illustration on basis of Günther (Günther, 2007, p. 167)

process the relative communication frequency plays a major role, as the $rcf_{i,j}$ is not only valid for describing the social network, but also has major influence on the individual probability for establishing a communication channel. There are further criteria for initialising a communication process: One factor would be the knowledge level $k_{j,f}$ and also the possible available time acf_j of the counterpart. The communication process within the social network is initiated by the attractiveness of the counterpart and is denoted as follows: (Günther, 2007, p. 187)

$$itc^{att}(i,j,f,t) = \left(k_{j,f,t} \times w_i^k\right) \times \left(rcf_{i,j} \times w_i^{rcf}\right) \times \left(acf_j \times w_i^{acf}\right)$$

s.t.

$$w_i^k + w_i^{rcf} + w_i^{acf} = 1$$

$$w_i^k \in [0,1]$$

$$w_i^{rcf} \in [0,1]$$

$$w_i^{acf} \in [0,1]$$

$itc^{att}(i,j,f,t) \ldots attractiveness\ of\ agent\ j\ for\ agent\ i\ in\ knowledge\ field\ f\ at\ point\ in\ time\ t$
$k_{j,f,t} \ldots knowledge\ level\ of\ agent\ j\ in\ knowledge\ field\ f\ at\ point\ in\ time\ t$
$rcf_{i,j} \ldots relative\ communication\ frequency\ between\ agent\ i\ and\ agent\ j$
$acf_j \ldots absolute\ communication\ frequency\ of\ agent\ j$
$w_i^k \ldots weighting\ factor\ for\ the\ importance\ of\ the\ knowledge\ level\ of\ agent\ j\ for\ agent\ i$
$\mathrm{w}_i^{rcf} \ldots weighting\ factor\ for\ the\ importance\ of\ the\ relative\ communication\ frequency\ of\ agent\ j\ for\ agent\ i$
$\mathrm{w}_i^{acf} \ldots weighting\ factor\ for\ the\ importance\ of\ the\ absolute\ communication\ frequency\ of\ agent\ j\ for\ agent\ i$

5.2.3.1 Step 1 – Ascertaining the weights

The previous formula gives latitude to a great variety of possible combinations and determines why a certain counterpart is chosen for the knowledge exchange. For some employees the fact that the counterpart is always available plays a major role e.g. due to a personal high involvement in projects. For others a close social connection is the most important factor. Another employee may only be interested in learning as much as possible, no matter how good the social connection or the availability of the counterpart is. There should be some general rules made for determining the exact value of the weights for the choice of the counterpart:

- Due to the top level priority of the agents to improve their knowledge, the weight for the knowledge level of the counterpart should initially be greater than the weights of the absolute communication frequency and the relative communication frequency leading to $w_i^k > w_i^{rcf}, w_i^{acf}$.

- The lower the own acf_i in relation to the $rcf_{i,j}$, the higher the weight on the counterpart´s acf_j, as it is assumed that people who have less time, stress more the availability criterion, than the social connection criterion, leading to $w_i^k > w_i^{acf} > w_i^{rcf}$.
- The higher the own acf_i in relation to the $rcf_{i,j}$, the higher the weight on the social connection, as it is assumed that the agent, due to the high possibility of being able to exchange knowledge every period, is more focused on exchanging knowledge with well known colleagues leading to $w_i^k > w_i^{rcf} > w_i^{acf}$.

It should be noted that the top level priority weight for the knowledge would result in the fact that the agent, who knows most within the social network, would be questioned by all other agents. Due to this, only the fewest would profit, as the superior agent is limited to one teaching process per period. This problem will be solved in step 4 later in this diploma thesis.

5.2.3.2 Step 2 – Ascertaining the values of acf_j, $rcf_{j,i}$ and $k_{j,f}$

For choosing the counterpart it is assumed that the searching agent is not meeting every agent in his social network, to ask for the exact values of acf_j, $rcf_{j,i}$ and $k_{j,f}$. Knowing all these values precisely would mean that there is perfect knowledge within the network, which would not be realistic. It should be noted that due to the bidirectional design of the social connections, a difference is made between $rcf_{i,j}$ and $rcf_{j,i}$. The relative communication frequency $rcf_{i,j}$ is the value of the social connection from agent i to agent j, where $rcf_{j,i}$ reflects the social connection from agent j to agent i. This is crucial for the following design of the initialising process, because the only factor that can be determined by the initiating agent i, who is searching for a perfect match, is $rcf_{i,j}$, the personal judgement of the social connection to agent j. The other parameters acf_j, $rcf_{j,i}$ and $k_{j,f}$ of the counterpart cannot be known for sure in the search process. For this reason fuzzy logic is introduced, to simulate imperfect knowledge[24]. The fuzziness of the variables is dependent on the only certain known value: the $rcf_{i,j}$. The closer the social connection of agent i to his possible counterpart is, the smaller the fuzziness about the acf_j, $rcf_{j,i}$ and $k_{j,f}$ levels of the counterpart is.

The fuzzy set theory was introduced by Zadeh (Zadeh, 1965) and was intended to be a mathematical framework to deal with inexact measurement. Introducing fuzzy variables for the purpose of simulating imperfect knowledge within the ABS has especially one reason: One application field of fuzzy logics is the quantification of linguistic expressions. It allows e.g. an allocation between

[24] The choice for fuzzy variables is done on purpose, as they provide other possibilities than probability distributions. For a clear separation of both terms see e.g. Roso (Roso, 2009, p. 41)

linguistic expressions like “Alternative A is “medium better” than alternative B.” to quantifiable intervals. (Wang & Chen, 2010, p. 204) By this ability it would be possible, to quantify estimates of single employees about e.g. the knowledge level of colleagues and create input variables for the ABS.

For the ABS a triangular fuzzy number A or simply a triangular number with membership function $\mu_A(x) \in \mathbb{R}$ is assumed. The interval $[a_l, a_r]$ represents the supporting interval and $(a_m, 1)$ the peak. (Bojadziev & Bojadziev, 1997, p. 23) This can be shown in a graph[25]:

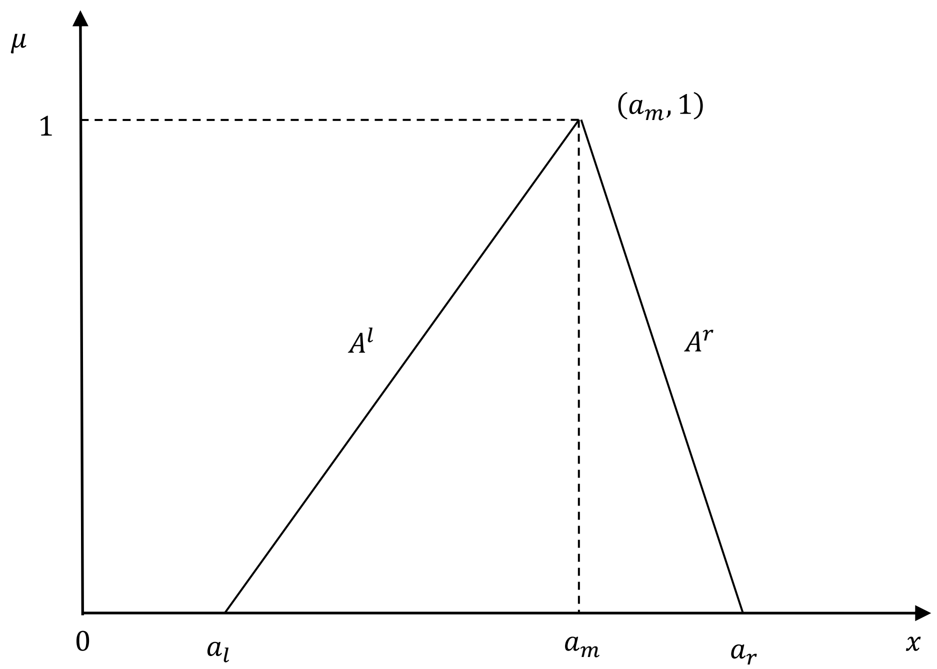

Figure 15 Triangular fuzzy number

This triangular fuzzy number can be denoted as follows: (Bojadziev & Bojadziev, 1997, p. 22)

$$A \equiv \mu_A(x) = \begin{cases} \dfrac{x - a_l}{a_m - a_l} & for\ a_l \le x \le a_m, \\ \dfrac{x - a_r}{a_m - a_r} & for\ a_m \le x \le a_r, \\ 0 & otherwise \end{cases}$$

and is often written as $A = (a_l, a_m, a_r)$. Therefore, within the search process for the counterpart agent i is only given the fuzzy values of acf_j, $rcf_{j,i}$ and $k_{j,f}$ looking e.g. like $acf_j = (0{,}3; 0{,}5; 0{,}7)$. However, agent i has not only one possible counterpart, but many and has three fuzzy variables with which he has to create a ranking to determine a favourite counterpart.

5.2.3.3 Step 3 – Creating a ranking based on expected value of fuzzy numbers

A great variety of methods exist since the early beginning of this research field, as described e.g. by Zimmermann (Zimmermann, 1987). Numerous techniques to create rankings with fuzzy variables

[25] Source: own illustration on basis of Bojadziev & Bojadziev (Bojadziev & Bojadziev, 1997, p. 23)

have been added since then, like e.g. the distance method (Cheng, 1998), ranking by integral value (Liou & Wang, 1992), the outranking method (Aouam, Chang, & Lee, 2003) etc. To avoid too complex mathematical models for a basic procedure, like the search for an optimal counterpart, the ranking by the expected value is referred to. In this case, the expected value of a fuzzy number is defined as follows: (Matarazzo & Munda, 2001, p. 410)

$$E(A) = \frac{\int_{-\infty}^{+\infty} x\mu(x)dx}{\int_{-\infty}^{+\infty} \mu(x)dx}$$

Where the integral converges absolutely $\int_{-\infty}^{+\infty} |x\mu(x)|dx < +\infty$, as otherwise A has no finite expected value. It should be noted that if A is a triangular fuzzy variable (a_l, a_m, a_r), according to the previous formula, the expected value of A is $\frac{1}{3}(a_l + a_m + a_r)$. (He, Wang, & Dequn, 2009, p. 64)

It should be noted that explicitly no central fuzzy variables are assumed. This special type would lead to the following effect: If the knowledge level of the counterpart is 0,7 and the $rcf_{i,j}$ is 0,1, the according fuzzification, in relation to the closeness of the social relation between the agents, would e.g. lead to $A = (0{,}6; 0{,}7; 0{,}8)$. The problem with central fuzzy variables would be that the expected value is not dependent on the interval, but on the position of the peak [26]. If the peak is equal to the "real value", the agents would again inherently get the "correct" values, independent on the closeness of their relationship, as the variables $A_1 = (0{,}6; 0{,}7; 0{,}8)$ and $A_2 = (0{,}5; 0{,}7; 0{,}9)$ would lead to the same expected value of $E(A_1) = E(A_2) = 0{,}7$. To avoid this inherent acquisition of the "correct" values central triangular fuzzy variables are explicitly excluded. But how can this be done?

To avoid central fuzzy variables the following procedure is applied: The vicinity of the relationship only determines the width of the membership function of the fuzzy variable. For the width of the membership function, simply the complementary value of the $rcf_{i,j}$ value with respect to one is taken, which leads to $rcf_{i,j} + width = 1$. So if $rcf_{i,j} = 0{,}6$ then the bandwidth of the fuzzy variable is 0,4, which is arranged around the peak $k_{j,f} = a_m$. The arrangement of the interval around the peak is done as follows: As it is assumed that a good relationship in reality positively influences the picture of the counterpart and leads to higher estimates about personal skills than they are, for the case of $rcf_{i,j} > 0{,}5$ the interval is placed in such a way that the expected value would lead to a higher expected value than the "real" value, which is stated true when $|a_l - a_m| < |a_m - a_r|$[27]. The

[26] The argument is also true for trapezoid fuzzy variables, as their expected value is calculated as follows: $E[A] = \frac{1}{4}(a_1 + a_2 + a_3 + a_4)$ (Zeng, 2006, p. 103). Triangular fuzzy variables have been chosen for their lower complexity.

[27] Of course for $rcf_{i,j} \leq 0{,}5$ the opposite happens and leads to an underestimation of the real value. In this case, $E(k_{j,f}) < a_m$, which leads to $|a_l - a_m| > |a_m - a_r|$.

"real" value is, as already defined, is e.g. $k_{j,f} = a_m$, where $a_l < a_m < a_r$ must be stated true. For our example this would mean e.g. that the fuzzy variable that agent i receives due to his close relation, looks e.g. like this: $k_{j,f} = (0{,}6; 0{,}7; 1)$. With this variable the "real" value of 0,7, as well as the second condition concerning the distance of a_l and a_r to a_m on the x-axis is fulfilled, as well as the width of 0,4. Furthermore, the localization of the bandwidth has to be in the interval $[0; 1]$, as the variables are limited to this range. By this procedure the expected value is either under or above the real value, which means the agent either under- or over-estimates the real value, which is exactly what is supposed to happen.

In principle, the search for a "perfect" counterpart, is a multiple attribute decision making problem (MADM), as the agents have to choose between different possibilities with differently valued attributes. Fuzzy MADM methods generally consist of two phases: In the first phase an aggregation of the performance ratings with respect to all the attributes for each alternative is created. In the second phase a ranking of each alternative according to the aggregated performance ratings is done. (Chen & Klein, 1997, p. 52)

In order to solve this problem a model of He et al. (He, Wang, & Dequn, 2009) is referred to. Let $X = \{X_1, X_2, \dots, X_n\}$ denote a discrete set of $n (n \geq 2)$ potential alternatives, where the alternatives are known and $N = \{1,2, \dots, n\}$. In the ABS X will represent the possible counterparts, where $G = \{G_1, G_2, \dots, G_m\}$ denotes the possible attributes of the counterparts acf_j, $rcf_{j,i}$ and $k_{j,f}$ so $G = \{G_1, G_2, G_3\}$. The attribute value for alternative $X_n \in X$ with respect to attribute $G_m \in G$ is given by the fuzzied real values of acf_j, $rcf_{j,i}$ and $k_{j,f}$. Thus, a fuzzy MADM problem can be expressed in a fuzzy decision matrix $A = (a_{ij})_{m \times n}$, where $a_{ij} = (a_{lij}, a_{mij}, a_{rij})$ is a triangle variable[28]: (He, Wang, & Dequn, 2009, p. 64)

	X_1	X_2	…	X_n
G_1	a_{11}	a_{12}	…	a_{1n}
G_2	a_{21}	a_{22}	…	a_{2n}
⋮	⋮	⋮	⋮	⋮
G_m	a_{m1}	a_{m1}	…	a_{mn}

Table 2 The decision matrix for the fuzzy MADM problem of choosing a counterpart j

The MADM model allows two possible attributes: benefit attributes and cost attributes. Due to the knowledge exchange setup, reference is made only to the benefit attributes. In order to make the values comparable, each attribute a_{ij} has to be normalized into the corresponding element in the matrix $R = (r_{ij})_{m \times n}$ by using this formula: (He, Wang, & Dequn, 2009, p. 64)

[28] Source: own table on basis of He, Wang & Dequn (He, Wang, & Dequn, 2009, p. 64)

$$r_{ij} = \frac{a_{ij}}{\|a_i\|}$$

where

$$r_{ij} = (r_{lij}, r_{mij}, r_{rij})$$

$$i \in M, j \in N$$

$$\|a_i\| = \sqrt{\sum_{j=1}^{n} a_{ij}^2}$$

resulting in (He, Wang, & Dequn, 2009, p. 64)

$$r_{ij} = \left(\frac{a_{lij}}{\sqrt{\sum_{j=1}^{n} a_{rij}^2}}, \frac{a_{mij}}{\sqrt{\sum_{j=1}^{n} a_{mij}^2}}, \frac{a_{rij}}{\sqrt{\sum_{j=1}^{n} a_{lij}^2}} \right)$$

It should be noted that these equations only hold for benefit attributes, although the MADM model also allows calculations for cost attributes. As all three relevant attributes are benefit attributes, the possibility of taking cost attributes into account is neglected. The denominators of r_{ij} are chosen due to the operational laws of triangular fuzzy variables (Chang & Wang, 2009, p. 357), whereas a_{ij}^2 is part of the normalization process.

