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Jump Diffusion Models for Option Pricing vs. the Black Scholes Model

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Abstract

In our complex and developed financial world the Brownian motion and the normal distribution have obtained enormous impact on the prices of option contracts traded on the stock exchange or over the counter. Due to empirical investigations during the last years two points have emerged which cannot be assumed to pertain to each option price calculation. The two points are that the return distribution of a stock does not always follow a normal distribution but has a higher peak and two heavier tails than those of the normal distribution and that there is a "volatility smile" in option pricing. The Black-Scholes approach implies that volatility is a constant function. This paper theoretically and empirically investigates three different option pricing approaches: the Black-Scholes approach, the Merton-Jump approach, and the double exponential jump diffusion model, which was proposed by Kou (2001) and Ramezani and Zeng (1998).

1. Current Market Situation and Main Purpose of the Paper

The most important option contracts are “Plain-Vanilla-Options”, which allow the buyer to sell or buy particular assets with a previously price determined between two parties. Options are traded both on stock exchanges and OTC. The two main different kinds of options are European options and American options, European options can only be executed at the end of their duration but American options can also be executed during the lock-up period. Furthermore options are divided into Call options and Put options. Call options give the buyer the right but not the obligation to buy a particular asset, and the seller has to provide it. A put option gives the buyer the right but not the obligation to sell the asset (see Hull 2012: 233-242).

On the one hand, the value of options is determined by supply and demand in the markets and on the other hand it is done by mathematical models.

This paper will investigate jump diffusion models for option pricing. The Brownian motion and normal distribution have been widely used in the Black-Scholes model of option pricing to determine the return distributions of assets. From many empirical investigations two riddles emerge: the leptokurtic feature says that the asset’s return distribution may have a higher peak and two asymmetric heavier tails than those of the normal distribution. The second puzzle is the empirical abnormity called “volatility smile" in option pricing. In other words the Black-Scholes approach does not consider jumps in an asset’s price-curve (see Kou 2001: 1)

One of the first approaches was the Merton Jump model by R.C. Merton, who was also involved in the process of developing the Black-Scholes model. The reason for this new approach was to render the Brownian motion negligible, to state the estimation of options’ fair prices more precisely and to involve more actual price curves to the estimation. Applying this approach, you only obtain a solution if there is total ruin or if the price jumps are log-normally distributed. Of course we are also interested in prices if these two constraints do not exist.

Accordingly, several kinds of jump diffusion models have been developed based on the Merton model over the last few years. In this paper we look at two models, the Merton model, which also can be seen as the foundation, and the Kou model as a new creation.

The main purpose of this paper is to investigate if plain vanilla option pricing data regarding accuracy, applicability and effort better suit the “Double Exponential Jump Diffusion Model (Kou Model)”, the “Normal Jump Diffusion Model (Merton Model)” or the “Black Scholes Model”.

The first part of this paper will obtain definitions of the basic terms and explanations of various kinds of models for pricing an option. All assumptions will be made before calculations are mentioned. Also the partial differential difference equations which have to be solved to arrive at an analytical solution for the option price model, will be shown for each model. After this theoretical part we will switch to the next part, where an empirical study concerning the different option price models will be carried out.

Thus the second part contains estimations of a European Call and a European Put option with three different kinds of models. At first all parameters which are used for the models are explained and if further assumptions have to be set also these and how these further assumptions are implicated in the calculation will be explained. In this section we will also show how the option price changes if various parameters vary.

With this test procedure, it is possible to see which parameter of the model influences the solution of the model most. After the evaluations the solutions will be compared according to the following criteria: accuracy, applicability and effort, to get an answer to the research question.

2. Mathematical Models for Option Pricing

2.1 Jump Diffusion Models

Jump diffusion models always contain two parts, a jump part and a diffusion part. The diffusion part is determined by a common Brownian motion and the second part is determined by an impulse-function and a distribution function. The impulse-function causes price changes in the underlying asset, and is determined by a distribution function. The jump part enables to model sudden and unexpected price jumps of the underlying asset. (see Runggaldier 2002: 11-13 and Merton 1975: 4)

A general formula is:

$$dS(t) = \mu S(t)dt + \sigma S(t)dW(t) + \eta S(t)dN(t) \quad (1)$$

where:

$S(t) is\ the\ asset\ price\ at\ time\ t$

$W(t) is\ a\ standard\ Wiener\ Process$

$N(t)\ is\ a\ Poisson\ process\ with\ an\ insensity\ of\ \lambda$

$\eta\ is\ an\ impuls-function\ which\ causes\ a\ jump\ of\ S\ to\ S(1+\eta)$

Here are some examples of different jump-diffusion models:

- Merton model (see Merton 1976: 1-30):

  $\eta(x) = N(\mu, \sigma)$

- Kou model double-exponentially distributed (see Kou 2001: 1-34):

  $\eta(x) = p\eta_1 e^{-\eta_1 x} 1_{\{x \geq 0\}} + q\eta_2 e^{\eta_2 x} 1_{\{1<0\}}$

- Variance Gamma model (see Madan/Seneta 1990: 511-524):

  $$\eta(x) = \begin{cases} C\frac{e^{G_x}}{-x} & x < 0 \\ C\frac{e^{-M_x}}{x} & x > 0 \end{cases}$$

- CGMY model (Carr/Geman/Madan/Yor 2002: 305-332):

  $$\eta(x) = \begin{cases} C\frac{e^{G_x}}{(-x)^{1+Y}} & x < 0 \\ C\frac{e^{-M_x}}{x^{1+Y}} & x > 0 \end{cases}$$

2.1.1 Merton Model

The approach of Black and Scholes has lead to a breakthrough in the areas of option price estimations and option trading. The Black-Scholes approach assumes that the price of an asset, which is the underlain asset of the option follows a geometrical Brownian motion. But a geometrical Brownian motion cannot reflect all attributes of a stock quotation. Especially price jumps in a stock quotation cannot be replicated by a Brownian motion (see Merton 1975: 1-3).

Consequently, Merton developed the following approach to include price jumps and a new kind of model emerged, the jump-diffusion model.

2.1.1.1 Assumptions

The following assumptions can be read in Merton 1975 (see pages 1,2,4 and 5):

(1) frictionless markets→ this means there are no transaction costs of differential taxes

(2) no dividend payments

(3) the risk-free interest rate is available and constant over time

(4) no restrictions regarding value of transaction and price development of the asset

(5) short trading is not prohibited

(6) stocks are randomly divisible

(7) all information is available to all market participants

(8) no arbitrage possibilities

(9) the option is a European style option

(10) the stock price $S(t)$ is defined as a stochastic differential equation:

$$\frac{dS(t)}{S(t)} = (\alpha - \lambda\kappa)dt + \sigma dW(t) + dq(t) \quad (2)$$

where:

$\alpha \; is \; the \; expected \; return \; on \; the \; stock$

$\lambda \; is \; the \; average \; number \; of \; arrivals \; per \; unit \; time$

$\kappa \equiv \varepsilon(Y-1) = \varepsilon(Y) - 1$

$(Y-1) \; is \; the \; random \; variable \; percentage \; change \; -$

$in \; the \; asset \; price \; if \; the \; Poisson \; event \; occurs$

$\varepsilon \; is \; the \; expectation \; operator \; over \; the \; random \; variable \; Y$