As the expected value method needs a weight vector for being calculated and the decision matrix has been normalized, the same must be done for the weight vector, which has been created in step one of the communication process. A weight vector $\omega = (\omega_1, \omega_2, \dots, \omega_m)$ can be normalized into $w = (w_1, w_2, \dots, w_m)$ by: (Zeng, 2006, p. 104)

$$w_j = \frac{\omega_j}{\sum_{j=1}^{n} E[\omega_j]}$$

s.t.

$$w_j \geq 0, \qquad j = 1,2 \dots, n$$

$$\sum_{j=1}^{n} E[w_j] = 1$$

For calculating the expected value the simple additive weighting method is applied. Given a normalized decision matrix $R = (r_{ij})_{m \times n}$ and a normalized weight vector $w = (w_1, w_2, \dots, w_m)$ the result is: (Zeng, 2006, p. 105)

$$f_j = \left(\sum_{i=1}^{m} r_{lij} w_i \, , \sum_{i=1}^{m} r_{mij} w_i \, , \sum_{i=1}^{m} r_{rij} w_i \right)$$

with f_j being a triangle fuzzy variable. In order to be able to create a ranking of two or more fuzzy variables, the overall preference values of alternatives can be expressed by real-valued functions $E(f_j)$, $(j \in N)$, which are calculated as follows: (Zeng, 2006, p. 105)

$$E(f_j) = \frac{1}{3} \left(\sum_{i=1}^{m} r_{lij} w_i + \sum_{i=1}^{m} r_{mij} w_i + \sum_{i=1}^{m} r_{rij} w_i \right)$$

$E(f_j)$ can now be used to create rankings, by bringing the different values of the alternatives into a linear order, like e.g. $E(f_1) > E(f_3) \; > E(f_2)$ to ascertain the best alternative.

5.2.3.4 Step 4 – Contact between the agents

After the initialising process, which leads to the choice of a communication counterpart, the real values for acf_j, $rcf_{j,i}$ and $k_{j,f}$ are determined (exchanged from agent j to agent i) and the exchange process starts. Agent i, as he believes agent j is the best colleague to ask for an knowledge exchange, is now physically walking into the office of agent j and specifically asking, how his actual work load situation and knowledge level in the possible knowledge fields is. Such values can easily be communicated. The judgement of the relationship of agent j, about the relationship to agent i, is more complicated, as persons are hardly honest about their relationship and what they think of others. Therefore, it is assumed that this factor is noticed subconsciously by agent i during the talk about the acf_j and $k_{j,f}$ with agent j. It should be noted that this finding process of the counterpart is performed every time anew, as the rcf and especially the knowledge levels change constantly. Although the acf is set constant through the whole simulation, the agents are not aware of this and are renewing their knowledge about the status of the counterpart, with every contact. This would reflect reality, as it is uncertain that the knowledge level and the social relation are static.

Agent i has found his most attractive counterpart with agent j, who´s real acf_j turns out to be 0,3, due to high involvement in other projects. As assumed the knowledge level is above the level of agent i. The social connection of agent j to i turns out to be very good, leading to $rcf_{j,i} = 0{,}7$. In the same way, as the good relationship $rcf_{i,j}$ had a positive influence on the forecasts in the search process, the good $rcf_{j,i}$ must have a positive effect on the probability that the knowledge exchange takes place, by increasing the acf_j value. This is comparable to creating extra time (staying longer in office) for good colleagues, if one is asked to help. Therefore, the average of both values is taken, leading to the inter communication frequency:

$$icf_{j,i} = \frac{acf_j + rcf_{j,i}}{2} = \frac{0{,}3 + 0{,}7}{2} = 0{,}5$$

$icf_{j,\mathrm{i}}$ ... $inter\ communication\ frequency$
acf_j ... $absolute\ communication\ frequency\ of\ agent\ j$
$rcf_{j,\mathrm{i}}$ ... $relative\ communication\ frequency\ between\ agent\ i\ and\ agent\ j$

In this case, the probability that agent j participates in a knowledge exchange is 50%. On the other hand of course, even if an agent has a lot of spare time $acf_j = 0{,}7$,, he will not treat a request from an agent with whom he has a weak social connection $rcf_{j,i} = 0{,}1$ with, equally. The weak relation will lead to an inter communication probability of $icf_{j,i} = 0{,}4$. Even if the $icf_{j,i}$ is 0,5 there is still a 50% possibility that the agents do not exchange knowledge during that period.

Now the dynamic relative communication frequency comes into place. The initial search process is dependent on the seeking agent i, but the question, if the exchange request is treated positively is dependent on agent j. Therefore, agent i can make agent j responsible for the outcome of the actual knowledge exchange probability. If agent i has now found his desired counterpart in agent j, but due to the $icf_{j,i}$ (derived from the acf_j and the $rcf_{j,\mathrm{i}}$) of agent j, the knowledge exchange does not take place. This procedure will negatively influence the relationship between the two agents, as the request of agent i is refused by agent j, the relative communication frequency $rcf_{i,j}$ is lowered. The relative communication frequency $rcf_{j,i}$ between agent j and agent i is remaining constant, as due to the request no negative influence for this side of the relationship arises. On the other hand, of course, a successful established and performed knowledge exchange leads to an increase in the $rcf_{i,j}$ value, as the agent is grateful for the knowledge received.

This concept is comparable to the concept of TRUST described by Günther (Günther, 2007, pp. 205-208), but works different. The TRUST concept adds a new relation type between the agents in addition to the rcf, acf and k that is influenced by successful or unsuccessful transfers. This brings further complexity into the model. The approach of the icf is different as it uses the existing parameters to rebuild the human behaviour of doing favours for good colleagues. Through bringing the acf and rcf together this behaviour can be easily mimicked. Note that this approach inherently assumes that all relations are always also on a personal level and not only pure emotionless business contacts. Although this mind sound like a disadvantage the author is convinced that this reflects reality.

The communication process is initiated by the individual agents, who would allow simultaneously requests from all agents. Therefore, further restrictions have to be made to build a framework, which keeps all interactions clearly separated:

- All communication processes within the social network are initialised sequentially. Therefore, the agents are chosen randomly each round, to choose their most attractive counterpart(s) and initialise the communication process. The searching agent i is calculating the attractiveness of every possible counterpart, with whom he has a social connection. The ranking of the attractiveness is performed every period by every agent, as the relative communication frequency and the knowledge level are dynamic and could change in any given period. The number of requests, where the agent tries to initialise a communication process is limited due to his personal workload situation acf_i. The requests are ranked due to the attractiveness level of the counterparts and executed sequentially by agent i. Only if the priority ranking of the counterpart changes, due to new established contacts, the new ideal partner, that has not been asked until now is contacted. Otherwise the agents continue to perform requests regarding to their priority ranking.
- Every agent is only allowed to be emitter and receiver of knowledge once per period. Therefore, a first-come-first-served principle exists. After having passed knowledge to another agent, all successive requests from other agents are rejected, independent from acf_i, rcf_i and icf_i of the specific agent.
- Within the social network there is always one agent, who knows best in a specific field. As the knowledge level is the attractiveness factor with the highest weight, a situation could arise, where the best knowing agent is asked all the time by the other agents. As he is limited to one teaching process per period, almost all requests are rejected by him. Every rejection influences the $rcf_{i,j}$ negatively. Therefore, the probability that the same agent is asked again is lowered every period. When the weight on the $rcf_{i,j}$ of agent i is low, there is a chance that agent i, although always rejected, keeps on asking every period, due to the high attractiveness level of agent j caused by his exemplary knowledge. However, this would not reflect human behaviour, as in reality after some attempts the requesting employee would resign and give up trying. To avoid that agent i keeps on asking all the time, it is proposed that after five rejected requests, agent j is not asked again for e.g. twenty-five periods; but this case is considered to be the exception.

5.2.3.5 Step 5 –The knowledge exchange

The investment situation at personal meetings should, as already described, reflect the situation where two people meet personally and a knowledge exchange takes place. Three possibilities of knowledge exchange can arise out of this meeting[29]:

[29] These possibilities are in accordance with the BTT and extended with the "no knowledge" exchange. Due to the different definition of information and knowledge, the exchange type notations have been renamed.

- Unidirectional knowledge exchange: This is the exchange situation, which can be mapped to the American call option situation. In this case, one agent is superior in knowledge in every knowledge field. The superior agent passes on knowledge with the hope to receive more valued knowledge in the future.
- Mutual knowledge exchange: In this case, two unidirectional knowledge exchanges happen sequentially within one time period. The two trading agents have superior knowledge in complementary fields, which leads to a learning situation for both of them.
- No knowledge exchange: In this case, either the absolute communication frequency of the agents or the relative communication frequency leads to a situation, where a knowledge exchange is not taking place.

In relation to the acf, rcf and k the three situations are distinguished as follows[30]:

Exchange situation	acf	rcf	knowledge level
Unidirectional knowledge exchange	pos.	pos.	$k_{i,f_n} < k_{j,f_n}$
Mutual knowledge exchange	pos.	pos.	$k_{i,f_1} < k_{j,f_1}$ & $k_{i,f_2} > k_{j,f_2}$
No knowledge exchange	neg.	neg.	$irrelevant$

Table 3 The connection between the exchange situations of the BTT and the agent parameters

It is assumed that the absolute communication frequency, as well as the relative communication frequency, has to be high enough to establish a communication channel between two agents. The only criterion that divides the cases of the mutual knowledge exchange and the unidirectional knowledge exchange is the specific knowledge of the agents. A mutual knowledge exchange takes place, when both trading agents can provide in different knowledge fields a knowledge level, which exceeds the other agent´s level. The exchanged knowledge in the different fields is seen as fair trade and leads to no further expectations of returned knowledge. It should be noted that the absolute amount of the exchanged knowledge is not compared. Both agents are interested in learning and are not holding knowledge back in a selfish way, if they can teach the counterpart more than they can learn from him. Of course, in the case that more than two knowledge fields are defined for the ABS, the exchange takes place in the fields, where the counterpart can increase his knowledge at most.[31]

An unidirectional knowledge exchange takes place, when one agent has superior knowledge in every field compared to the counterpart. In this case, the superior agent shares his knowledge in the desired field of the counterpart, as he is hoping to receive more valued knowledge in the future. This is possible when agent i is gathering additional knowledge from other agents in the meantime and

[30] Source: own table

[31] The "difference in knowledge fields" is of course also valid for this exchange type. The receiver of the knowledge determines from which field of the counterpart he wants to learn.

improves his actual knowledge level over the knowledge level of agent j. This situation reflects the call option situation defined by the type-2 information transfer of the BTT. Agent j does not altruistically pass away knowledge, but has a right to exercise the option that is created in the moment of exchange, at a later point in time, when agent i may have improved over agent j´s knowledge. This right can be compared to reminding agent i of the favour agent j has done to him in the past, by giving him additional knowledge without any cost and now calling for a favour in return.

As the unidirectional knowledge exchange means an investment risk for agent j, he is of course interested in having a payback in form of returned knowledge. The difference to the impersonal exchange situation is the fact that the option can only theoretically be exercised at any point in time. However, as the option is created at a personal meeting, it can only be exercised, if the agents meet each other again. Therefore, agent j is interested to have a second meeting, at least at the expiry date, should the option not have been executed until then. If this happens, the search of agent j is not activated at expiry date of an option, but due to the top level priority he arranges an appointment with the option writer for a meeting.[32] It is of no importance if agent i is available or not (due to the acf), as the option represents an obligation for the writer. In the case that agent i has increased his knowledge, the option is executed. If not, nothing happens and the agents have to wait for the next period to arrange new knowledge exchanges.

The effects on the single parameters of the agents through the defined exchange situations can be shown as follows[33]:

Exchange situation	acf	rcf	knowledge level
Unidirectional knowledge exchange	const.	$rcf_{i,j} \uparrow$	$1st\ k_{i,f_n} \uparrow\ then\ k_{j,f_n} \uparrow or \rightarrow$
Mutual knowledge exchange	const.	$rcf_{i,j}\ \&\ rcf_{j,i} \uparrow$	$k_{i,f_n} \uparrow + k_{j,f_n} \uparrow$
No knowledge exchange	const.	$rcf_{i,j} \downarrow$	$irrelevant$

Table 4 The effect of knowledge exchange situations on the agent´s parameters

In line with the personal knowledge exchange the created option is not written at a knowledge exchange (an analogue to the stock exchange) and is therefore only viewable for the holder and the writer of the option. This is comparable, to having it mapped in the brain, which is intrinsic and not observable by people, who are not involved in the knowledge exchange deal. (Barachini, 2003, p. 43) No knowledge exchange is taking place, when either the absolute communication frequency is not sufficient (no meeting) or the social connection between the agents is insufficient (no knowledge exchange).

32 Of course only, if he is participating at the communication process at all in this period.
33 Source: own table

5.2.3.6 Summary

By this five step procedure the human process of searching for a counterpart is perfectly reflected. It takes aspects, like not asking for help due to a bad personal relationship, or preferring good relations, instead of high knowledge levels with the search for a counterpart, which is also a very human choice procedure. The five step communication process starts with the idea of Günther to choose the counterpart due to a weighted search procedure and extends this idea with concepts like the fuzzification of variables due to the closeness of the relationship between the agents, as well as with concepts like the icf, which directly influences the possibility of a successfully conducted knowledge transfer. The idea of this five step procedure has been, to rebuild reality and to avoid completely random modelling of aspects like meetings and knowledge exchanges, which would hardly provide basis to draw conclusions for reality. The basic idea has been that this model can be used to copy the knowledge transfer reality of e.g. a department, as all necessary variables can be found out by questionnaires and to make it transferable into a simulation, where the setup can be observed under controllable circumstances.

5.2.4 BTT and the personal knowledge exchange

After now having shown, how the agents are modelled and how the knowledge is supposed to be transferred within the ABS, the next step is to connect the BTT with the financial part and the ABS.

5.2.4.1 General clarifications

The BTT states, that due to the option like process, exchanging knowledge can be evaluated by finance-mathematic models like Black-Scholes or the binomial model. Especially, due to the relation to the financial economics, severe restrictions and guidelines for the dynamics of this knowledge exchange process occur. The main question that arises is: "Is it possible to evaluate knowledge exchange with the binomial model, respectively the Black-Scholes option evaluation formula?" Barachini himself labelled the theory of the BTT a thought model (Barachini, 2003, p. 44) and as such, it should be critically reviewed.

In the publications of Barachini regarding the BTT an explicit distinction between personal and impersonal exchange has never been done. This division and further small extensions like e.g. the third exchange situation type (no knowledge exchange) are defined in this diploma thesis for the first time. In addition Barachini never explicitly applied the BTT to an organisational setup. These changes represent no fundamental changes in the theory itself, but incremental extensions to complete the theory. It is assumed that Barachini referred only to the personal exchange, when he created the BTT. This impression arises, as the only examples he gives, when writing about the type-2 exchange situation, are the following: "This is the case when we either earn money due to our profession as e.g. a teacher or when we offer information to individuals in the hope to get even more valuable information back some day in future.” (Barachini, 2003, p. 43) Therefore, the proof of the applicability of the BTT to the personal exchange is of central concern for this diploma thesis.

The BTT consist mainly of two parts: First, the assumption that the knowledge exchange process can be mapped to an option like situation and second, the resulting assumption that it can therefore be evaluated by financial option evaluation models. The following argumentation should therefore be divided into these two parts and proven separately on validity.

5.2.4.2 Knowledge exchange can be mapped to options

At first sight this analogy is of impressive robustness. Even, if someone is not especially familiar with the financial instrument of options, the underlying idea that one passes on knowledge and hopefully receives more valued knowledge in future, can be easily followed. One agent receives knowledge in exchange for guaranteeing a right to the provider of the knowledge, to receive knowledge back, should at some future point in time the receiver’s knowledge exceed the provider’s knowledge. Therefore, an option in a knowledge setup simply represents a right for the holder to receive knowledge in future. The idea creates a setup that is not contradicting human nature, as it does not assume that knowledge is passed away altruistically, but for the selfish aim of improving the own knowledge in future. However, if a closer look is taken at this theory some discrepancies occur:

One problem is the fact that the option writer is personally responsible for the value of the returned knowledge. On the financial market the option writer has no influence at all on the development of the stock price and the resulting option value, as the option writer and the company of the underlying asset are not necessarily the same. Even in the case of a covered call, the option writer only owns the share of the company[34] and has no influence on the company’s strategic, operational or tactical decisions and therefore future development, which is also dependent on unforeseeable market changes like e.g. radical product innovations, crashes of market bubbles, etc. The trading situation arises out of different expectations of the future development. In the ideal case either the writer gains the premium, or the option holder gains the intrinsic value. At the knowledge exchange situation the optimal situation for the option writer would be the case where he is unable to increase his knowledge until option expiration. In this case, he gained the knowledge increase of the option holder and is not obliged to return knowledge, as the holder would not exercise the option, and loses his premium. On the other hand it can be assumed that in return for the received knowledge, humans feel grateful and try to increase their knowledge as far as possible, to maximize the intrinsic value for the option holder. This conflict of interest could be part of further extensions for the ABS, where selfish agents are brought together with grateful agents. For this diploma thesis a homogenous group of grateful agents is assumed. Also the fact that humans are able to lie, should in

[34] No majority share is assumed.

the first step not be implemented into the ABS. In this case, the writer would increase his knowledge further on the basis of the received knowledge and would conceal his own knowledge development before the option holder, so the holder does not execute the option.

Another problem is the premium. On the financial market the option buyer pays the option writer a certain amount of money to receive the right for an option contract. This amount is called the premium. Transferring this setup one-by-one into the knowledge exchange situation within a company, would mean that the superior employee pays his counterpart a certain fee, to buy the right to be taught back, if the counterpart improves over the superior agent´s knowledge level in this certain knowledge field. The superior agent not only shares his knowledge, but also has to pay the receiving counterpart in return for *maybe* more valued knowledge. At this point it seems that the BTT must be wrong, as the informal exchange between individuals does not happen on monetary basis and one person never teaches AND pays; but the given example is not “fair”, as two “goods” (money and knowledge) are transferred in one direction.

It should be noted that an analogy between the money transfer on the financial market and the knowledge transfer in the personal setup exists. Like there is no knowledge transfer between the writer and the holder on the financial market, as the holder simply buys a right to exercise, there is no money transfer between the writer and the holder, in the case of the personal knowledge exchange. As a consequence the monetary premium of the financial market can be substituted by the *immaterial premium* of the knowledge exchange[35], which can be labelled as “costs of knowledge transfer”. These costs can be seen as opportunity costs for the holder of the option, which arise through the time that is invested to codify and transfer the knowledge. As the knowledge is shared, it is no longer unique and cannot be used to the personal advantage of the option holder. This conviction that the own position within a company is weakened, if knowledge is shared, is part of organisational research (Hanft, 1996, p. 144), as knowledge can be seen as organisational resource and is one factor for having power within the organization. (Pfeffer, 1992, p. 81)

How can these findings be transferred into the ABS? The main problem is to ascertain the amount of the immaterial premium. If the knowledge transfer between the agents would be linear, then the receiving agent would reach exactly the level of the teaching agent. This situation would be equal to having no immaterial premium. In this case, the option would already be “at-the-money” and the option holder has almost no risk that the option would not exceed the intrinsic value of zero[36].

[35] It should be noted that the absence of money makes it inherently necessary that the option holder is always above the knowledge level of the option writer, as otherwise no exchange good would exist.
[36] The risk of a negative option value development, due to a knowledge loss of the receiving agent, is equal for the case of the linear knowledge exchange and the knowledge exchange, which includes the restriction through the difference in knowledge fields, and can therefore be neglected for this comparison.

Implicitly the solution to this problem has already been given by the model of Günther and the "difference in knowledge levels". Through the difference in knowledge levels, the value of the premium is determined and the dynamics of the two concepts are perfectly fitting. The higher the difference in knowledge levels is, the higher the loss in process of the knowledge exchange, the higher the immaterial premium and the higher the value for the writer. This linear correlation indicates that the risk of not receiving valued knowledge back for the holder is rising with the difference in knowledge levels, which is an acceptable assumption for reality.

By having transferred the premium into the knowledge exchange situation, two other problems have been solved: the asset price and the exercise price. The asset price is equal to the knowledge level of the receiving agent (agent i), while the exercise price is the knowledge level of the emitting agent (agent j). It should be noted that this transformation implicitly assumes that agent j is keeping his own knowledge level stable for the running time of the option. However, agents should not rely on the unsure returns, but in the meantime further improve their knowledge levels with other knowledge deals. In this case, the running time stays fixed, while the exercise price is modelled dynamically. In the meantime occurring knowledge losses of the emitting agent j could of course also be taken into account. This case is more realistic, as the intrinsic value correlates with the actual knowledge status of agent j. This transformation perfectly fits, as the option holder would only exercise the option, if it exceeds the exercise price and has an intrinsic value. As the exercise price equals his own knowledge level, he only exercises the option, if he will learn from the counterpart. The knowledge increase diagram (profit diagram) with a static exercise price can be drawn as follows[37]:

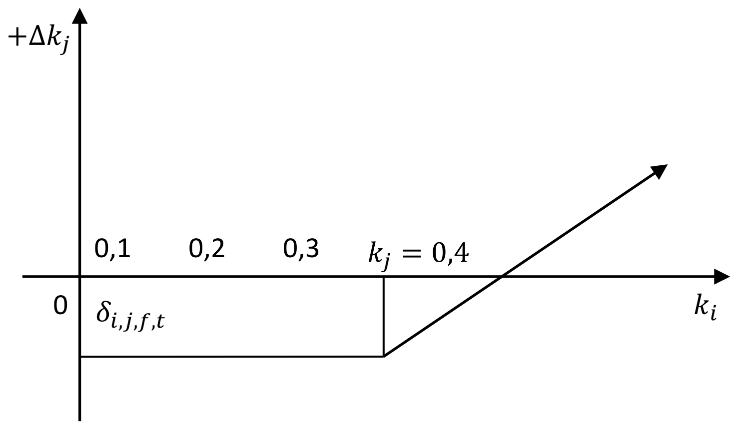

Figure 16 Knowledge increase diagram with holding a knowledge call option

[37] Source: own illustration

In the case that a unidirectional knowledge exchange took place and an option is created, an expiry date has to be defined.[38] To solve this problem, two possibilities can be considered: One possibility would be to assume that, as agent j has provided knowledge first, he is the one to set the expiry date. This would be reasonable, as he is the only one who can judge, when the maybe returned knowledge is of no longer of use to him. Another possibility would be that a bargaining procedure between the agents takes place. As agent i is supposed to be grateful, he is interested in having a running time for the option, being as long as possible, whereas agent j is restricted to certain deadlines. Between both positions a compromise could be found.

To sum up it can be said that the knowledge exchange process, with some modifications, can indeed be mapped to an option-like situation, when the option is seen as a right to execute. As the basic assumption holds, the next step is to prove, if the option value can be evaluated with financial option evaluation models.

5.2.4.3 Knowledge exchange can be evaluated by financial option evaluation models

This proof should be in analogy to the financial part of this diploma thesis divided into two parts: the evaluation of the model assumptions and the option evaluation formula itself. This chapter refers to the findings and explanations of the finance chapter and is limited to the necessary comments to follow the discussion. The main problem for evaluating the assumptions is the different setup, namely that the B-S model is used to evaluate knowledge exchange between humans. The literature has until now only analysed the assumptions for financial market setups and their relation to the real financial market dynamics. An analysis for the current purpose is performed for the first time.

5.2.4.3.1 The assumptions

If a look is taken at the assumptions of the model, most of them cannot be applied to the personal knowledge exchange. The major problem is that there is no market created for the traded knowledge, as all transaction relevant information is only mapped to the two involved agents. This setup will be of great importance for the following discussion of the single assumptions.

5.2.4.3.1.1 For constant $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$, $\boldsymbol{dS = \mu S dt + \sigma S dW}$

The first assumption states that given a constant drift parameter (expected value) and a constant volatility, the stock price development is following a geometric Brownian motion. This assumption must hold, if the option evaluation model of Black-Scholes is used, as Merton points out: Only as long as the stock price dynamics can be described by a continuous-time diffusion process, which have a continuous sample path with probability one, the arbitrage technique of the Black-Scholes model is still valid. (Merton, 1994, p. 310) To be precise, not specifically the GBM must be assumed for the

[38] Note that this is crucial also for the value of the option, as shown before in the finance chapter, and therefore must be of central concern for the agents.

stock price development, but a continuous-time stochastic process, as the actual value of a derivative is equal to the up to date discounted expected value. Therefore, an assumption about future developments must be made in order to be able to discount the expectations.

There seems to be no reason to question the applicability of the geometric Brownian motion to the knowledge value development. Undoubtedly, the knowledge process value development has a fixed starting point in time, which is equal to the point, where the option like situation arises. Also the normal distribution of the increases is transferable, as still medium changes are more likely than extreme developments. This similarity arises due to the difference in knowledge fields and the resulting learning ability of the agents, who adapt their search for their counterpart, due to their total transferred knowledge.

The process is also continuous in t[39]. The only attribute of the Brownian motion that could be questioned is the Markov property. It seems unlikely that future knowledge developments are not dependent on historical developments of the knowledge level. In the case of an impersonal exchange, where a virtual information market exists and the information price development can be separated from the knowledge level of the providing agent, this Markov property is more likely to exist.

For the knowledge level development the same problems with the Brownian motion exist, as for the stock price development. The first problem is that the process can still have negative values, which is not desirable for a knowledge process development, as it is assumed that “negative knowledge”[40] does not exist. The theoretical extreme case would be the absence of any knowledge, but this is still equal to having a knowledge level of zero and not a negative level. The second problem is the likelihood of changes in the knowledge level. Also for the knowledge development, it is assumed that extreme changes are less likely than small increases, respectively decreases. Therefore, the lognormal distribution of the GBM is accepted. Furthermore, over the drift parameter positive trends in the knowledge development can be reflected. Itô´s lemma is therefore also true and the option value and knowledge level development follow a joint stochastic process. This assumption can therefore be transferred into the knowledge exchange setup.

5.2.4.3.1.2 There are no penalties to short selling

The second assumption states that short selling is allowed with full use of proceeds. This assumption cannot hold for several reasons: First, the borrowing of a stock cannot be transferred into the

[39] In this case, an analogy between the closing of the stock markets and the inability to be able to learn while eating, sleeping, etc. exists.
[40] Knowledge itself is seen as value-free in relation to its application. Using knowledge for negative actions is therefore not meant.

knowledge exchange setup, as this would mean the agents can borrow knowledge pieces and sell them. Neither can an agent go to another agent and “borrow” his knowledge, as the borrowing itself would permanently increase his knowledge level[41], due to the face-to-face knowledge transfer through personal conversation, nor can he sell this knowledge, as there is an exchange situation on non-monetary basis.

Second performing short sales has only one goal – creating a financial profit. There is no interest in the knowledge itself, if it is borrowed from a third party, instantly sold, and, when hopefully the knowledge value has fallen, re-bought and returned to the third party, while in the meantime having earned the risk-free rate. The performer of such a transaction simply expects the knowledge level to fall in price and to profit financially from this development. As long as the short position is in hold the knowledge cannot “earn” an interest rate, as for the personal knowledge exchange a non-monetary situation exists. Even, if such a monetary exchange situation would exist, this goal would harm the idea that the agents are trading only for their personal benefit through an increase in knowledge, which is their top level priority. This assumption must be therefore refused for the personal exchange situation.

5.2.4.3.1.3 There are no transaction costs in buying or selling the stock or option

As the focus lies on knowledge, as the underlying asset, neither transaction costs nor taxes exist. This assumption that is often used as a criticism of the Black-Scholes formula, because it does not meet the reality of the financial market, is for the knowledge exchange setup perfectly stated true. If knowledge exchange is considered as face-to-face communication, no costs incur. Even if the knowledge exchange process is happening through telephone, internet, in written form, etc. all occurring costs are negligibly small and should therefore find no consideration in this analysis. This assumption is therefore fully accepted.

5.2.4.3.1.4 The stock pays no dividends or other distributions

If stocks are the underlying asset of an option, the possibility that dividends are paid throughout the life time of the option, exists. The personal exchange situation does not allow the buying of stocks, but only the creation of options. Stocks would be directly received shares of the knowledge level of an agent. The problem is that the exchange situation is non-monetary, which leaves the inferior agent with no exchange good for receiving knowledge from a superior agent. This situation makes direct acquiring of knowledge impossible, as the superior agent, who possesses the only exchange goods, namely more knowledge, would never be interested in acquiring knowledge from inferior agents. The option-like exchange is therefore the only possibility.

[41] It is assumed that knowledge cannot be forgotten on purpose.

Through the knowledge investment of the option holder, which equals the financial payment on the financial market, the option holder reaches through his knowledge investment a shareholder-like position, where the stock value is equal to the knowledge level development of the option writer. The option holder may not be able to sell his share to a third party, but he has a share of the option writer, respectively his knowledge development. Out of this situation, it would be possible that the option pays dividends, which would be different to the financial market, where the stock pays dividends. Dividends in a non-monetary knowledge exchange setup can only be one: knowledge. In the case of the non-monetary intra-personal exchange, dividends could be seen as piecewise exchanged knowledge on small, maybe accidental meetings, where the option writer gives the option holder a brief summary of his, in the meantime, performed progress. As the provided knowledge is exchanged before the expiry date and is not reflecting the whole potential of finally receivable knowledge, these exchanges could be interpreted as dividends[42]. They would have the same value-diminishing effect as the financial dividends, as they would reduce the relative distance in knowledge levels. Furthermore, these dividends would allow a positive outcome for the option holder, even if the initial positive knowledge development of the option writer is followed by a decreasing development, which results in no option value at the expiry date.

This assumption is valid for transformations into the knowledge exchange setup, although there can be situations thought of, where options pay dividends. If the assumption holds, the only point in time, where knowledge is returned back, is the execution date (which is not necessarily equal the expiry date) of the option. This is a simple restriction to the exchange procedure and therefore this assumption is fully accepted.

5.2.4.3.1.5 The short-term interest rate is known and constant through time

The assumption of a risk-free interest rate is very critical for the B-S model, as the hedged portfolio is constructed in such a way, that the risk-free rate of interest is earned. On the financial market the risk-free rate is seen as a T-Bill with virtually no risk, as it is state owned. It is not feasible to assume a risk-free asset in the knowledge exchange setup, as this would mean that the agent has the possibility to put his knowledge in a certain (state-owned) location, where it is constantly increased e.g. by 3-5% per year. This “state agent” cannot exist in the personal exchange situation.

One possible solution would be, to set the risk-free rate to 0%[43], as the discounting of the expected value would still be possible. However, the idea of “parking” knowledge without losing it would foil

[42] It should be pointed out that the divisibility of knowledge may decrease the value, as the coherence of the knowledge may be lost. This corresponds to the problem of the indefinitely divisibility of the knowledge in chapter 5.2.4.3.2. The dividends may therefore also be excluded due to the idea that the integrity of the knowledge itself must be kept in order to keep its value.
[43] In this case, the model still stays valid.

the basic idea of the "knowledge loss" within the ABS. From a knowledge theoretic point of view, the risk-free rate must therefore be refused, when trying to combine it with the requirements of the financial world. Therefore, the assumption of a known and constant interest rate must be refused.

5.2.4.3.1.6 The option is "European" and can therefore only be exercised at maturity

As already stated before, the knowledge exchange option must be "American", as it, contrary to the original B-S assumption, must be executable at (theoretically) any point in time until expiry date. In the personal exchange situation the execution of the option is limited to the personal meetings of the agents, but as these can happen at any period, the option cannot be "European". The approximation methods for valuing American options have already been excluded, due to their missing degree of preciseness.