$\sigma \; is \; the \; volatility \; of \; the \; stock \; price$

$dW(t) \; is \; a \; standard \; Wiener \; process$

$q(t) \; is \; an \; independent \; Poisson \; procces$

The likelihoods of this Poisson process can be described as:

- P {the event does not occur in the time interval $(t, t+h)$} = $1 - \lambda h + 0(h)$
- P {the event occurs once in the time interval $(t, t+h)$} = $\lambda h + 0(h)$
- P {the event occurs more than once in the time interval $(\mathrm{t}, \mathrm{t}+\mathrm{h})$} = $0(\mathrm{h})$

2.1.1.2 The Model

The dynamics of the stock price returns consist of two components. The first component is described by the normal price changes, because of disequilibrium in supply and demand on the market. This kind of attributes is expressed by a standard Brownian motion with a constant drift, a constant volatility and almost continuous paths. The second component is described by changes of the stock price influenced by new available information. These jump-processes are normally outlined by a Poisson process. So if the Poisson event occurs, the random variable Y describes the influences of the asset price changes. Let us define S(t) as the current stock price at time t; due to that, the stock price at time $(t+h)$ would be expressed as $S(t+h) = S(t)Y$. But it is assumed that the random variable Y is a compact support and $Y \geq 0$ counts. All random variables of Y have to be independent and identically distributed. If we now look back to equation (2) we can see that the $\sigma dW(t)$ part characterizes the instantaneous part of the sudden return due to the normal price changes and $dq(t)$ describes the price jumps (see Merton1975: 5-6).

If we assume that $\lambda = 0$, also $dq(t) \equiv 0$ and then the stock price returns have the same dynamics as those in the Black Scholes and Merton approaches (see Merton 1975: 6 and Merton 1973: 160-173 and Black/Scholes 1973: 640-645).

As a result we can convert equation (2) to:

$$\frac{dS}{S} = \begin{cases}(\alpha - \lambda\kappa)dt + \sigma dW(t) & , if\ the\ Poisson\ event\ does\ not\ occur \\ (\alpha - \lambda\kappa)dt + \sigma dW(t) + (Y-1), & if\ the\ Poisson\ event\ does\ occur\end{cases} \tag{3}$$

where, with a probability of one only one Poisson event occurs in a moment and if the event occurs, (Y-1) is the impulse function which affects that S(t) jumps to S(t)Y.

The resulting path will be mostly continuous with some finite jumps, which have got different values and amplitudes. If $\alpha, \lambda, \kappa\ and\ \sigma$ are constant, the relationship of S(t) and S(0) can be rewritten in this form (see Merton 1975: 6-7):

$$\frac{S(t)}{S(0)} = exp\left[\left(\frac{\alpha-1}{\sigma^2} - \lambda\kappa\right)t + \sigma W(t)\right]X_n \tag{4}$$

where:

$W(t) is\ the\ normal\ distributed\ random\ variable\ with\ \mu = 0\ and\ \sigma^2 = t$

$X_n = 1\ if\ n = 0$

$X_n = \prod_{j=1}^{n} Y_j;\ for\ n \geq 1$

$Y_j\ is\ independently\ and\ identically\ distributed$

$n\ is\ the\ number\ of\ jumps\ and\ is\ Poisson\ distributed\ with\ the\ parameter\ \lambda t$

Now let us take a look at the dynamics of the option price. We assume that option price V can be written as the twice differentiable stock price, in other words, the option price can be written as a C^2 function of the stock price and time: $V(t) = F(S,t)$. So if the stock price follows the same dynamics as described in equation (2), the option price dynamics can also be written in a very similar form (see Merton 1975: 7):

$$\frac{dV(S,t)}{V(S,t)} = \left(\alpha_{opt} - \lambda\kappa_{opt}\right)dt + \sigma_{opt}dW(t) + dq_{opt}(t) \quad (5)$$

where:

α_{opt} *and* σ_{opt} *are the expected return and the volatility of the option*

q_{opt} *is an independent Poisson process with the parameter* λ

$\kappa_{opt} = E\left[Y_{opt} - 1\right]$

$\left(Y_{opt} - 1\right)$*is the change of the option price if the Poisson event occurs in percent*

If we now use Ito's Lemma for jump processes, we get the following relationship:

$$\alpha_{opt} = \frac{\frac{1}{2}\sigma^2 S^2 V_{SS}(S,t) + (\alpha - \lambda\kappa)SV_S(S,t) + V_t(S,t) + \lambda E[V(SY,t) - V(S,t)]}{V(S,t)} \quad (6)$$

$$\sigma_{opt} = V_S(S,t)\sigma\frac{S}{V(S,t)} \quad (7)$$

where subscripts on $V(S,t)$ indicate partial derivatives.

Moreover, the Poisson process $q_{opt}(t)$ of the option price depends on the Poisson process $q(t)$ of the stock price. That means that, if a Poisson event occurs for the stock price, also a Poisson event for the option price will occur. If the random variable $Y = y$ then the random variable Y_{opt} will be $\frac{V(Sy,t)}{V(S,t)}$. Although the two processes are interdependent there is, however, no linear dependency because the option price V is not linearly dependent on S (see Merton 1975: 8).

Now let us consider a portfolio consisting of a stock, an option and a risk-free asset with an interest rate of r per annum. The portfolio is divided into three parts with the proportions ω_1, ω_2 *and* ω_3 where $\sum_{i=1}^{3}\omega_i = 1$. If P is the price of the portfolio, the dynamic can be expressed by (see Merton 1975: pages 8-9):

$$\frac{dP}{P} = (\alpha_P - \lambda\kappa_P)dt + \sigma_P dW(t) + dq_P(t) \quad (8)$$

where:

α_p *and* σ_p *are the expected return and the volatility of* $-$
the portfolio, if the Poisson event occurs

$q_p(t)$ *is an independent Poisson process with the parameter* λ

$\kappa_p = E\left[Y_p - 1\right]$

$\left(Y_p - 1\right)$ *is the percentage portfolio value change if the Poisson event occurs*

From equation (2) and equation (5) we get that:

$$\alpha_P = \omega_1(\alpha - r) + \omega_2\left(\alpha_{opt} - r\right) + r \quad (9)$$

$$\sigma_P = \omega_1\sigma + \omega_2\sigma_{opt} \quad (10)$$

$$Y_P - 1 = \omega_1(Y - 1) + \omega_2[V(SY,t) - V(S,t)]/V(S,t)] \quad (11)$$

where $\omega_3 = 1 - \omega_1 - \omega_2$ has been replaced.