In the financial chapter the solution to this dilemma has been the argumentation that it is never optimal to exercise a call on an underlying that pays no dividends. This has been the central argument that the Black-Scholes option evaluation model is applicable to American options too. But, as this argument is based on assumptions like e.g. interest rate earnings or short selling (Deutsch, 2008, p. 83), it does not hold for transformations into the knowledge exchange setup, as the interest rate and short sales are not transferable. Although, as shown before, the execution of an "American" option before maturity is not feasible for a rational decision maker, this is not true for the knowledge exchange setup. This leads to a central problem: The Black-Scholes model is no longer capable of evaluating the knowledge exchange option. This assumption is therefore refused.

5.2.4.3.2 *It is possible to borrow any fraction of the price of a security to buy it or to hold it, at* the short-term interest rate

The above statement is especially difficult to transfer into a knowledge exchange setup, as it assumes a variety of different aspects, namely that borrowing of knowledge is possible, that knowledge is infinitely divisible, that knowledge has a price and that a short-term interest rate exists. The biggest problem is, as already pointed out, that there is no interest rate; but all the other aspects of these assumptions are not transferable as well: Knowledge cannot be borrowed or lent, as this would have a permanent effect on the receiving agent, as for the personal exchange situation the knowledge is transferred orally. Knowledge cannot be given back and forgotten on purpose. Once transferred, it increases the knowledge level of the receiving agent and only decreases due to the knowledge loss function, which is not a consciously controlled process. Another problem is the assumption that knowledge is infinitely divisible. Within the ABS the S-curve concept takes network effects of knowledge into account. If knowledge is split into infinitely small pieces, it loses its value, as no one can use the small knowledge pieces without the relation to the rest of the knowledge. It is like being able to calculate the interest rate or the volatility, but not knowing the whole B-S formula for calculating the fair value of an option. The knowledge must be provided in full extent to be of any value. Even the last part of the assumption is not applicable, as the personal knowledge exchange is defined as non-monetary exchange. Therefore, this assumption must be fully refused for the knowledge exchange setup.

5.2.4.3.2.1 Finance mathematic inherent assumptions

5.2.4.3.2.1.1 No arbitrage (i.e. market is at equilibrium)

A market is a place where buyer and seller interact and either single or related goods are traded. (Perloff, 2004, p. 3) In the classic economic definition the buyers and sellers determine, through their potential or real interactions, the price of a good. As the personal knowledge exchange happens non-monetarily, this would relate to the area of countertrades. (Pindyck & Rubinfeld, 2003, p. 30) Several problems, when trying to define a market and the according equilibrium, occur: First, there are no real goods exchanged in the knowledge exchange situation. Basically, knowledge is exchanged for an execution right. Both are non-material goods. Second, the classic economic definition of the countertrade market is assuming that at least two goods, which are unequally distributed over at least two people, exist. Out of this situation an exchange situation arises, where both parties have an advantage through the countertrade. (Pindyck & Rubinfeld, 2003, pp. 797-804) This relation is not given in a knowledge setup, as knowledge is the only good, which is exchanged for execution rights. The trading situation is speculative, with an uncertain character and does not arise out of abundance or absence of several goods.

In macroeconomics it is differentiated between equilibrium on the goods market and equilibrium on the financial market. As we refer to the financial market, the money supply and money demand equilibrium is important. (Blanchard, 2009, pp. 85-106) Besides the problem that there is a non-monetary exchange situation, the main issue is the fact that the "price", which is in our case equal to the knowledge level, is not dependent on supply and demand dynamics. It does not matter how many employees offer the exact same level of knowledge or how many agents ask for knowledge in the personal exchange situation. The value is simply derived from the knowledge level. It can therefore be stated that the market equilibrium, in the personal exchange situation, is not equal to the economic idea of an equilibrium.

However, the equilibrium exists in another respect: Knowledge value is always evaluated at the "fair price", which is equal to the "no arbitrage" price. (Chargoy-Corona & Ibarra-Valdez, 2006) As the ABS represents a simplified approach for rebuilding reality, knowledge levels are always evaluated at a "fair price". It is not possible that the knowledge value is differing from the knowledge level. Therefore, a mis-"valued" situation cannot arise and arbitrage, due to disequilibria, cannot exist in the intra-personal setup. It should be pointed out that this is only true for the ABS. In reality due to value judging problems discrepancies can occur.

Although at this point it can already be stated that the hedge portfolio cannot be transferred into the knowledge exchange setup, from an arbitrage point of view, the argument of two portfolios, which have the same value at t must have the same value at $t < T$, holds. The transferability of the option value boundaries, which are stated true under the no arbitrage argument, is given. To sum up, it can be stated that the assumption of no arbitrage holds for the personal exchange situation.

5.2.4.3.2.1.2 Continuous trading (rebalancing of portfolio is done instantaneously)

The main problem, when trying to transfer the idea of hedging into the knowledge exchange setup, is that the hedged position is created consisting of a long position in the stock and a short position in the option. The long position in the stock cannot be created, as no stocks can be "bought" directly, due to the missing exchange good. Although the short position in the option in the personal exchange situation can be created, the hedge is not possible, as it needs both positions. As already pointed out, the creating of short positions over short sales is not possible, which makes the procedure of creating a hedged position impossible. Therefore, the dynamic delta hedging cannot be applied and furthermore, the central argument of the Black Scholes model, namely the PDE, does not hold anymore. The knowledge exchange setup avoids creating a risk-less situation.

The knowledge exchange situation therefore stays only "option-like" and not all aspects of the financial market can be transferred. The knowledge exchange situation remains a speculative investment, where the future development is unsure and can result in a loss[44]. The assumption of continuous trading is therefore refused.

5.2.4.3.3 Option evaluation formula

As already described in the former finance chapter, the Black-Scholes option evaluation formula depends on five variables: $x, c, r, t^* - t$ and σ. The problem that arises is that, in the intra-organisational setup, the knowledge exchange does not happen on a monetary basis. The agents exchange knowledge to improve their own knowledge level and the knowledge of the other employees to increase the total (theoretical) output of the company. Models exist, which set the value of knowledge pieces in relation to prices e.g Schmidt (Schmidt, 2000), in which knowledge can e.g. be paid in a theoretical created "knowledge currency". This seems not to be desirable for the intra-organisational exchange, as such models would bring further complexity into the ABS. In consequence, factors need to be (quantitative as well as qualitative) introduced, which determine this relationship between value and price.

[44] In this case, this would be providing information, without receiving anything back in future.

Due to the linear correlation of knowledge value and knowledge level, it would be feasible to replace the price with the knowledge level, to overcome the pricing problem. In this case, the variables would be renamed to the current knowledge level (x), the exercise knowledge level (c). But the exercise knowledge level is, contrary to the original formula, modelled dynamically and not static and is therefore one reason why the formula cannot be transferred. The total running time of the option $(t^* - t)$ is easily transferrable into the knowledge exchange setup, as this period is simply set between the two parties involved. There are still two variables left: the risk-free rate of return and the volatility. The risk-free rate of return is one assumption that cannot be transferred to a knowledge exchange situation. This results in a problem for the volatility. In principle, it is possible to link the estimates about the volatility with the acf and knowledge loss factor of the specific agent, as due to the linear correlation of knowledge level and knowledge value a high acf and knowledge loss factor automatically leads to a high volatility of the knowledge development. To ascertain the exact value of the volatility at point $T = 0$, an implied volatility has to be taken, as no historical data exists. It is optional that the implied volatility could be after some periods converted into a historical volatility; but as the risk-free rate does not exist, the implied volatility cannot be ascertained and a crucial modelling problem at the point of origin arises.

5.2.4.4 Conclusion

The term "option-like" does not mean that exactly all dynamics of the knowledge exchange are comparable to the financial market. If no risk-free rate of interest can be implemented, no portfolio can be created, no short sales performed, no hedging can be done, no borrowing is allowed etc., the option evaluation formula is not valid anymore. The B-S model is not applicable, if all these assumptions are not stated true, as the dynamics, ideas and concepts like the PDE, on which the model is based, do not hold.

Under these circumstances the author of this diploma thesis is of the opinion that the option evaluation theory of the BTT is not applicable for a knowledge exchange setup. The restrictive assumptions of the finance mathematic world are avoiding a successful transformation into the knowledge exchange setup. Many of the underlying assumptions of the B-S model do not hold, when trying to be transferred. Even the evaluation formula itself cannot be used, as the risk-free rate of return represents an insuperable handicap. If the risk-free rate is simply set to a constant parameter, with no further questioning, the formula itself only represents an empty shell, which produces meaningless figures that are not comparable at all.

To sum up it can be sated that, although the process of the knowledge exchange is comparable to an "option-like" situation, the value of the knowledge cannot be determined by the Black-Scholes formula. Generally it can be said that three major problems arise for the evaluation of option-like knowledge transfers with the Black-Scholes option evaluation model: the incapability of evaluating "American" options, the not transferable PDE with all related ideas and the not transferable risk-free rate. A model that includes neither of these factors and still is able to evaluate option values would be a solution to this problem.

5.2.4.5 Looking for other solutions

The first alternative which can be thought of in this context is the binomial approach. It allows the same evaluation possibilities based on more elementary mathematics for the discrete case, but unfortunately this model is, with minor exceptions, based on the same assumption as the Black-Scholes model: Some assumptions are again not relevant for the knowledge exchange case, as the binomial model e.g. does not take transaction costs, margin requirements and taxes into account. (Cox, Ross, & Rubinstein, 1979, p. 231) Other assumptions, like e.g. that building a hedging position is necessary, the risk-free rate of return, borrowing and short sales of securities are allowed etc., are far more critical, as these assumptions cannot be transferred into the knowledge setup. The binomial approach must therefore be seen as insufficient for evaluating the knowledge value in a knowledge exchange setup.

One possibility for a solution to this problem seems to be simulations of price developments like e.g. the Monte-Carlo simulation. Monte Carlo is an analysis method based on artificially recreating a chance process, which is performed many times and where the results are directly observed. (Barreto & Howland, 2006, p. 216) The simulations are basically random walks with unrestricted random sampling, which makes the up- and down-movements of the price development in a financial environment equally likely. (Chorafas, 1994, p. 318) The biggest advantage of this method compared to the binomial approach and the B-S model is, that the finance market assumptions are not necessarily to be stated true for basic Monte Carlo simulations. (Deutsch, 2008, p. 166) Another advantage would be the possibility to use the geometric Brownian motion. In this case, the stochastic price development of the underlying has a drift and certain volatility and is simulated many times, while the outcome is averaged.[45] Furthermore, a stochastic volatility can be taken into account like e.g. with the Markov Chain Monte Carlo approach, the quasi-maximum likelihood method, etc. (Mills & Markellos, 2008, pp. 171-172)

The main application field of the Monte-Carlo simulation is the calculation of integrals. This is perfect for the need of calculating derivative prices, as the price of an option can be denoted over the integral of the pay-out profile of the probability distribution of the stock price development on expiry

[45] This need for many simulation passes is labelled "the law of large numbers". (Bouleau & Lépingle, 1994, p. 46) The more passes, the closer the results are to the expected value. Ideally the amount should approximate infinity, but is always limited to resources, like money and calculating capacity.

date. (Deutsch, 2008, pp. 105-108) It is important to be aware that, also within the Monte Carlo simulations techniques, understanding the value of an option, as the up today discounted value of future expectations, is not possible, as this requires an interest rate, which is not given with the personal knowledge exchange situation. Monte Carlo simulations, like for simulating PDEs or pricing call options with stochastic interest rates (McLeish, 2005, pp. 149, 215), are therefore not applicable. Furthermore, all approaches that have been found by the author in the literature, concerning the use of Monte Carlo simulations for pricing American options are not usable, as they are all discounting the expected value and therefore are including the risk-free interest rate. See e.g. Broadie and Glasserman (Broadie & Glasserman, 1997), Barranquand and Martineau (Barraquand & Martineau, 1995), Longstaff and Schwartz (Longstaff & Schwartz, 2001), García (García, 2003), etc. This is not surprising, as this rate is fundamentally grounded in finance mathematics and its applicability is not questioned on the financial market. (Boyle, Broadie, & Glasserman, 1997)

One alternative that could offer a solution to this dilemma are quasi Monte Carlo (QMC) approaches. The points of the price development simulation are more uniformly distributed instead of being random. (Lin & Wang, 2008, pp. 109-110) Some authors even say: "Quasi-Monte Carlo methods are deterministic versions of Monte Carlo methods.". (Niederreiter, 2003, p. 428) What makes this approach so interesting? In principal a value of the knowledge development at any point in time has to be ascertained. Due to the restrictions found, the value cannot be seen as a discounted expected value. Although the option holder does not have perfect information about the value development, he has to decide when to exercise his option. Therefore, he must have an idea of the value development process of the option writer. How can this be done?

The option holder is aware of two facts: First that the knowledge development curve is following an S-shaped curve. The QMC approach allows over the pseudorandom numbers a possibility to integrate the S-shaped type into a projection of a possible future development. "Numbers computed from specified formulas, but satisfying an accepted set of tests, just as though they were random numbers, are called *pseudorandom numbers*." (Sobol, 1998, p. 103) Second, at some points in time the option holder and writer meet each other to exchange information on the development of the "investment". This is similar to asking a colleague, how he is progressing and if the provided knowledge has been useful. What the holder cannot know for sure, is how exactly the S-curve of the option writer is shaped. Undoubtedly he must have an idea of a possible development. This resembles making estimates of the potential of other people. The potential would be divided into two parts: First, the total reachable knowledge level of the writer, which is defined by $k_i^{max}$and second, the actual knowledge level k_i. The perfect counterpart for the option holder would therefore be an agent with a value of k^{max} close to one and an actual knowledge level close to zero. For the period between the option creation and the first meeting, the option holder is dependent on unsure estimating simulations about his investment. As soon as the first meeting takes place, the estimates about the value development can be corrected by the real values and therefore also used to adjust future expectations. The process would therefore not be random, but quasi-deterministic.

It is clear to the author of this diploma thesis that this represents only a basic idea and would need extensive mathematical explanations and clarifications. To model this process in detail would go far beyond this diploma thesis and could be an issue for later works on this topic. Furthermore, this solution represents a very complex issue that increases the computational effort for the ABS significantly, as every agent would have to use this complex value development evaluation possibility. The fact that these calculations have to be done at every period and adapted constantly, the question arises, if the utility relation between effort and result is still positive. Furthermore, it must be stated that also with the QMC approach only the knowledge level of the option writer is simulated. The agent therefore ascertains the optimal exercise point unlike with the method of the "fair value", as a discounted expected value, but simply derives the actual intrinsic value. Seen from this point of view, the knowledge level of the option writer is the only unsure parameter to determine an intrinsic value and therefore represents the only parameter, which needs to be simulated for the agents.

5.2.5 Knowledge and option value development

In the intra-organisational setup social connections between the agents exist. In such a setup it would make no sense to link knowledge levels to monetary figures, as in reality this exchange happens also on a non-monetary basis. No one pays his colleague for an informal knowledge exchange. Therefore, the value of the offered piece of knowledge equals the knowledge level of the specific agent in the specific knowledge field.