In the Black Scholes analysis it is possible to render the portfolio risk-free by setting $\omega_1 = \omega_1^*$ and $\omega_2 = \omega_2^*$, so that $\omega_1^*\sigma + \omega_2^*\sigma = 0$. In this case the expected return of the portfolio has to be the risk-free interest rate r because of the arbitrage approach. Looking at equations (9) and (10), this means (see Merton 1975: 9 – 10):

$$\frac{\alpha - r}{\sigma} = \frac{\alpha_{opt} - r}{\sigma_{opt}} \tag{12}$$

From equations (6), (7) and (12) the famous Black Scholes formula for option pricing emerges:

$$\frac{1}{2}S^2 V_{SS} + rSV_S - rV + V_t = 0 \tag{13}$$

Unfortunately it is now possible to set the proportions in such a way that there is no jump risk because of the presence of the jump process $dq(t)$. This is caused by the non-linear dependency of the option price and the stock price because the portfolio optimization is a linear process. However, it is possible to work out the portfolio value if the proportions are set the same way as in the Black Scholes case. If P^* is the value of the portfolio with the Black Scholes loading, then from (8) we gathered the following (see Merton 1975: 10):

$$\frac{dP^*}{P^*} = (\alpha_P^* - \lambda\kappa_P^*)dt + \sigma_P dW(t) + dq_P^*(t) \tag{14}$$

Note that the value of the portfolio is a pure jump process because the continuous part of the stock price changes does not exist anymore because of the parameters' choice. Equation (14) can now be rewritten in the form of equation (3) (see Merton 1975: 11):

$$\frac{dP^*}{P^*} = \begin{cases} (\alpha_P^* - \lambda\kappa_P^*)dt & , if\ the\ Poisson\ event\ does\ not\ occur \\ (\alpha_P^* - \lambda\kappa_P^*)dt + (Y_P^* - 1), & if\ the\ Poisson\ event\ does\ occur \end{cases} \tag{15}$$

Now it is very easy to see that the price of a portfolio is predictable most of the time and yield $(\alpha_P^* - \lambda\kappa_P^*)$. However, on average in each time interval $\frac{1}{\lambda}$ there is one jump. Following equations (7) and (11) we can work out further qualitative attributes of the portfolio price, namely (see Merton 1975: 11):

$$Y_P^* - 1 = \omega_2^* \frac{V(SY,t) - V(S,t) - V_S(S,t)(SY - S)}{V(S,t)} \tag{16}$$

2.1.1.3 The Formula for Option Pricing

As we have shown in the previous section, there is no possibility to construct a risk-free portfolio of stocks and options, so it is not possible to adapt the no-arbitrage approach of Black and Scholes. However regarding Samuelson (Rational Theory of Warrant Pricing), it is possible to determine a formula for option pricing if the price is expressed as a function of the stock price and the remaining time until maturity. $g(S,\tau)$ is the equilibrium which reflects the expected rate of return on the option, with S as the current stock price and $\tau = T - t$, which is the remaining time until maturity. From equation (6) we gather that the price V is dependent on τ instead of t on the partial differential difference equation

$$0 = \frac{1}{2}\sigma^2 S^2 V_{SS} + (\alpha - \lambda\kappa)SV_S - V_\tau - g(S,t)V + \lambda E[V(SY,\tau) - V(S,\tau)] \tag{17}$$

with satisfy the boundary conditions (see Merton 1975: 13):

$$V(0,\tau) = 0 \tag{18a}$$

$$V(S,0) = (S - K)^+ \tag{18b}$$

Another approach concerning the pricing problem follows along the assumption that the Capital Asset Pricing Model (CAPM), developed by Black and Scholes, was the legal description of stock returns and equilibrium. In the previous part we described that the dynamic of the option price depends on two components, the continuous and the jump part. The latter describes jumps which are determined by new important information. If the information is firm- or sector-specific, then this information has only little influence on the market. Such information represents the non-systematic risk, which means the jumps are not correlated with the market. If we look at equations (14), we realize that only the jump component is the source of uncertainty in the return dynamics. Considering that the CAPM holds, the expected return has to be the risk free interest rate, so $\alpha_P^* = r$. This condition implies that equation (9) can be rewritten this way: $\omega_1^*(\alpha - r) + \omega_2^*\left(\alpha_{opt} - r\right) = 0$, or substituting for ω_1^* and ω_2^* and we get (see Merton 1975: 13-15):

$$\frac{\alpha - r}{\sigma} = \frac{\alpha_{opt} - r}{\sigma_{opt}} \tag{19}$$

Concerning equations (6) and (7), this implies that the option price V must satisfy $0 = \frac{1}{2}\sigma^2 S^2 V_{SS} + (r - \lambda\kappa)SV_S - V_\tau - rV + \lambda E[V(SY,\tau) - V(S,\tau)]$ (20)

with the boundary conditions of equations (18a) and (18b).

Formally, this equation has the same form as equation (17) but does not depend on $g(S,\tau)$ or α. In the formula, however, only the risk-free interest rate appears as regards the Black Scholes approach. If we set $\lambda = 0$, which means there are no jumps, the equation is reduced to the Black Scholes equation. Note that, if the jumps even represent pure non-systematic risk, the jump process does influence the equilibrium of the option price. This is why the fair option price cannot be determined without considering the jump part (see Merton 1975: 15).

We define the mean as:

$$E = \int_0^\infty Y_g(Y)dY \tag{21}$$

With this definition we can rewrite equation (20) to

$$V_\tau = \frac{1}{2}\sigma^2 S^2 V_{SS} + (r - \lambda\kappa)SV_S - (r + \lambda)V + \lambda\int_0^\infty V(SY,\tau)g(Y)dY \tag{22}$$

$g(y)$is the probability density function of the jump process

2.1.1.4 Closed-Form Solutions of the Merton Model

Unfortunately, it is impossible to write down a complete closed-form solution of the Merton's formula even for European-style options. Merton, however, developed solutions where he specified the distribution for Y. Merton developed two different analytical solutions. One possibility is that the stock price jumps during one jump process to a price of 0, which is also called "Total Ruin". The other possibility is that the jumps follow a log-normal distribution. These two cases will be described in the next two parts (see Merton 1975: 15-16).

2.1.1.5 Total Ruin

In the first case of an analytical solution there is a total ruin which occurs suddenly. This means if the Poisson event occurs, the stock price decreases to zero. As a result, the random variable Y, which represents the change if the Poisson event occurs is zero with a probability of one. The percentage change of the stock price is then at $(Y - 1) = -1$ and expresses a default. In this case the price of a European style call option with the remaining time $\tau = T - t$ is, as follows (see Merton 1975: 16-17):

$$V_C(S,\tau) = e^{-\lambda\tau} BS_C\left(Se^{\lambda\tau};\tau;K;\sigma^2;r\right)$$
$$= e^{-\lambda\tau}\left(Se^{\lambda\tau}N(d_1) - Ke^{-r\tau}N(d_2)\right)$$
$$= SN(d_1) - Ke^{-(r+\lambda)\tau}N(d_2) \qquad (23)$$

with

$$d_1 = \frac{\log\left(\frac{Se^{\lambda\tau}}{K}\right) + (r + \frac{1}{2}\sigma^2)\tau}{\sigma\sqrt{\tau}} = \frac{\ln\left(\frac{S}{K}\right) + (r + \lambda + \frac{1}{2}\sigma^2)\tau}{\sigma\sqrt{\tau}}$$

and

$$d_2 = d_1 - \sigma\sqrt{\tau}$$

$BS_C\left(Se^{\lambda\tau};\tau;K;\sigma^2;r\right)$ is the solution of the standard Black-Scholes formula but with a higher interest- not only the risk free interest rate but this interest plus λ. Regarding the characteristic that the option price is a function of the interest rate, an option with a stock as underlying and a positive probability of a total ruin is more expensive than an option which neglects this possibility (see Merton 1975: 17 and Merton 1973: 160-173).