5.2.5.1 Knowledge value development

The question that now arises is: "How can knowledge value development be modelled and which parameters are influencing the exchange?" As the mutual exchange represents a simple swap of knowledge levels in different knowledge fields and the case of "no knowledge exchange" needs no further discussion, the focus of this chapter lies on the unidirectional option-like knowledge exchange situation. The knowledge exchange is divided into three steps: Step one is the transfer from the superior agent j to agent i which can be shown in the following graph[46]:

[46] Source: own illustration

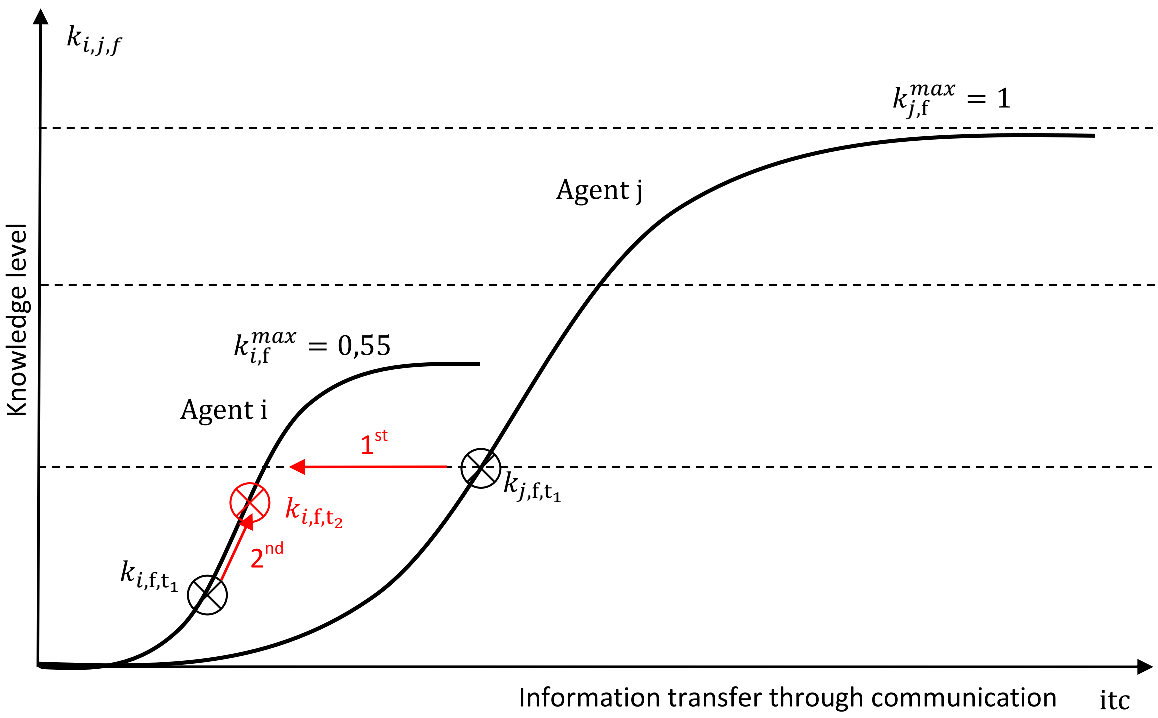

Figure 17 Step one of the unidirectional knowledge exchange

Agent i´s knowledge level is raised to agent j´s knowledge level minus the effect due to the distance in knowledge fields. The second step would be the period in which agent i hopefully increases his own knowledge through knowledge exchanges with other agents from the social network. Step three would be the meeting of both agents, where agent j executes his option and receives agent i´s knowledge, which has in the meantime increased over agent j´s knowledge. It should be noted that the diminishing factor due to the difference in the knowledge fields is also applied to the re-exchange. Step two and three can be illustrated as follows[47]:

[47] Source: own illustration

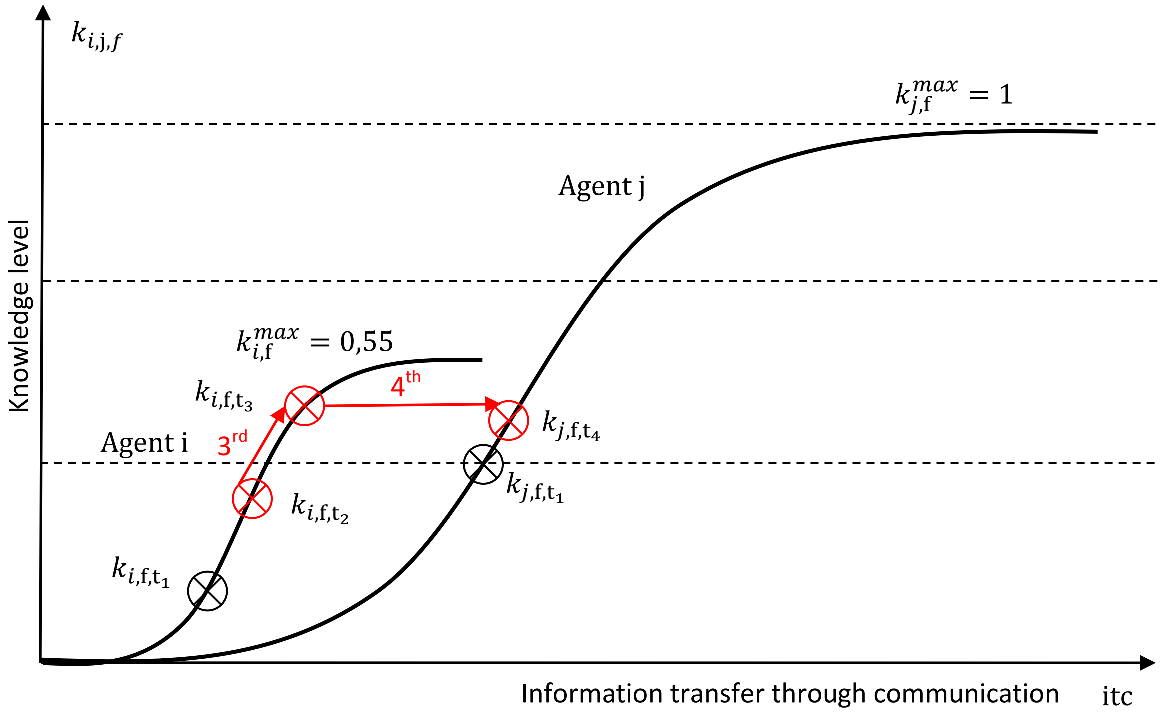

Figure 18 Steps two and three of the option-like knowledge exchange

Figure 18 shows how the re-exchange in the option-like knowledge exchange situation takes place. Necessary for the re-exchange is an increase in knowledge level of the option writer. If this takes place and the option holder executes the option, the knowledge is transferred back. But due to the difference in knowledge fields the knowledge level of agent j is also not raised to the full value of agent i.

This is the process of knowledge exchange in terms of the knowledge curves. The knowledge value can be explicitly formulated, by denoting the absolute knowledge level values over time. The knowledge value development in the intra-organisational setup is therefore deterministic, as it is related to the development of the knowledge level of the receiving agent in the specific field $k_{i,f,t}$. It performs all increases (due to improved knowledge) and decreases (due to knowledge loss) simultaneously to the actual knowledge level of the receiving agent $k_{i,f,t}$. The value of knowledge starts at the actual knowledge level of the emitter (agent j with $k_{j,f,t_1} > k_{i,f,t_2}$) minus the difference in knowledge field effect and can of course not exceed the maximum knowledge level of the receiver $k_{i,f}^{max}$. It should be noted that the value development could exceed the maximum knowledge capacity of the emitter $k_{j,f}^{max}$, but would only lead to an increase in knowledge up to this level.

The only parameters that could influence the progress of the knowledge value development are personal characteristics of the two agents involved. There is no possibility that other employees are influencing this exchange process, as the two agents involved are the only ones, who are aware of this deal. No open market exists, where supply and demand are influencing the knowledge value.

Due to the analogy of $k_{i,f,t}$ and the knowledge value, this development would theoretically increase all the time up to the point where agent i reaches his maximum knowledge $k_{i,f}^{max}$. This can be shown as follows[48]:

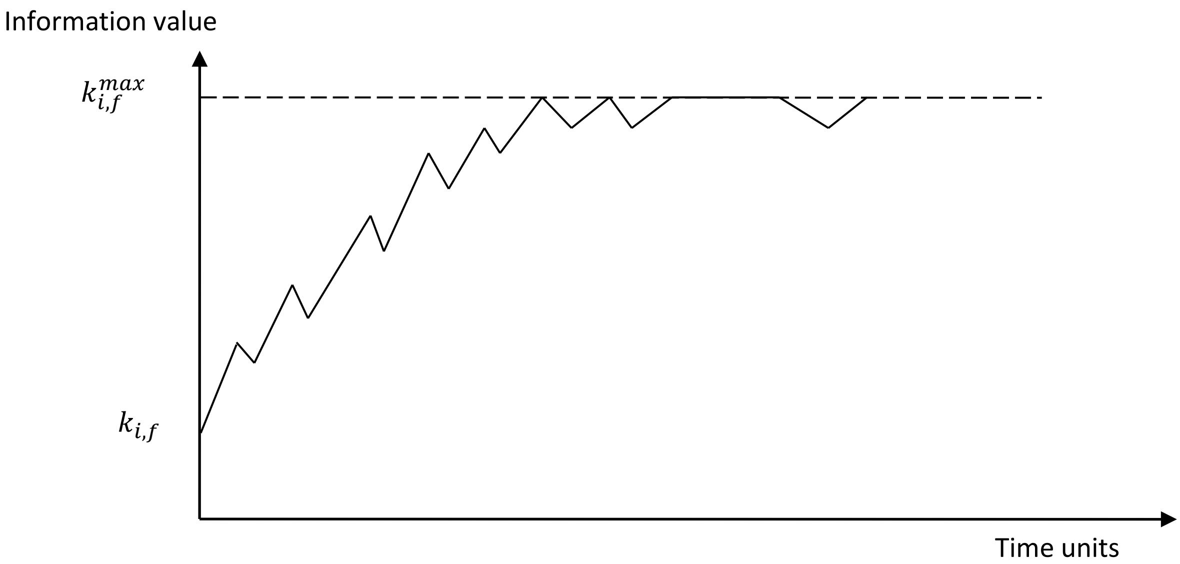

Figure 19 Knowledge value development at the intra-organisational knowledge exchange

Figure 19 represents the “ideal” case of an agent who his actively participating in knowledge exchanges and often activates his knowledge by transfer. There are many other possibilities that can be thought of, as it is possible that, due to certain circumstances, the agent is unable to improve his knowledge in a certain knowledge field at all; or improves up to a certain amount and loses, due to later inactivity in this field, his previously gained knowledge. The “ideal” case should simply be a demonstration of one of many possible developments.

Due to the S-shaped development of $k_{j,f}$ the increases would be quite small, if agent j is either at the beginning or the end of his knowledge development and big, if he is actually in the middle of the S-curve. The small decreases could happen due to inactivity in the specific knowledge field and the resulting knowledge loss. But generally the knowledge value development would always follow an increase until $k_{i,f}^{max}$ is reached and then flattens out. From then it can only decrease due to inactivity, can be sustained through constantly passing on knowledge (reactivation of knowledge) and regained through learning.

5.2.5.2 Option value development

In the financial world the option value is dependent on the stock price and the maturity, as already pointed out and as the stock price exceeds the exercise price, the option will be exercised to realise profits. This analogy should also hold for knowledge options. The knowledge value definitely

[48] Source: own illustration

influences the option value, as it determines the intrinsic value and the longer the running time of the option, the more likely it is that the option writer is able to improve his knowledge.

One discussable point with options is the execution procedure: As the option represents a right, the option holder can force the option writer for a meeting to execute his option, even if both agents would have had other meetings at the same period, due to the normal search procedure. This would be the “price” the option writer pays for the benefit of the received knowledge. But this is only one possibility. In reality, meetings can never be guaranteed due to e.g. illness, deadlines, etc. Therefore, the option holder claims his desire for executing the option and the option writer treats this request with top level priority; but as he is still limited to the acf, he could e.g. fulfil the request not until three periods later. For the author of this diploma thesis this procedure would be more desirable, due to its more realistic character.

Until now, the option value development and the knowledge development of the option writer have been set as equal. This is the case for the so called “standard option”. For this option there exists an expiry date, and the intrinsic value over the lifetime is ascertained from the knowledge level difference of the writer and holder. The value development of these options is calculated by simulating the knowledge level development of the writer with the QMC method and ascertaining the intrinsic value.

But in the organisational setup there are many knowledge exchange deals which have a specified need. As certain knowledge value has a time dependent character, the option value development should be now separated from the knowledge value development. In this case, the focus is on the personal value for the option holder. Knowledge value has a time related character, which means that the value of the option on the knowledge is dependent on the point in time when it is passed. Every project an employee is working on is limited to a specific period and has inherent deadlines. If the executing employee needs further knowledge to be able to bring the project to an end and decides to share his actual knowledge with another employee, to receive more valued knowledge in the future, the knowledge created by the other employee would be of no value at all, if it is passed back to the first employee after the projects end.

Although the knowledge level of agent i may be further increasing or constant, there is a point where the personal value for the holder of the option (agent j) is decreasing. Therefore, it must be distinguished between a desired and a latest possible point in time, after which the returned knowledge is useless for the option holder. The value of the transferred knowledge increases until the desired point in time (dp_t) and decreases from then onwards until the latest possible point in time (lp_t), which marks the expiry date of the option. This can be shown in the following graph[49]:

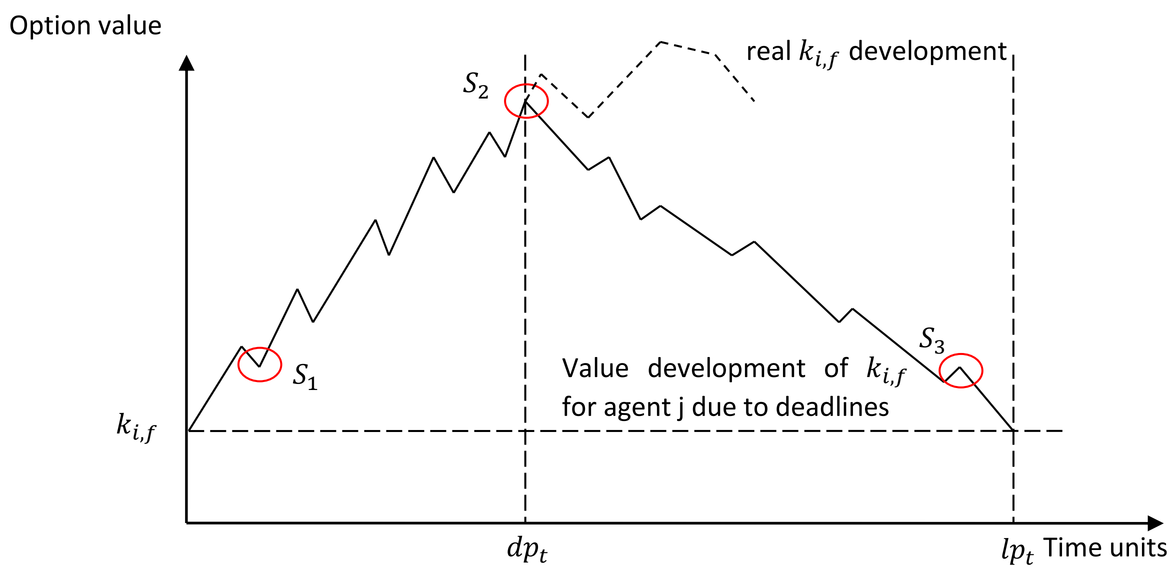

Figure 20 Option value development at the intra-organisational personal knowledge exchange

Until the desired point in time the knowledge value development (knowledge level development of agent i) and the option value development perform a joint walk. At the dp_t the option value development is decoupled from the knowledge value development and follows a decreasing function until the latest possible point, which is equal to the end of the running time of the option. Agent j not only needs the knowledge for his personal enrichment, but for a concrete need in order to be able to finish the project. Therefore, the closer the expiry date of the option approaches, the less the provided knowledge is worth, as agent j needs time to understand the provided knowledge, adjust it for his needs and adopt it to the project. All these factors should be considered by the decreasing function.

In figure 20 at situation (S_1) the agents meet quite soon after the knowledge exchange took place. The option has already increased in value but not significantly. The holder of the option can now either exercise the option and realise a small increase of knowledge or hope to meet again when the option is worth more. In situation (S_2) the option holder and the option writer meet each other again. Now the value of the option is worth much more, than the initial value and has reached its maximum value. As the agents have met at the dp_t the holder of the option would exercise it, as the option has reached the maximum personal value for him. In Situation (S_3) the two involved agents only manage to meet after a long period, where the option has decreased considerably in value. As the value development is already on the declining part, the option should be exercised immediately,

[49] Source: own illustration

in order to avoid further losses. Meetings after the lp_t are of no value for the option holder anymore, but can be used to set up new option contracts or for performing new mutual knowledge exchanges. It should be noted that there is a chance that the two agents never meet again. In this case, the option simply expires. As the investor is aware of the long term negative development of the knowledge value, the latest possible exercise time would be the point where the option reaches the initial buying value.

At this point the question arises, how long is the running time of an option and how is the desired point in time placed within this running period? The lengths of the dp_t and lp_t periods are set by the emitting agent, as these periods are only of importance to him. Therefore, at the time of setting up the ABS, an entity is created for every agent, who determines the desired running times of the options. In reality, so many factors like personal workload, deadlines, risk attitude, etc. are influencing the decision of the employee. For simplifying reasons it is suggested to model it within the ABS randomly. In this case, the running time of the option is reflecting the running time of the project of the employee, for which he needs this piece of knowledge and could e.g. be between one and six month (periods). The dp_t can be set e.g. between half the running time, or at three quarters of the total running time.

Maybe the biggest advantage of these “deadline dependent options” is the easy integration into the ABS. As the option holder is aware of the dp_t, where his investment is worth most, independent of the knowledge level development of the option writer, it makes estimates about the perfect execution date redundant. Therefore, complicated processes, like the solution of the value development over the QMC approach, are not necessary anymore and significantly reduce the computational effort for the ABS, as well as the complexity. Furthermore, the deadline dependent options seem to be close to reality, as diffuse knowledge development estimates, based on feelings and personal judgements about colleagues, are needless. The execution date is known to the option holder and on this date, he verifies if the investment has paid off, or not.

5.3 Impersonal information exchange at a virtual information market

This scenario is reflecting the situation of employees, who are able to gather external information over a virtual information market (VIM). In this case, no social connection between the agents exists. Within the social network, which represents the company, there is always one agent, who knows best in a specific field. Due to the successive learning function, this agent can never improve his knowledge further, if he is limited to his social network only. Such an agent can only improve his knowledge further, if he deals on the virtual information market. Within the ABS internal research departments are no option for the companies, as the model does not allow an agent to improve his knowledge level on his own, e.g. through self-studies. Improvements of the knowledge level result only out of knowledge/ information transfers between agents. This is one limitation of this approach, which stands e.g. in contrast to ideas like knowledge creating value networks. (Büchel & Raub, 2002) The social networks can therefore be better classified as knowledge/ information distributing networks, rather than knowledge creating networks[50].

As this diploma thesis focuses on the information exchange from an option-theoretic point of view, only information transfer possibilities, where such option-like situations arise should be analysed in detail. Therefore, “classic” knowledge creating sources for companies like e.g. (Research) Joint Ventures ((R)JVs) should not be taken into account, as this example represents knowledge creation through cooperation. The RJV partners are not paying each other for receiving a certain information in future (which would be an option-like situation), but are working jointly on a certain project. Within the ABS, due to the successive learning function, no knowledge transformation (Berdrow & Lane, 2003, p. 18) would take place with RJVs, but an information swap in different knowledge fields. This would be equal the *Type-1* exchange type.

Another possibility to acquire external knowledge would be the “buying” of information by using the service of business consulting companies like e.g. Boston Consulting Group or PricewaterhouseCoopers Int. Ltd.. In this case, the business consulting firms could also be modelled as a social network. Whenever a company is consulting such a firm, a teaching process is initiated, where selected agents are taught by the consultant[51]:

[50] Given that the “rising” of knowledge levels of other agents through information distribution is not seen as creation of new knowledge, but a distribution of already known knowledge.

[51] Source: own illustration on basis of Günther (Günther, 2007, p. 186)

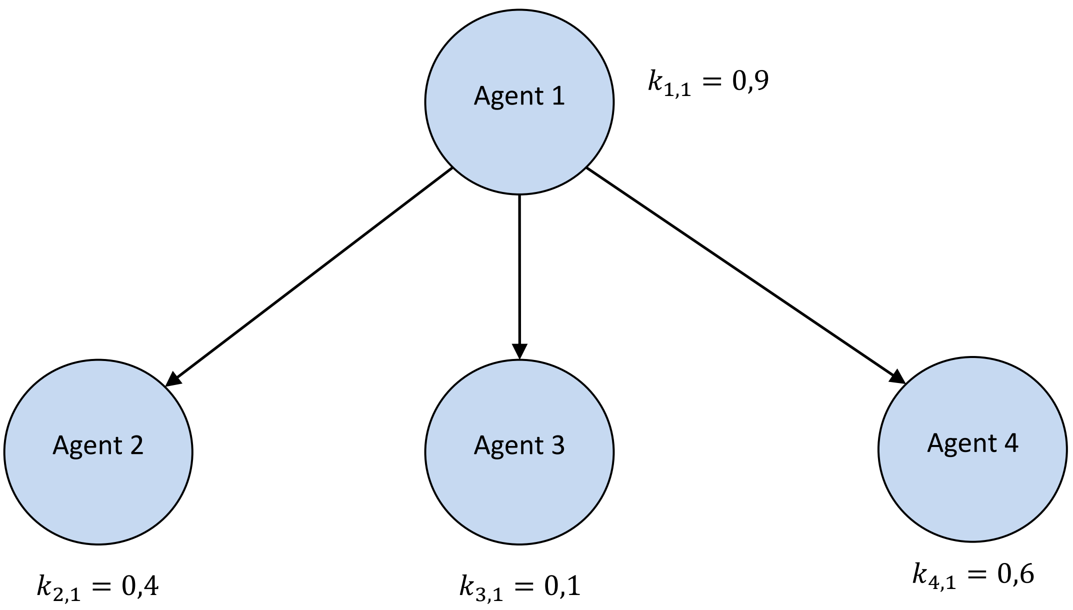

Figure 21 Illustration of a 1:n teaching procedure

Due to the “difference in knowledge field”, the final knowledge increase would be different with every agent. But this example does not end in an option-like procedure and is therefore not explained further. Before continuing with an option-like example, the concept of the virtual information market has to be explained and the differences to the intra-organisational knowledge exchanges stated.

5.3.1 Virtual information market (VIM)

The virtual information market model has his archetype in the financial stock/ option market. The pieces of information can be traded like at the stock exchange. However, several adjustments have to be made, in order to make the pieces of information exchangeable, which will be explained in the following chapters.

But how is “external information” defined? In principle, “external” in this coherence is dependent on the scale of the observed network. Within the ABS, several from each other separated social networks are assumed. The networks can represent e.g. a single department, business units, a whole organization, sub-companies etc. The classifications can vary, dependent on the organisational structure of the company. One important distinction criterion has to be defined: Intra-organisational knowledge exchanges are always non-monetary, which is not necessary true for the VIM. The virtual information market can therefore have two possible forms:

5.3.1.1 Non-monetary virtual information market

As only intra-organisational knowledge exchanges are supposed to be non-monetary, this market is located within the company and can be imagined as an IT-supported platform, where employees are able to exchange information. The main goal of this information market would be, to spread information within the company over the boundaries that arise out of social, organisational or institutional arrangements. Therefore, a centralized platform is created, which is accessible by every agent and where the agents are able to participate in information exchange procedures[52].

In principle the dynamics are very similar to the personal knowledge exchange. The exchange good for receiving the information can only be an option right, as no money is transferred. This means that in exchange for the received information piece, the receiving agents guarantees the provider a right for returning information at a later point in time[53]. The advantages for the providing agent on this market are the following: First, he is able to make his knowledge accessible to a larger audience, compared to being limited to his social network. This results in potentially more information exchange deals and therefore a greater possibility for him to improve further in his knowledge level, as he receives more option rights. Second, the risk that one receiving agent cannot provide valuable information in future is greater, than the risk that a number of agents are unable to improve in their knowledge levels. The effort for the providing agent stays the same, as he only has to codify his knowledge level once and then places it at the VIM. The advantage compared to the personal exchange is that the probability of a positive output is raised, due to the diversified risk.

There are two major differences of the non-monetary VIM to the personal exchange situation: the missing of social connections and the possibility to execute the option at any point in time. What stays the same is the personal characteristic of the option contract. Although the VIM represents a market place, it is following different dynamics: There are no value increases due to e.g. changing supply and demand situations caused by shortages of information provision. The information value and the resulting intrinsic value are strictly connected to the knowledge levels of the two involved agents, as the information is evaluated at “fair-value”. The non-monetary VIM therefore simply represents a new distribution channel for the agents, where all assumptions and arguments of the personal exchange situation hold. Due to the missing social connection and the possible spatial separation of the trading agents, the option holder relies on his simulations of the quasi Monte Carlo approach for the option value development for *standard options* in order to ascertain the optimal exercise date for a basic option development. In case of a time dependent option the dp_t represents

[52] It should be noted that it is not the task of this diploma thesis to find solutions for problems, like motivating employees over incentive systems, in order to provide their knowledge on this platform. Also problems like that due to the missing social connection and the higher anonymity on the market a certain default risk, due to dishonesty or fraud of the receiver arises, are not solved. The ABS represents a simplified reflection of reality and as such, it is assumed, that agents are interested in sharing their knowledge and receivers are interested in returning as much information back as possible.

[53] Technically the download of information can be traced by IP addresses in the intra-organisational network and transferred to the provider of the information.

the point, where his investment is worth most, as independent from the actual value at this point, it constantly decreases in value for him since then.

5.3.1.2 Monetary virtual information market

As all intra-organisational knowledge exchanges are supposed to be non-monetary, this virtual information market can only be located outside the organization. The monetary VIM can provide a possibility for different companies to offer and buy information. Knowledge is provided e.g. codified in the form of a paper, article, book, etc. As the knowledge is codified and therefore only in written or electronic form accessible, no context or additional explanations by the author of the information is provided, which results in the difference between the transfer of knowledge and the transfer of information. Information pieces make misunderstandings and own interpretations more likely.

The biggest difference to the personal exchange, besides the fact that money exists as an exchange good, is the possibility, not only to create options, but to buy information pieces directly on the market. This is only possible on the monetary VIM, as with the non-monetary VIM the sole provision of information pieces could not be compensated, due to the missing of money. As humans are not passing information away altruistically, the direct purchase of information pieces is limited to the monetary VIM only.

If the VIM is a place, where individuals provide, buy and sell information, the monetary VIM is not likely to exist for most industrial sectors, as companies are always in a competitive situation. The organisations would hardly allow their employees to sell their knowledge on an anonymous market, as the competitor would be able to buy the information and even the knowledge difference. This would especially be a big problem for technological and innovation driven companies, as they would lose their competitive advantage. An extra-organisational information exchange within the same branch is therefore not taking place. Also cross-branch inter-organisational information exchanges seem unlikely, as providing information of the own business field may provide the basis for the other company to enter the own market. Due to the fact that the companies are, or may be direct competitors, they would never allow single employees to provide information on an anonymous market. An additional problem would be the fact that the trading agents would appear on the market as private brokers, which trade for the personal benefit and not for the benefit of the company. But over which option-like situations, from extra-organisational resources could companies then create knowledge?

5.3.1.2.1 Academic researchers and research companies

One possibility that fulfils the option-like need is the information transfer between universities/ researchers and companies. The symbiosis between universities, which provide information and companies, which provide financial resources, is a long servicing and established procedure. It is also common that e.g. large pharmaceutical companies invest in small biotechnology firms, which are specialised in very specific areas of expertise, in exchange for receiving the research results.

For the ABS this means that a new type of agents called “academic”- or “research”-agents is introduced. These agents are characterised by having a high potential (maximum k^{max}), due to their personal ability. This potential should not be limited to a specific knowledge field, as the fact of being “gifted” is not limited to one knowledge field, but represents a general ability to rapidly gather, assimilate and create knowledge. As researchers tend to specialise in one field, they should have exemplary knowledge in one of the knowledge fields, while on the contrary in the other fields they may have initially no knowledge at all. The general knowledge fields of the academic agents do not differ from the knowledge fields of the employee agents. The defined knowledge fields are globally stated true. All general characteristics for the agents, like the absolute communication frequency, knowledge level and loss etc., as they represent individual characteristics, are of course also true for the academic research agents. What changes is that, due to the different setup, new definitions e.g. concerning the ability to provide information have to be added.

Academic agents are also placed in a social network, whereas this network reflects the scientific community and not a company/ department. As the existence of several academic agents, who are specialists in different fields and assuming a high knowledge exchange rate within this scientific community, so called “super” agents could arise, which have the maximum reachable knowledge level in every knowledge field. This would not reflect reality, as only few persons can be called “all-round geniuses”. Therefore, total knowledge saturation limits should be introduced for these agents, which would reflect the idea that human beings are unable to be a specialist in every field. The boundary could be easily modelled as follows: Agents have e.g. four knowledge fields. Given that academic agents are extremely gifted, they have a potentially reachable knowledge level of a value close to one in every knowledge field. The maximum knowledge potential for the agent is therefore close to the value of four, assuming that he could reach the maximum value in every knowledge field. To avoid this, the total knowledge saturation limit for all four knowledge fields can be restricted to e.g. 2,5. For being specialist in one field the value of one is subtracted, leaving 1,5 points left for the remaining three knowledge fields. Furthermore, if the agent reaches the maximum knowledge level in a second field, he can only reach half of his potential in one of the two left fields, or less in both fields. The total limit should not be limited to one knowledge field, as this limit is already defined by $k_{j,i,\mathrm{f}}^{max}$, but to the agent as a whole. Given that the agent loses knowledge in one field, he can gather new knowledge in another field. By setting different limits for this boundary, academic all-round geniuses are avoided.

One academic agent can offer several pieces of information, but not of the same knowledge field and knowledge level. As the agent is also receiving information and improving his knowledge over time, it is assumed that he will have several papers simultaneously on the market: One, for each knowledge level he has reached in each knowledge field. The amount of provided information he is able to produce, is determined by the absolute communication frequency, as this attribute is reflecting the workload for other activities. If the acf is high e.g. 0,8, it means that the agent is highly involved in other projects and as it is representing a personal attribute, it is influencing all knowledge fields. Before a piece of information is offered on the virtual information market, it has to be codified in the form e.g. of a paper, in order to make it transferable. The higher the acf, the less time for codifying his knowledge is available, the longer the periods are, in which the agent is able to publish his information on the virtual information market. The paper publishing probability is therefore the inverse function of the acf with respect to one, leading for our example to a 20% possibility to publish. But one has to take one fact into account: the publishing of the paper is dependent on the fact that the agent is not participating in this period at the communication process, as both actions are unable to perform at the same time. As publishing is dependent on the fact that the agent is not participating at the communication process the probability is $\frac{1}{5} \times \frac{1}{5} = \frac{1}{25}$, as the chance for not participating at the communication process is 20%. The probability to publish is therefore 4%, which is a very realistic probability for someone, who is very busy with other tasks.

Another question that arises is, if the agent is e.g. only able to publish one paper every 8th period, in which knowledge field will he put out a paper on the virtual information market, given the possibility to improve his knowledge in the meantime, in more than one knowledge field? This question can be easily answered, as the second level priority of every agent is to maximize the financial profit. Therefore, the agent will publish in the knowledge field, where he knows best, as this paper will be worth most and maximize his earnings, if sold.

5.3.2 Exchange process

The fact that the agents have, respectively need money makes several configurations necessary. Each agent must have a seed capital in order to be able to buy information pieces and options. The emitter wants to sell his information on an anonymous market and is charging regarding to his expertise in the specific field a certain amount e.g. ranging from]€0;€1.000]. Basically, only one factor is crucial for the buying decision of a trading agent: the quality of the provided information, which is dependent on the knowledge level in the specific knowledge field of the emitting agent at the point of publication.