2.1.1.6 Log-Normal Distributed Jumps

As we have already mentioned in the introduction to this part, in the second case the random variable Y, which expresses the price changes if a jump occurs is log-normal distributed. So this following probability density function $g(Y)$ has to pertain (see Merton 1975: 17-20):

$$g(x) = \frac{1}{\sqrt{2\pi\sigma x}} \exp\left(-\frac{(lnx-\mu)^2}{2\sigma^2}\right) \qquad (24)$$

The price can now be rewritten on this condition as follows:

$$V_C(S,\tau) = e^{-r\tau}\sum_{n=0}^{\infty} P(n\,jumps)E_0[\max(0, S_T - K)|n\,jumps] \qquad (25)$$

$$= \sum_{n=0}^{\infty}\left[\frac{e^{-\varepsilon\lambda\tau}(\varepsilon\lambda\tau)^n}{n!}\right]E_{0,x_n}\left[BS_C\left(SX_ne^{-\lambda\kappa\tau},\tau,K,\sigma^2,r\right)\right] \qquad (26)$$

$$= \sum_{n=0}^{\infty}\left[\frac{e^{-\varepsilon\lambda\tau}(\varepsilon\lambda\tau)^n}{n!}\right]BS_C(S,\tau,K,v_n^2,r_n) \qquad (27)$$

where:

E_{0,x_n} *is the expected value regarding the distribution of* X_n *at time* 0

$$S_T = Sexp\left[\left(r - \frac{1}{2}\sigma^2\right)T + \sigma W_T\right]$$

$$d_{1,n} = \frac{\log\left(\frac{S}{K}\right) + (r_n + \frac{1}{2}v_n^2)\tau}{v_n\sqrt{\tau}}$$

$$d_{2,n} = d_{1,n} - v_n\sqrt{\tau}$$

$$v_n^2 = \sigma^2 + \frac{n}{\tau}{\sigma_j}^2$$

$$r_n = r - \lambda * (\varepsilon - 1) + n * \frac{\log(\varepsilon)}{\tau}$$

σ_j^2 *is the varianz for the jump diffusion*

ε *is the average jump size*

In the case of log-normally distributed jumps we also have an application of the Black-Scholes formula with changed parameters. In the calculation of the option price an infinite but convergent sum and with a Poisson distribution weighted sum has to be evaluated (see Merton 1975: 18-20).

2.1.2 Kou Model

Another model for option pricing is the Kou Model developed by Steven Kou. Kou assumes that jumps of a stock are not log-normally distributed, as Merton assumes, but follow a double-exponential distribution. All other assumptions for the market stay the same, so only the modelling of the stock prices changes (see Kou 2001:2-3 and Kou/Wang 2003: 1-2).

2.1.2.1 The Model

The model again consists of two different parts. The first part is a continuous part driven by a normal geometrical Brownian motion and the second part is the jump part with a logarithm of jump size, which are double exponentially distributed and the jumps times are determined by the event times of a Poisson process. The stock quotation is described by the following partial differential equation (see Kou 2001: 3 and Kou/Wang 2003: 3):

$$\frac{dS(t)}{dS(t-)} = \mu dt + \sigma dW(t) + d\left(\sum_{i=0}^{N(t)}(V_t - 1)\right) \qquad (28)$$

where:

μ *and* σ *are the expectation value and the volatility*

$W(t)$ *is a standard Brownian motion*

$N(t)$ *is a Poisson process with the parameter* λ

$\{V_i\}$ *is a series of independent identically distributed nonnegative random variables*

$Y = log(V)$ *and has got an asymmetric double exponential distribution*

The density of the double exponential distribution is given by:

$f_Y(y) = p\eta_1 e^{-\eta_1 y} 1_{\{y \geq 0\}} + q\eta_2 e^{\eta_2 y} 1_{\{y<0\}}$ with the condition $\eta_1 > 1$ *and* $\eta_2 > 0$

$p, q \geq 0, p + q = 1$ are the probabilities of the upward and downward jumps of the stock price. So we can express this also in this way:

$$\log(V) = Y = \begin{cases} \zeta^+, & \text{with the probability } p \\ -\zeta^-, & \text{with the probability } q \end{cases} \qquad (29)$$

where ζ^+ *and* ζ^- are exponential distributed random variables with an expectation value of $\frac{1}{\eta_1}$ *and* $\frac{1}{\eta_2}$ and both must be distributed the same way. All random variables in equation (29) are independent, and - for simplicity and to obtain an analytical solution for option prices - the drift μ and the volatility σ are assumed to be constant. Further, the Brownian motion and the jump processes are supposed to be one-dimensional. All these constraints can be easily rescinded to develop a general model (see Kou 2001:4 and Kou/Wang 2003: 3).

If we solve the differential equation (29), we see the following dynamic of the stock price:

$$S(t) = S(0)exp\left\{\left(\mu - \frac{1}{2}\sigma^2\right)t + \sigma W(t)\right\}\prod_{i=1}^{N(t)} V_i \qquad (30)$$

where:

$$E[Y] = \frac{p}{\eta_1} - \frac{q}{\eta_2}, Var[Y] = pq\left(\frac{1}{\eta_1} - \frac{1}{\eta_2}\right)^2 + \left(\frac{p}{\eta_1} + \frac{q}{\eta_2}\right) \; and$$
$$E(V) = E(e^Y) = q\frac{\eta_2}{\eta_2+1} + p\frac{\eta_1}{\eta_1-1}, \eta_1 > 1, \eta_2 > 0 \tag{31}$$

have to pertain.

It is essential that $\eta_1 > 1$ because otherwise it cannot be ensured that $E(V) < \infty$ and $E(S(t)) < \infty$; due to this assumption it is impossible that an average jump exceeds 100%. The double exponential distribution has got two features which are significant for the model. The first property is the leptokurtic feature and the second feature is the memorylessness of the distribution (see Kou 2001:4).

If the price of a stock follows the dynamic of equation (31), the equation of V for a European style option is the following (see Kou 2001:24-31 and Toivanen n.d.: 6-9):

$$V_t = -\frac{1}{2}\sigma^2 S^2 V_{SS} - (r - \lambda\alpha)SV_S + (r + \lambda)V - \lambda\int_{\mathbb{R}^+} V(Sy,t) f_Y(y)dy \tag{32}$$

2.1.2.2 Closed-Form Solutions of the Kou Model

As we have mentioned in the previous part for the Merton model there only are two closed-form solutions. For the jump diffusion model of Kou there is an analytical solution for European style options.

2.1.2.3 Analytical Solution

The derivation of the analytical formula can be found in Kou's "A Jump Diffusion Model for Option Pricing". Here we will show only the price of a call option regarding to the Martingale approach (see Kou 2001: 16-18).

$$V_C(S,0) = S(0)\Upsilon\left(r + \frac{1}{2}\sigma^2 - \lambda\xi, \sigma, \lambda_K, p_K, \eta_{1,K}, \eta_{2,K}; \log\left(\frac{K}{S(0)}\right), T\right)$$
$$-Ke^{-rT}\Upsilon\left(r - \frac{1}{2}\sigma^2 - \lambda\xi, \sigma, \lambda, p, \eta_1, \eta_2; log\left(\frac{K}{S(0)}\right), T\right) \tag{33}$$

where:

$$p_K = \frac{p}{1+\zeta} * \frac{\eta_1}{\eta_1 - 1}$$

$$\eta_{1,K} = \eta_1 - 1$$

$$\eta_{2,K} = \eta_2 + 1$$

$$\lambda_K = \lambda(\zeta + 1)$$

$$\zeta = \frac{p\eta_1}{\eta_1 - 1} + \frac{q\eta_2}{\eta_2 + 1} - 1$$

another form which is used more often in reality is this:

$$V_c(S,0) = S(0)\alpha_1 \sum_{n=1}^{\infty} \pi_n \sum_{k=1}^{n} P_{n,k}\left(\sigma\sqrt{\tau}\eta_1\right)^k I_{k-1}(h; 1 - \eta_1, -\frac{1}{\sigma\sqrt{\tau}}, -\sigma\eta_1\sqrt{\tau})$$

$$-Ke^{-r\tau} d_1 \sum_{n=1}^{\infty} \pi_n \sum_{k=1}^{n} P_{n,k}\left(\sigma\sqrt{\tau}\eta_1\right)^k I_{k-1}(h; -\eta_1, -\frac{1}{\sigma\sqrt{\tau}}, -\sigma\eta_1\sqrt{\tau})$$

$$+S(0)\alpha_2 \sum_{n=1}^{\infty} \pi_n \sum_{k=1}^{n} Q_{n,k}\left(\sigma\sqrt{\tau}\eta_2\right)^k I_{k-1}(h; 1 + \eta_2, -\frac{1}{\sigma\sqrt{\tau}}, -\sigma\eta_2\sqrt{\tau})$$

$$-Ke^{-r\tau} 2 \sum_{n=1}^{\infty} \pi_n \sum_{k=1}^{n} P_{n,k}\left(\sigma\sqrt{\tau}\eta_2\right)^k I_{k-1}(h; \eta_2, -\frac{1}{\sigma\sqrt{\tau}}, -\sigma\eta_2\sqrt{\tau})$$

$$+\pi_0\left[S(0)e^{-\lambda\zeta\tau}\Phi(b_+) - Ke^{-r\tau}\Phi(b_-)\right] \quad (34)$$

with

$$b_{\pm} = \frac{\log\left(\frac{S(0)}{K}\right) + (r \pm \frac{\sigma^2}{2} - \lambda\zeta)\tau}{\sigma\sqrt{\tau}}; \quad \zeta = \frac{p\eta_1}{\eta_1 - 1} + \frac{q\eta_2}{\eta_2 + 1} - 1$$

$$\alpha_i = e^{-\left(\lambda\zeta + \frac{\sigma^2}{2}\right)\tau} d_i; \; i = 1,2; \; d_i = \frac{e^{(\lambda\eta_i)^2 * \frac{\tau}{2}}}{\sigma\sqrt{2\pi\tau}} \quad h = \log\left(\frac{K}{S(0)}\right) + \lambda\zeta\tau - \left(r - \frac{\sigma^2}{2}\right)\tau$$

$$P_{n,k} = \sum_{i=k}^{n-1} \binom{n-k-1}{i-k} * \binom{n}{i} * \left(\frac{\eta_1}{\eta_1 + \eta_2}\right)^{i-k} * \left(\frac{\eta_2}{\eta_1 + \eta_2}\right)^{n-i} * p^i * q^{n-i}; \quad 1 \le k \le n-1$$

$$Q_{n,k} = \sum_{i=k}^{n-1} \binom{n-k-1}{i-k} * \binom{n}{i} * \left(\frac{\eta_1}{\eta_1 + \eta_2}\right)^{n-i} * \left(\frac{\eta_2}{\eta_1 + \eta_2}\right)^{i-k} * p^{n-i} * q^i; \quad 1 \le k \le n-1$$

$$P_{n,n} = p^n; \quad Q_{n,n} = q^n; \quad \pi_n = \frac{e^{-\lambda\tau}(\lambda\tau)^n}{n!}$$

$b_{\pm}$ is very similar to the d_1 and d_2 of the Black Scholes Model, also with $b_{\pm}$ risk adjusted probabilities are calculated

ζ is the expected value of the jump distribution

α_i are the means of the stock prices

$P_{n,k}$ and $Q_{n,k}$ are the probabilities of the jumps, P is the probability that there is a positive jump and Q that there is a negative jump

π_n is a constant value

The price of the put can be calculated regarding the put call parity (see Kou 2001:17):

$$V_P(S,0) = V_C(S,0) + e^{-rT}E * \left(\left(K - S(T)\right)^+ - (S(T) - K)^+\right)$$

$$= V_C(S,0) + e^{-rT}E * \left(K - S(T)\right) = V_C(S,0) + Ke^{-rT} - S(0) \quad (35)$$

2.1.2.4 Volatility Smile and Leptokurtic Feature

Although each model has got it´s inaccuracies, properties can be specified which should be fulfilled so that stock prices can be replicated the best way. The two main properties are the asymmetrical leptokurtic feature and the volatility smile. The leptokurtic feature means that the distribution of stock returns is skewed to the left side and there are a higher peak and two heavier tails compared to the normal distribution. It is not so easy to show the leptokurtic feature and so we would like to illustrate that with an example. The value of the stock over the time horizon Δt is given regarding to equation (31):

$$\frac{\Delta S(t)}{S(t)} = \frac{S(t+\Delta t)}{S(t)} - 1 = exp\left\{\left(\mu - \frac{1}{2}\sigma^2\right)\Delta t + \sigma[W(t+\Delta t) - W(t)] + \sum_{i=N(t)+1}^{N(t+\Delta t)} Y_i\right\} - 1 \quad (36)$$

The sum over an empty set is taken to be zero. If the time horizon Δt is small, for example, if the observation horizon is only one trading day, the distribution of the stock return can be approximated and the terms with a higher order than Δt can be ignored. The expansion $e^x \approx 1 + x + \frac{x^2}{2}$ can be used and is expressed in the distribution by (see Kou 2001: 8-10):

$$\frac{\Delta S(t)}{S(t)} \approx \mu\Delta t + \sigma Z\sqrt{\Delta t} + B * Y \quad (37)$$

where:

Z *is a standard noramlly distributed random variable*

B *is a Bernoulli distributed random variable with* $P(B = 1) = \lambda\Delta t$

and $P(B = 0) = 1 - \lambda\Delta t$

Y *is given by equation* (30)

Here are illustrations where the density of the double exponential jump diffusion model is compared to the normal distribution. The figures were made with Wolfram Mathematica 9 (the programming code can be found in the appendix)

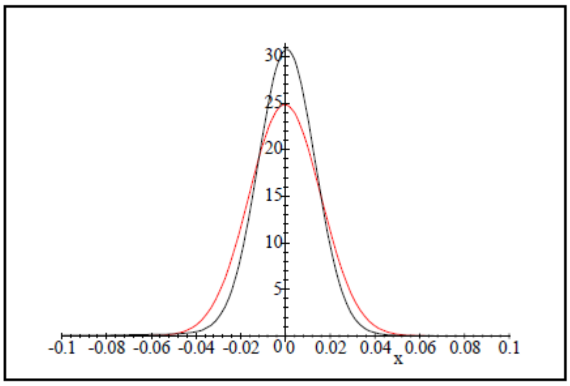

Illustration 1: Overall Comparison;