The option dynamics change, due to the existence of money. The impersonal exchange situation more approximates the financial option dynamics. As information can be bought, it first has to be defined, how the initial value of the offered piece of information is determined. On an anonymous market there is a need for pricing the piece of information, in order to create a possibility to exchange and compensate the deal. This should happen according to the actual knowledge level of the specific agent in the specific knowledge field. Therefore, the maximum reachable S-curve $\left(k_{i,f,t} = 1\right)$ is subdivided along the y-axis and the different levels are attributed to specific amounts of money. This can be graphically shown as follows[54]:

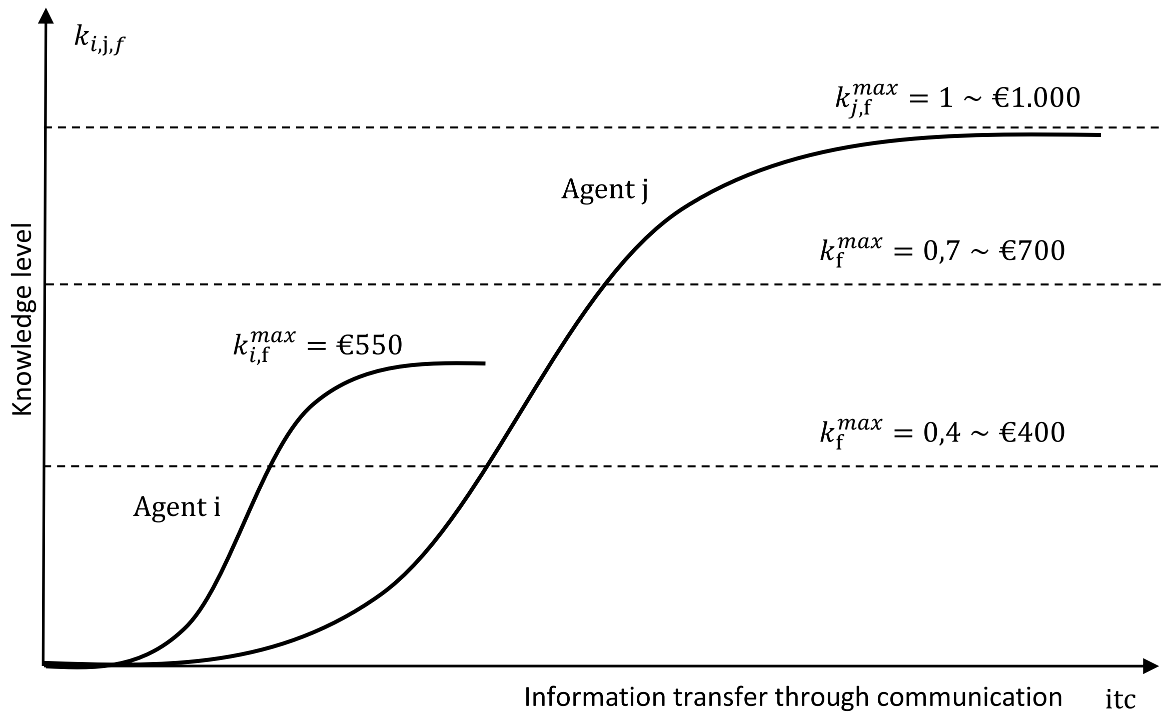

Figure 22 Relation between knowledge level and initial information value

As $k_{i,f}^{max} = 1$ (perfect knowledge) is only reflecting a hypothetical reachable limit (Günther, 2007, p. 162), the initial value of a provided piece of information would never reach €1.000. Due to the different potentials of the agents, e.g. agent i, even if he reaches his maximum knowledge level, can only offer information which initial value is worth maximum €550.

Within the ABS the developments in knowledge of the single agents can be shown like in figure 22 and placed on the market[55]. If the knowledge development of every agent is made external, perfect knowledge exists on the VIM. Companies could predict that a specific research agent is soon going to be on the rising part of the knowledge S-curve and will improve rapidly in the knowledge level for a certain period. The agent himself therefore becomes the "investment object". Investing at the right time could provide the option holder with much more information for a lower price. The timing of buying and executing would be critical. The advantage for the academic researcher lies in the

[54] Source: own illustration

[55] This is deterministically only true for the ABS. In reality it must be doubted that quantifying models can be found, which make these universally true publications of knowledge developments feasible.

payment of the premium, which can be used to finance the research. Another advantage of the monetary VIM, concerning the information pieces, is that the creating of a long position in the information piece would be possible, contrary to the personal exchange situation.

With the personal knowledge exchange the missing of money allowed only one possible role allocation for the option-like situation: With the personal exchange the option holder must have had a superior knowledge level, in order to have something to exchange. The superior agent therefore must be the option holder, whereas the inferior agent must be the option writer. This process changes completely for the monetary impersonal exchange. In the monetary impersonal exchange, the money itself is the exchange good. Therefore, a fourth exchange possibility, in addition to the already defined exchange types arises: the *unidirectional information exchange*[56]:

Exchange situation	*acf*	*rcf*	knowledge level
Unidirectional knowledge exchange	*pos.*	*pos.*	$k_{i,f_n} < k_{j,f_n}$
Unidirectional information exchange	*pos.*	*pos.*	$irrelevant$
Mutual knowledge exchange	*pos.*	*pos.*	$k_{i,f_1} < k_{j,f_1}$ & $k_{i,f_2} > k_{j,f_2}$
No knowledge exchange	*neg.*	*neg.*	$irrelevant$

Table 5 The unidirectional information exchange

The *unidirectional knowledge exchange* is in the ideal case a bidirectional knowledge exchange, but separated with respect to time. However, a possibility exists that the knowledge exchange stays unidirectional, contrary to the mutual knowledge exchange, where knowledge is exchanged immediately in both directions. The difference to the *unidirectional information exchange* is that instead of exchanging knowledge, information is exchanged for money, which makes the need of the *unidirectional knowledge exchange* that the option holder must have superior knowledge, obsolete. Furthermore, with the *unidirectional information exchange* the information flow in the case of an option is either unidirectional[57] or not happening[58], but never bidirectional time related. For the purchase of an information piece the information flow is only unidirectional.

Contrary to the personal knowledge exchange, where the choice of the trading partner is dependent on many factors like the acf, rcf , ... the only criterion for the buying decision of an information piece at the VIM is the information value, respectively the knowledge level of the providing agent at creation of the information piece. The information value of the bought information piece must be of course higher than the actual knowledge level of the buyer, as otherwise no learning effect takes

[56] Source: own table

[57] If the knowledge development is positive and the information level is above the knowledge level of the information buyer.

[58] This is only possible in an option deal with negative or no knowledge improvement of the option writer, as an agent would never buy an information piece that lies below his own knowledge level.

place. As already described, the acf and rcf are only relevant for the information creation procedure. Once, the information piece is offered on the market, it can be instantly bought, and used to increase the own knowledge level, as no personal meeting with the provider is necessary. As already described in chapter 5.2, for buying an option the actual knowledge level of the writer in relation to the actual knowledge level of the holder is determining the intrinsic value. Further details regarding the buying of options/ information pieces are now explained in detail in the following chapter.

5.3.3 BTT and the impersonal information exchange

5.3.3.1 General clarifications

The following chapter has great similarities to chapter “5.2 Personal knowledge exchange through a social network”, which is intended to be so. Contrary to chapter 5.2 the following chapters have a reduced extent, as only the differences to the impersonal exchange should be stressed. Redundant information regarding already stated findings, e.g. that the BTT is divisible in two different ideas, are avoided.

The unidirectional information exchange represents an additional possibility for acquiring information. The procedure of buying information pieces and increasing the own knowledge is clear. It represents an additional decision alternative and must be subdivided into two cases: The agent can either buy the information piece and realise the knowledge improvement in relation to the information level of the bought piece, or he decides to buy an option on the information piece. As information pieces are always fair valued, the agent would in the case of the information piece purchase and pay exactly the “correct” price for the value he receives. The option provides the possibility to receive much more information with less investment, but also includes a default risk. The agents must therefore have a risk preference attribute, which influences the investment decisions and the relation between “sure” investments in form of bought information pieces and “risky” investments in the form of options. The higher the risk preference factor, the higher the probability of investments in options. This attribute can be, in analogy to the other agent attributes, modelled as follows:

$$rpi_i \in [0,1]$$

$rpi_i \ldots risk\ preference\ indicator$
$i \ldots agent\ index$

As the acquisition of knowledge over the social network is assumed to be always preferred, the buying of information from external sources would rather concern the top knowing agents, who search for other possibilities to improve their knowledge. If the decision has fallen to purchase information on the VIM, the rpi determines, if the agent is buying the information piece directly, or choosing the option. A rpi value of 0,8 would mean that the agent is, with an 80% probability, choosing an option and not the information piece for improving his knowledge.

5.3.3.2 Information exchange can be mapped to options

As shown in chapter 5.2 the knowledge exchange process can indeed be mapped to an option-like situation. The problems identified are almost the same, as with the impersonal exchange situation, as e.g. the writer is still personally responsible for the development of his knowledge curve. However, due to the fact that a money-driven market is given, also other factors must be taken into account:

One problem could be that, according to the dynamics of the option exchange deal, the writer of the option is again inherently expecting the knowledge level to fall. This would mean that the academic agent is expecting that he cannot improve his knowledge in a specific field and uses the information asymmetry between him and the potential investing company, to gain a financial profit. This would be a fraud on purpose; but one has to be aware of the uncertainness of research. Years of research may produce no usable outcome at all, although especially the researchers are convinced of the success of their research. If a pharmaceutical firm decides to invest money into academic research in the field of creating an active immunization against the HI-Virus, this represents a gambling situation for both sides. The research may be successful or not and has therefore the same nature as financial options, where the value of the company may increase or not. For the academic researcher the options represent a possibility, to secure financial earnings, even if the research procedure is not successful. For the companies the options represent the possibility, to receive a lot of information for less money compared to the direct information purchase, if the research is successful. This situation is exactly like writing an option on the financial market.

In the personal exchange situation the value of the option has been always equal to the intrinsic value of the option, which has been defined by the difference in knowledge levels of the writer and the holder. This is an attribute that is not true anymore for the monetary VIM. As information is now payable, the option represents not a right to return information back, but to offer information for a specific price, at a specific point in time. The strike price is set to the actual value of the information. By doing this the option holder only profits if the knowledge development of the option writer is positive. In order to receive this right the option holder pays the option writer a premium. The intrinsic value of the option therefore changes from an intrinsic information value to an intrinsic financial value[59]. Like on the financial market the option value at the monetary VIM is therefore not any longer dependent on the personal development of the option holder, but only on the knowledge development of the option writer, which represents the underlying. Another result of this reconfiguration is that now the strike price stays fixed over the running time and the option only has a positive intrinsic value, if the knowledge development of the option writer exceeds the strike price.

The premium, as it is paid with money, shows that the monetary information exchange situation is more related to the financial option situation. Therefore, it would be more suitable not to talk of an *immaterial premium* but a *material premium*. The amount of the premium is the difference in knowledge levels between the trading agents, in the sense of a financial value. As the information is valued at fair price this can be done. A knowledge difference of $0{,}3$ would therefore lead to an premium of $€300$. Given the situation that the inferior agent has a knowledge level of $0{,}4$ and the superior agent a knowledge level of $0{,}7$, the buying of an actual information piece from the superior agent would be much more expensive, namely $€700$. This relation of paying more for a guaranteed increase in information and paying less for an uncertain increase is perfectly fitting.

A problem that may seem to arise is the following: As the option type is American, the agent could buy the option, pay the $€300$ premium and immediately execute it, as the execution point is freely selectable. But this would be of no sense, because the strike price is equal the actual price of the information. The agent would therefore not only pay the actual market price for the information piece, but also the premium in addition. The agent would therefore only execute the option, as soon as the information value exceeds the market price plus the premium, which is exactly like with financial options. The potential to receive information below the fair value must include a financial risk and be connected with substantial costs[60].

To sum up it can be concluded that the monetary impersonal information exchange can be mapped to options. Agents are seen as investment objects in respect to their knowledge developments. The buyer of an option can realise a knowledge increase with spending less money, than by buying the information directly from another agent. The dynamics are, in contrast to the personal exchange, not different to the financial world. The only advantage that arises out of the possibility to buy options, is the fact that now every agent, not only superior, can participate in this form of knowledge increase.

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[59] It should be noted that both values are performing a joint walk. The financial value increases, when the difference in knowledge levels increases and vice versa.

[60] The seed capital must therefore be chosen in a way that this condition is fulfilled.

5.3.3.3 Information exchange can be evaluated by financial option evaluation models

In analogy to chapter 5.2 the actual chapter is divided into a review of the assumptions and separate analyses of the option evaluation formula itself. Therefore, the focus of this chapter lays on the finance mathematic aspects of the BTT.

The top level priority of the agents, as stated already before, is to improve their knowledge. If maximizing the profit would be the top level priority, then we would have agents, who are primarily financial trading agents and treat pieces of information not for their intrinsic value of gaining knowledge, but only for increasing their wealth. They could be therefore modelled e.g. after budget constraints, return functions, portfolio optimizing constraints.... (LeBaron, 2000, p. 681) But in this case, the agents have the choice between a risky asset and the risk-free bond. This possibility does not exist on the VIM, although information is now payable on an existing market. The reasons will be explained later.

Further, the agents in a financial setup would be able to decide how many shares of the risky asset/ risk-free bond they want to possess. This would mean that the agents would have the possibility to buy several shares of the same piece of information, which would be not reasonable, as they are not learning more, by decoding the same piece of information.

Possessing several shares of the same piece of information would only be reasonable, if the agents plan to sell them with a financial gain at a later point in time, not being interested in the content of the information at all. As this characteristic would end up in a market, which does not differ from the real world financial market, instead of renaming stocks into "pieces of information", this possibility is refused. Setting the knowledge increase as top level priority, avoids that agents behave like on a financial market and possess more than one option from the same option writer.

5.3.3.3.1 The assumptions

Although not all assumptions are valid, even for the financial market (e.g. no taxes and transaction costs), the aim of this diploma thesis should be, to analyse every assumption, in order to see, if it is stated true for the virtual information market.

5.3.3.3.1.1 For constant μ and σ, $dS = \mu S dt + \sigma S dW$

As already stated before, this assumption must hold in order to keep the arbitrage technique of the Black-Scholes model valid. There is no reason, why the information development could not be modelled over a GBM on the VIM, as still all characteristics are fulfilled: The fixed starting point is given, the normal distribution permissible to accept, the knowledge development is continuous in t and the Markov property more likely to exist, as it is on the VIM possible to separate the price development from the knowledge level development. Also the lognormal distribution and restrictions regarding the likelihood of changes from the GBM are feasible. This assumption therefore can be transferred into the impersonal information exchange setup.

5.3.3.3.1.2 There are no penalties to short selling

The main problem with the personal exchange has been the necessary borrowing for performing a short sale was not possible, as forgetting information on purpose, has been excluded as a feasible assumption. The setup of the VIM on the other hand would make a procedure like borrowing possible. As the information pieces are codified in a written form, it is possible to borrow the information piece and, without reading it, transfer it back at a later point in time. Like on the financial market, the initiator of the short sale must not even physically possess the information piece, but can only perform the deal on a contractual basis, which guarantees the right to own it. Especially, being able to buy and sell the information on monetary basis is essential for being able to perform the short sell.

Crucial is the fact that after borrowing the information from the third party and having it sold on the VIM the agent possesses real money. In reality this money can indeed be used to invest it on the financial market to earn the risk-free rate. In the ABS no financial market as investment alternative exists. At this point a further problem arises, as the short sale performer, due to the dynamics of the short sale, expects the information piece to fall in price. But this is not possible, as once the information piece is placed on the VIM, the financial value is fixed to the actual knowledge level of the agent at the time he published it on the market. Personal knowledge developments after the placement on the VIM, do not influence the fair value charged for this information. Nevertheless, in reality the realised money could earn the risk-free interest rate, as long as the short position is on hold, which means at least small earnings. But the information providing agent would at least charge borrowing fees, which must be subtracted from the risk-free earnings, which makes the possibility of having the chance of short sales questionable, as the financial gain would be next to nothing. The short sale would only be feasible, if the price development is not fixed, but stochastic.

The procedure of short selling for the ABS is not possible on the VIM, due to the fact that the risk-free rate still requires a state player. The fixed information value is an additional problem that makes short sales economically nonsensical. Although borrowing is possible, contrary to the personal exchange situation, this assumption is therefore refused.

5.3.3.3.1.3 There are no transaction costs in buying or selling the stock or option

For the personal exchange this assumption was stated true, due to the personal communication. For the impersonal exchange the case is more complex. The VIM represents a trading possibility just like the financial market. Assuming that such a market would ever be introduced in reality, it is likely that within no time the need for certified traders, regulatory authorities, rating institutes and standard procedures for evaluating knowledge levels, etc. would arise. But the VIM is explicitly not intended to be exactly like the financial market. The agents trade to improve their knowledge not their capital.