Source: own illustration

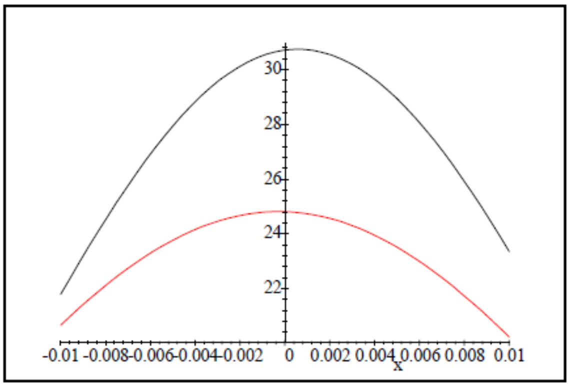

Illustration 2: Left Tail Comparison;

Source: own illustration

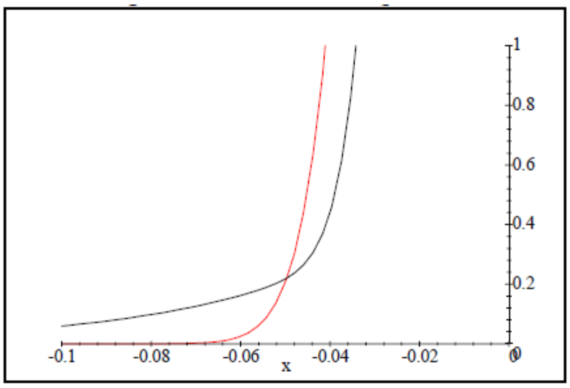

Illustration 3: Peak Comparison;

Source: own illustration

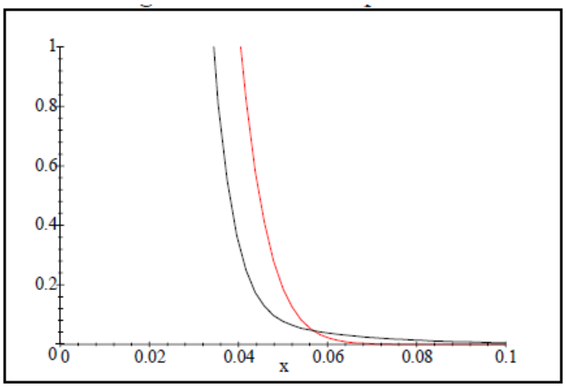

Illustration 4: Right Tail Comparison;

Source: own illustration

The red line represents the normal density and the blue line represents the density of the double exponential jump diffusion model. The parameters are given by:

$$\Delta t = 1\ day = \frac{1}{250}$$

$\sigma = 20\%\ p.a.$

$\mu = 15\%\ p.a.$

$\lambda = 10\ p.a.$

$p = 0{,}30$

$\frac{1}{\eta_1} = 2\%\ and\ \frac{1}{\eta_2} = 4\%$

The leptokurtic feature is quite obvious when you look at the illustrations above. The peak of the model's density is at approximately 31 whereas the peak of the normal distribution's density is at approximately 25. Also the heavier tails are quite evident in the figures.

The volatility smile can be shown if the implied volatility regarding the strike price is calculated. In the case of the Kou model the solution is a strict convex function. If the same is done with the parameters of the Black-Scholes model, the solution is a constant volatility function (see Kou 2001: 21).

2.2 Black-Scholes Model

One of the best known models for option pricing is the model of Black and Scholes, the so called Black-Scholes model. It was developed in 1973 and has been the foundation of the worldwide option trading since then. With this model it was possible for the first time to estimate the fair price of an option with a dividend paying stock as underlying (see Black/Scholes 1973: 637-640).

2.2.1 Assumptions

To get a formula for the fair price of an option regarding the underlying stock price ideal conditions in the market are assumed. The following assumptions have to be taken so that there is a perfect market (see Black/Scholes 1973: 640):

(1) the risk free interest rate r is given and constant through time

(2) the stock pays no dividend payments

(3) the option is a European style option, so it can only be exercised at maturity

(4) there are no transaction costs

(5) there is the possibility to borrow any fraction of the price of a security

(6) it is allowed to do short trades

(7) for all parties the same information is available

(8) there are no arbitrage possibilities

(9) stocks are randomly divisible

(10) the stock price $S(t)$ follows a linear stochastic differential equation:

$$dS(t) = \mu S(t)dt + \sigma S(t)dW(t) \quad (38)$$

where:

$\mu\ and\ \sigma\ are\ constant\ parameters\ with\ the\ properties\ \mu \in \mathbb{R}\ and\ \sigma \in \mathbb{R}^+$

$W(t) is\ a\ Wiener\ process$

$N(t) is\ a\ standard\ Brownian\ motion$

$N(0,t) is\ a\ Gauß'sch - normally\ distribution\ with\ mean\ 0\ and\ variance\ t$

Due to this characteristic you can see that the strike price is modelled by a geometrical Brownian motion with the parameters μ, the drift and σ, the volatility.

2.2.2 The Black-Scholes Equation

Black and Scholes show that it is possible to create a dynamic risk-free portfolio consisting of α stocks and an amount of money M. Independent of the stock price, this portfolio pays the same payment as a European-style option at time T. Due to the no-arbitrage possibility the price of the option has to be equal to the initial investment at the beginning. In mathematical language this means (see Black/Scholes 1973: 641-642):

$$V(S,t) = \alpha S(t) + M \quad (39)$$

With this construction of a risk-free portfolio and the partial differential equation as mean tool, Black and Scholes show that the price of a European style option with constant interest rate r and constant volatility σ follow the following Black-Scholes equation (see Black/Scholes 1973: 642-643):

$$\frac{\partial V}{\partial t} + \frac{\sigma^2}{2} S^2 \frac{\partial^2 V}{\partial S^2} + rS\frac{\partial V}{\partial S} - rV = 0 \quad (40)$$

2.2.3 The Black-Scholes Formula

Equation (40) has an analytical solution. So it is possible to calculate and express the price of a European style call option with this equation:

$$V_C(S(0),t) = S(0)N(d_1) - Ke^{-r(T-t)}N(d_2) \quad (41)$$

where d_1 and d_2 are given with:

$$d_1 = \frac{\ln\left(\frac{S(0)}{K}\right) + \left(r + \frac{1}{2}\sigma^2\right)(T-t)}{\sigma\sqrt{T-t}} \text{ and } d_2 = d_1 - \sigma\sqrt{T-t} \quad (42)$$

$N(d)$ is a cumulative normal distribution with a mean of 0 and a variance of 1:

$$N(d) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{d} e^{-\frac{y^2}{2}} dy \quad (43)$$

The price of a European style put option can be calculated with the pull-call parity and so the price is given by (see Black/Scholes 1973: 644):

$$V_P(S(0),t) = Ke^{-r(T-t)}N(-d_2) - S(0)N(-d_1) \quad (44)$$

3. Estimation and Hypothesis Testing of a European Call and a European Put Option

After this theoretical part we would like to show in this section how these different models are used for the pricing of a European call and put option with a stock as underlying asset. In the first part we will show the option price estimated with the Black-Scholes Approach. This solution will then also be used as a testimonial for all other models.