For the VIM of the ABS it is simply assumed that there are no transaction costs. Seen under the aspect that this assumption does hold for the Black-Scholes model, although in reality many different transaction costs are charged, this assumption is accepted for the transformation into the VIM, even if fees are assumed. As it represents a simplifying assumption for establishing and performing the perfect hedge and is not crucial for the B-S model in order to obtain, the assumption is stated true.

5.3.3.3.1.4 The stock pays no dividends or other distributions

With the personal exchange only option-like procedures were possible. On the VIM it seems that such a stock-like product exists: the offered information pieces. This is not exactly true. Stocks on the financial market represent shares of a company, which generate hopefully financial earnings. The financial value of the shares increases, due to the performance of the company. This is not the dynamic of a provided information piece on the VIM. Although the information piece may be interpreted as a share of the knowledge level of the provider the value of the information, as already pointed out, does not increase or decrease. Furthermore, there is the problem of the intention of the buyer: a buyer of a share is interested in creating a financial profit, whereas the buyer of an information piece is interested in increasing his own knowledge. Therefore, even, if the information value is decoupled from the financial value, the information piece would be bought and the information value transformed into a knowledge increase immediately, as this value is not supposed to rise. Holding it would therefore not make sense, except, if it has been only bought to be resold for a higher price, which is not happening due to the top level priority of the agents.

In principle, also dividends for options, like explained at the personal exchange situation, could take place at the VIM, with the same value diminishing dynamics. In the case of the impersonal exchange, where money in exchange for information is possible, the dividends would be exactly treated as financial dividends, which reduce the information price; but as the assumption states that no dividends are paid, it can be fully accepted.

5.3.3.3.1.5 The short-term interest rate is known and constant through time

This assumption is a very interesting one for the VIM, as through the monetary character of the transactions such a rate is supposed to exist. But on the VIM this risk-free rate cannot exist too, as it again would mean that the information value can be constantly increased by parking it at a state owned location. The rate has therefore already been excluded to be transferable into the VIM. The assumption of a risk-free rate of 0% must also be refused for the VIM, due to the foiling of the knowledge loss dynamic. This assumption is therefore fully refused, which is critical for the B-S model, as the discounting of the expected value is not possible anymore.

5.3.3.3.1.6 The option is "European" and can therefore only be exercised at maturity

As already pointed out the information exchange situation, nevertheless, if it is personal and non-monetary or impersonal and monetary must be American styled. It therefore seems that the Black-Scholes model cannot be applied. But, as pointed out in chapter 4.2.6., a possibility to bypass this problem exists. And this bypass is applicable for the VIM as short sales are possible. The argumentation of the rational decision maker does therefore, contrary to the personal exchange situation, mathematically hold for the VIM. A central argument, why the Black-Scholes model could not be applied for the personal exchange is therefore invalidated for the monetary VIM. This argument is fully accepted.

5.3.3.3.1.7 It is possible to borrow any fraction of the price of a security to buy it or to hold it, at the short-term interest rate

Unlike with the personal exchange, this assumption is not totally refused, as for the impersonal exchange the borrowing and the financial exchange for information is possible. The infinitely divisibility of information is still questioned, as it is supposed that information, which is divided into very small pieces, loses its value. The value of the information is founded in its entireness, as only in this case, the cross-references sustain and the line of the argumentation can be followed. The risk-free rate is still refused, which makes the second part of the analysed assumption, namely the holding of the piece at the short-term interest rate impossible. Furthermore, the procedure of holding would not make sense at the VIM, as already argued before. Generally it can be said that although borrowing is allowed, this assumption has to be refused, as neither the information is divisible, nor does a risk-free rate exist. This is especially problematic for the building of the perfect hedge.

5.3.3.3.1.8 Finance mathematic inherent assumptions

5.3.3.3.1.8.1 No arbitrage (i.e. market is at equilibrium)

This assumption is in principle true, as information is priced at the fair value. The existence of a fair value pricing makes arbitrage possibilities impossible. It should be noted that this kind of equilibrium is only possible within the ABS and would not be transferable into reality. Again, like with the personal exchange, this is not equilibrium in the classic economic sense. Equilibrium built out of demand and supply is only possible, if the information value and the price are decoupled and therefore dynamics, like increasing prices, due to scarce information supply, are possible.

5.3.3.3.1.8.2 *Continuous trading (rebalancing of portfolio is done instantaneously)*

At this point the same problems as for the financial market are faced: trading cannot be continuous in t for the financial market, as markets close at the end of the day. The VIM on the other hand, as it is only part of an ABS, can without any problem, be opened the whole time. This would allow constant rebalancing of the portfolio, if a portfolio can be built. The buyer of an option is in the long position. With the possibility of paying for the information the long position can easily be created. The short position in the option is possible as well. The creation of the hedged position is therefore indeed possible, but nevertheless the concept, why this position is created on the financial market, cannot be transferred. The position created, is not riskless, as the value of information stays constant. The information piece stays at the defined value, while on the contrary the option value constantly changes, not only due to the development of the option writer, but also due to the knowledge level development of the option holder. The movements of the information piece are unable to hedge the movements of the option. The created position can therefore not follow a joint stochastic walk and as a consequence the central idea of the PDE within the Black-Scholes model does not hold anymore, which makes the application of it impossible. Creating a hedged position would in addition not be feasible, as the only reason for creating such a position is the avoiding of risk. Furthermore, the portfolio cannot earn the risk-free rate, as this rate does not exist on the VIM. This assumption is therefore refused.

5.3.3.3.2 The option evaluation formula

Separated from the assumptions, the option evaluation formula itself should now be analysed again. It consists out of the five variables: $x, c, r, t*-t$ and σ. The biggest advantage, compared to the personal exchange, is the possibility of being able to pay for information. Therefore, the current price (x) and the exercise price (c) stay the same. Also the running time (t) of the option can be transferred. The remaining problems are the risk-free rate and the volatility. The risk-free rate does not exist on the VIM, which is one reason, why the evaluation formula cannot be applied. But as the risk-free rate does not exist, also concepts like the implied volatility are, as a result, impossible to apply.

The problems are not only in the used variables of the evaluation formula, but also the dynamic configuration of the intrinsic value. The option evaluation formula is supposed to calculate the fair value for an exercise price that stays fixed over the running time. This is crucial for being able to discount the expected value. This is not stated true anymore, as the exercise price is changing in accordance with the knowledge development of the involved agents. The option evaluation formula is therefore not applicable, even if all variables would have been transferred successfully into the information exchange setup.

5.3.3.4 Conclusion

The impersonal exchange situation at the VIM did raise great expectations that the Black-Scholes model, contrary to the personal exchange situation, could be applied to evaluate information exchange between humans. The situation at the VIM is more similar to the situation on the financial market, as it provides option and stock like situations combined with the possibility to pay for the information. But this assumption did not become true. Basically, what has been a problem with the personal exchange stays a problem with the impersonal exchange: the non-transferability of the risk-free rate, the problems with the short selling and the problem that the central idea, the PDE, is not stated true anymore.

Although on the financial market some assumptions are also not stated true like e.g. the divisibility, the Black-Scholes model is still applied. But central ideas like the PDE can be mathematically proven and are stated true, which is not given for the VIM. The information exchange situation, also with the impersonal exchange, does only stay option-like and is not evaluable by finance mathematic formulas.

5.3.4 Information exchange and value development

The ascertaining of the initial value of information is essential for the pricing. For the impersonal exchange, a linear correlation between knowledge level and the initial price is given. It is assumed that the agent is containing his whole knowledge level into one piece of information. This is comparable to lecturers at university, who bring out books that reflect the actual knowledge of a specific research field, in which the lecturer is active.

For transformations into reality this very simple procedure would not be applicable, as the knowledge level of persons represents a diffuse attribute and cannot be quantified for sure. By taking the effort of transferring the knowledge into the written form in terms of hours and assuming an hourly wage rate, a motivated figure in money terms is produced. In order to rate knowledge at the university level additional factors like publications in top journals, ratings from other research colleagues etc. could be added to ascertain the value of the provided information.

5.3.4.1 Information/ price value development

The information value of the information pieces have so far been equal to the actual knowledge level of the providing agent at the publishing point and been kept constant over time. As information in reality is supposed to have a time-related-character, the information value can be also modelled over a decreasing function from the point of publication onwards. Information provided ten years ago has definitely not the same value today, as the research has progressed and new findings and conclusions have been drawn in the meantime. This process is supported by the author of this diploma thesis, as it is more realistic. With this extension the value and price development still perform a joint walk and information is priced at “fair value”.

Another possibility would be to decouple the information value development and the price development, as already indicated before. The provided information piece can therefore either have the actual value of the knowledge level of the information provider at the moment the information piece has been created, or a decreasing information value over time. As the price development is decoupled, it loses its linear correlation and can now be modelled over supply and demand. This possibility would be most appealing to model the separated price development. The financial value e.g. is influenced, when an agent, due to his exemplary knowledge level, is supplying the market with a rare piece of information that can only be provided by him. On the financial market this scarceness would automatically increase the price of the product, as an asymmetry between supply and demand exists. The provided information piece is of special value to the market participants, as it may be the only information piece that contains such a high knowledge level and therefore represents the sole possibility to increase the knowledge level of well knowing market participants further. However, the price is only a financial value. An increasing demand can never influence the contained information value provided by the information piece. This is a great difference to the financial market, where the value is only a financial value (price).

By modelling the price after supply and demand dynamics, one of the earliest methods of modelling the price development in ABS on financial markets is used. This method has several advantages: it is fast, keeps the market continuously in disequilibrium and offers, due to the simplicity of the process, the possibility to analyse occurring dynamics more easily. However, there are also some disadvantages, as a factor is needed, by which the price is adjusted, according to the supply and demand situation. The whole model is very sensitive to this one variable. Setting the parameter too low or too high would cause the market price either to react to slow, or overreact with high price fluctuations. (LeBaron, 2001)

For the ascertaining of the information price over supply and demand dynamics, first the supply needs to be determined. The supply has to be calculated in every period, as it is a dynamic figure, which changes according to the amount and quality of the provided information pieces on the market. The supply needs to be separately seen for each knowledge field.

Second the demand is determined. This has to be done in every time period. Therefore, the knowledge level of every agent in every knowledge field is set in relation to every other agent within the ABS. This is possible, because knowledge is supposed to be sequent. It is necessary to learn the basics in a certain knowledge field, like mathematics, to proceed with further studies. Therefore, the knowledge level on the S-curve is comparable. As the main goal of every agent is to improve his knowledge and the virtual information market is anonymous, he will buy pieces of information from every agent, who is above his own knowledge level. This need is seen as a theoretical request, which determines the demand. According to this, a piece of information, which level is above all other provided pieces, gets a request from every other agent, who leads to a huge demand for this specific piece of information. On the other hand, a piece of minor quality only gets requests from agents, who are below this knowledge level, leading to a situation where e.g. only a tenth of all agents are requesting this piece, to improve their knowledge. It is important to notice that the basic population for this calculation are really all existing agents, not only agents from a specific social network, as every agent is able to buy information pieces at the virtual market. As soon as a piece of information of higher quality is provided on the market, also the demand has to be adjusted as well. This procedure is only true for the information pieces, not for the options.

The supply and demand elements in the information value development lead towards different life times of the traded information at the stock exchange. It is assumed that once the information peace reaches the value of zero[61] it drops out of the market automatically.

5.3.4.1.1 Option value development

One big difference to the personal exchange would be the opportunity to observe the value development on the market. This makes the timing of the perfect execution much easier and the need that the option holder has to simulate the value development obsolete, as he can observe it at the market. Therefore, the option value development is only dependent on the knowledge developments of the two involved agents.

Deadline dependent options are also appropriate to assume for the VIM, as this kind of option makes a distinction between the *personal value* and the *market value* necessary. The personal value would decouple from the market value at the dp_t and follow a decreasing function. From this point in time onwards the market value, which may be observable by a third party has lost its function and only the option holder can for sure determine the value for himself. All other already described dynamics, concerning the options, are also stated true for the impersonal exchange.

[61] In the sense of information value, as well as price value.

6 Executive summary

The aim of this diploma thesis has been to analyse intra- and extra-organisational knowledge exchanges within an agent based system from an option theoretic point of view. The point of origin has been the BTT, which states that information exchange can be mapped to options and therefore be evaluated by the binomial model, respectively the Black-Scholes model. Contrary to the existing analyses by Barachini, which focus on the knowledge management point of view, the combination of the BTT and the Black-Scholes model is analysed from a finance mathematic and economic point of view. The ABS, on the other hand, has been of central concern, as it represents the point where the BTT and the Black-Scholes model are combined and extended with concepts concerning the knowledge development and transfer in order to create an idea of a functioning simulation.

Trying to merge the BTT and the B-S model, especially the transformation of the finance mathematic assumptions, has been problematic. Unlike the Black-Scholes model, where assumptions are made that do not meet reality, this diploma thesis follows the idea of feasibility for reality, in order to make the model applicable. Therefore, for example short selling is not allowed, a risk-free interest rate cannot be applied, etc. to enumerate only o few of the fundamental problems found. However, within the ABS, solutions have been shown, to allow agents to ascertain the personal value of the options over the dynamic intrinsic value. The knowledge transfer remains option-like and indicates large differences to the finance mathematic option procedure, as e.g. with the execution procedure. This finding is stated true not only for the non-monetary intra-organisational knowledge exchange, but also for the monetary extra-organisational information exchange.

The above can be summed up as follows: Although the information exchange can be mapped to an option-like situation, the specific requirements of the financial evaluation models make it impossible, to apply them to evaluate information exchanges. In this diploma thesis it has been proven that the BTT, as it is defined in literature, is not fully applicable to the specifically designed knowledge/ information exchange ABS.

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8 Appendix

8.1 Abstract (E)

This diploma thesis analyses the concept of the Business Transaction Theory (BTT). This theory states that human knowledge exchange can be evaluated by finance mathematic evaluation models. Through an interdisciplinary approach, it combines the areas of knowledge management (represented by the BTT), finance mathematics (represented by the Black-Scholes option evaluation formula) and agent based simulations (ABS), in order to create a possibility to simulate knowledge exchanges within a company. After having analysed the three above mentioned models in detail, the compatibility of the BTT and the B-S model has been proved. This was done by verifying that all necessary requirements and assumptions that arose from the finance mathematic side were transferable into a knowledge exchange setup within an ABS. The diploma thesis not only focuses on the intra-organisational knowledge exchange, but also introduces the model of a virtual information market, where employees and companies can acquire additional information from external sources, in order to increase their own knowledge level. By analysing critically all concepts used, as well as addressing occurring problems that arose with combining the different areas, this diploma thesis represents an innovative approach and contribution to academic research.

8.2 Abstract (D)

Die vorliegende Diplomarbeit analysiert das Konzept der Business Transaction Theory (BTT). Diese Theorie besagt, dass der Austausch von Wissen zwischen Menschen durch finanzmathematische Evaluierungsmodelle bewertet werden kann. Darüber hinaus kombiniert die Diplomarbeit, durch einen interdisziplinären Ansatz, die Gebiete des Wissensmanagements (repräsentiert durch die BTT), der Finanzmathematik (repräsentiert durch das Black-Scholes Modell) und der agentenbasierten Simulation (ABS), um den Wissensaustausch innerhalb einer Firma mittels des ABS zu simulieren. Nachdem die drei erwähnten Modelle im Detail analysiert wurden, wurde die Kompatibilität der BTT und des B-S Modells kontrolliert. Dies wurde nachgewiesen, indem eine Überprüfung aller finanzmathematischen Anforderungen auf deren Transferierbarkeit in ein Wissensaustausch-Szenario durchgeführt wurde. Die Diplomarbeit bezieht sich nicht nur auf den intra-organisationalen Wissensaustausch, sondern schafft ein Modell eines virtuellen Informationsmarktes, auf dem Angestellte und Firmen Informationen aus externen Quellen, zur Erweiterung des eigenen Wissensstandes, akquirieren können. Durch eine kritische Analyse der dargelegten Konzepte und durch eine Auseinandersetzung mit den, bei der Kombination der unterschiedlichen Forschungsgebiete entstandenen Problemen, versucht diese Diplomarbeit einen innovativen Ansatz, sowie einen Beitrag zur wissenschaftlichen Forschung zu leisten.

8.3 Curriculum vitae

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