3.1 Introduction and Definition of Parameters

The data which is used for the option pricing has been taken from the "Thomson Reuters Wealth Manager".[1] The underlying are the daily stock returns of the OMV AG (ISIN: AT0000743059) in 2011. The strike price of the options is assumed to be € 25.00. The 1year EURIBOR is assumed to be 0.602% which is the close quote on 6 November 2012. Here is an overview of the general parameters used.

[1] Here is the link to this wealth manager: http://rwm.reuters.de/login/classic.html

General Parameters	
Stock	€ 23,44
Strike	€ 25,00
Volatility	0,3287
Risk-Free Interest Rate	0,602%
Duration	0,24 years
Dividend Yield	0,00
Trading Days	248

Table 1: General Parameters for all Models; Source: own table

All further used parameters will be described in the part where they are used.

3.2 Black Scholes Model as Testimonial

In this part we will estimate the long call and long put price of the option regarding the Black-Scholes approach. The prices which are shown in the following illustration will be compared to the solutions of the other models in the next parts. Furthermore also the payoff profile of the option with a current stock price of € 23.44 will be illustrated. All illustrations and tables which will follow in the next two parts were created in Microsoft Excel 2007 or Mathematica 9. All programming codes which have been used to get all the data can be found in the appendix.

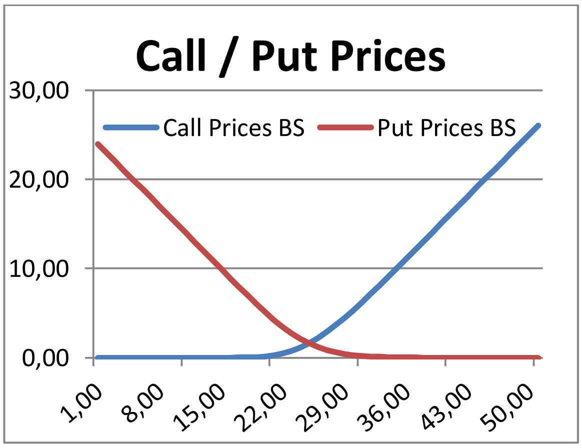

Illustration 5: Call / Put Prices;
Source: own illustration

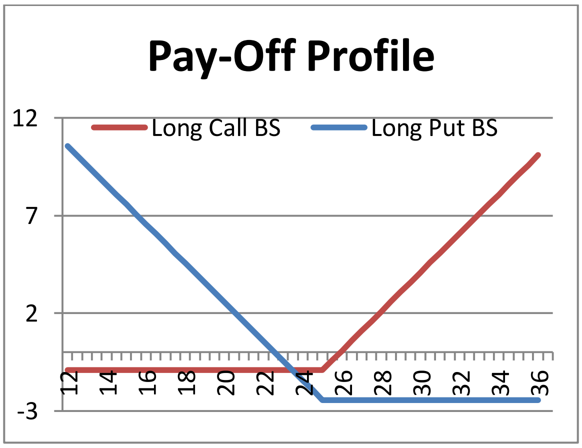

Illustration 6: Pay-Off Profile;
Source: own illustration

3.3 Merton Model

3.3.1 Parameters

To evaluate the price of a long call or put option with the Merton Jump approach, we have to define further parameters. First of all it is important to define what a jump is. In the literature you find only the following: Jumps are determined by new important information. If the information is firm- or sector-specific, then this information has only little influence on the market. Such information represents the non-systematic risk, which means the jumps are uncorrelated with the market.[2]

This explanation, however, is vague because it does not say anything about how the market can be defined and which discrepancy there has to be between the returns of a stock and of the market so that the stock motion can be defined as a jump.

We assumed that the MSCI World Index (ISIN: XC000A0V7491), which is published by Morgan Stanley Capital International, reflects the market because of its huge stock portfolio which is its underlying. Then we assumed that a jump occurs if the daily return of the OMV AG stock is higher or lower ± the volatility of the MSCI index in 2011. Due to that definition the jump rate, λ is 0.47368.

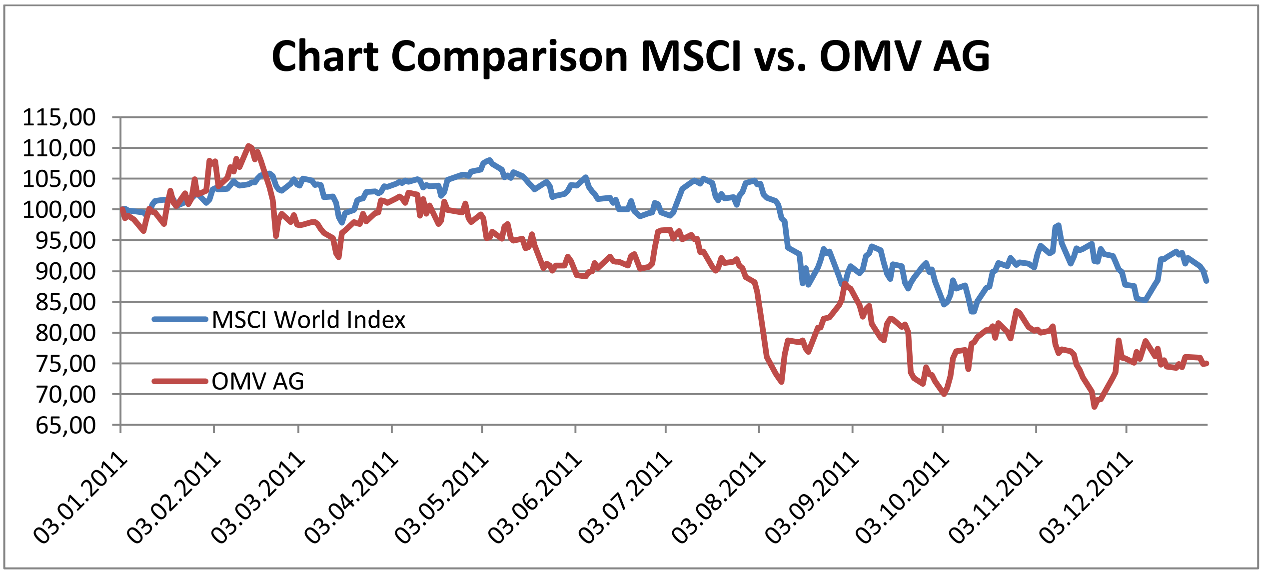

Illustration 7: Chart Comparison MSCI vs. OMV AG; Source: own illustration

[2] cf. Merton R. C. (1975): pages 14 and 15

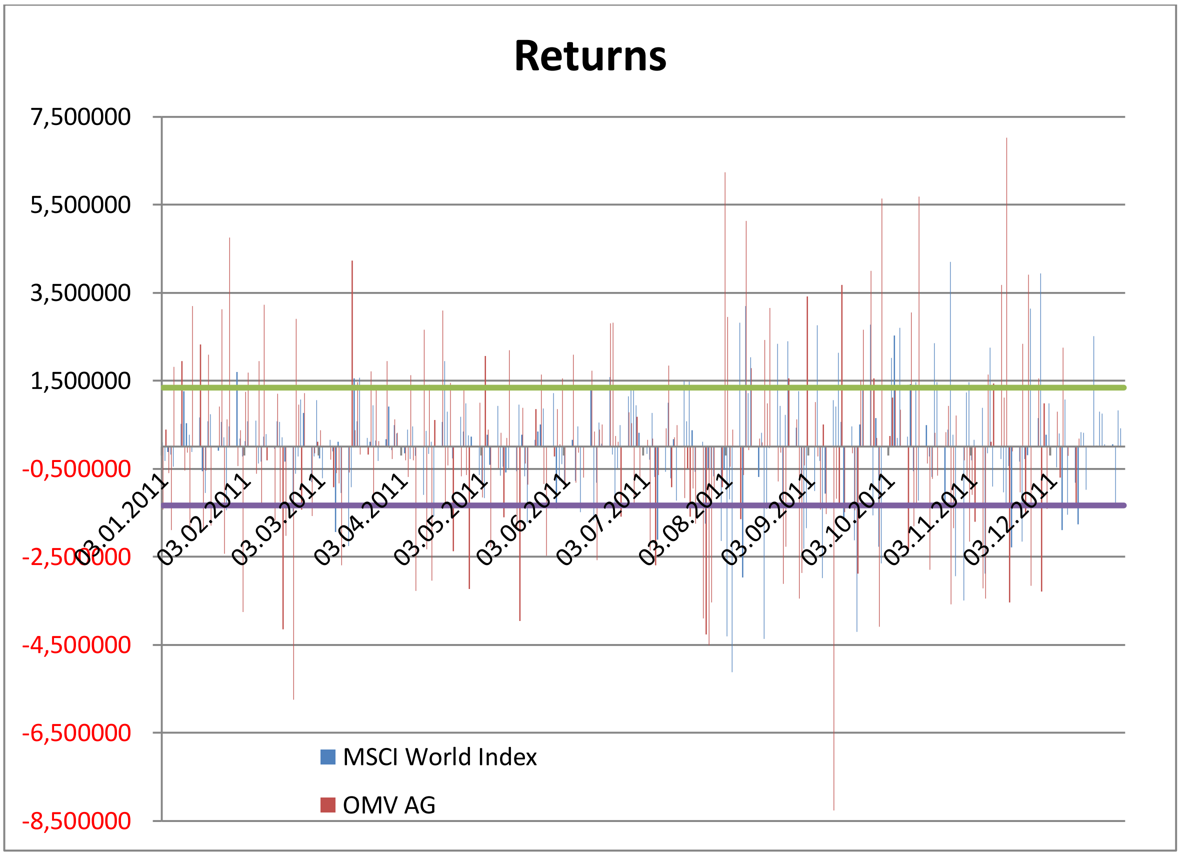

Illustration 8: Daily Returns; Source: own illustration

The green and violet lines are ± the volatility of the MSCI index.

Special Parameters for Merton Model		
	Normal distributed	LOG Normal distributed
λ	0,4736842	
σ_j	0,465109567	0,4647414
σ_j^2	0,013736772	0,2159846
ε	-0,001446049	0,9989906

Table 2: Parameters for Merton Jump Model; Source: own Table

3.3.2 Total Ruin

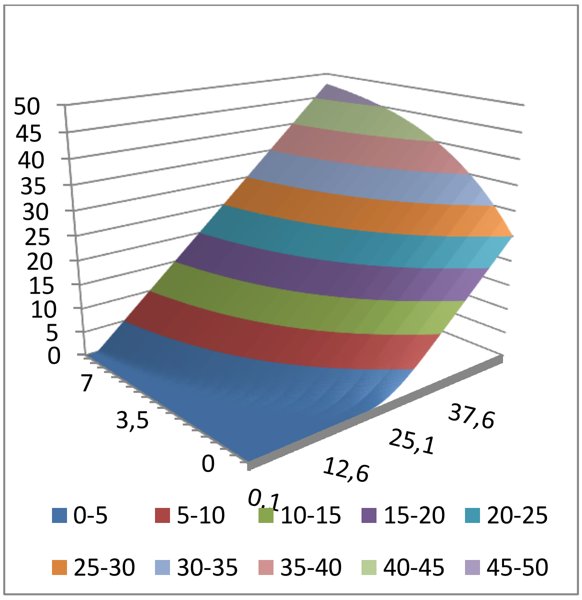

Illustration 9: Call-Option Prices regarding Stock Prices and Jump Intensities in the Case of a Total Ruin; Source: own illustration

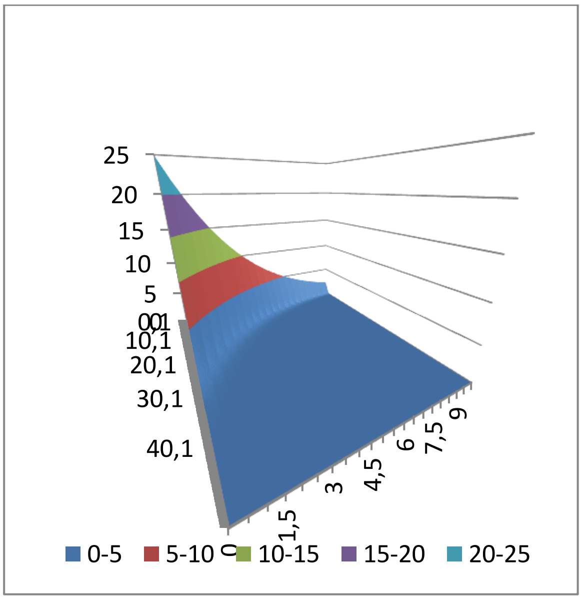

Illustration 10: Put-Option Prices regarding Stock Prices and Jump Intensities in the Case of a Total Ruin; Source: own illustration

You can see that the value of a call option with an increasing stock price and an increasing jump rate also grows.

The possibility that a stock with a high jump rate has not "jumped" at maturity is very low and so this low likelihood, which would grant a high profit, has to be paid by a high option price.

In the case of a put option the option price with a decreasing jump rate and decreasing stock price increases. Profits can be gained if the stock price is lower than the strike price; regarding this the highest profit can be achieved if the stock price decreases to zero. All in all, the highest option price results if the stock price at the beginning of the contract is very small and the jump rate is also low because then the likelihood of a volatile stock price is very volatile is low. As already mentioned in the theoretical part in 2.1.1.5 the option price follows a Brownian motion if the jump rate is equal to zero.

The illustrations below show the option price and the profit / loss statement regarding the parameters of my example:

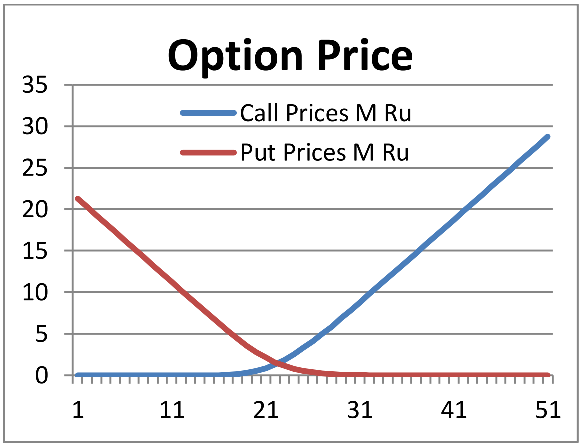

Illustration 11: Option Price with Merton Jump Model in the Case of Total Ruin;
Source: own illustration

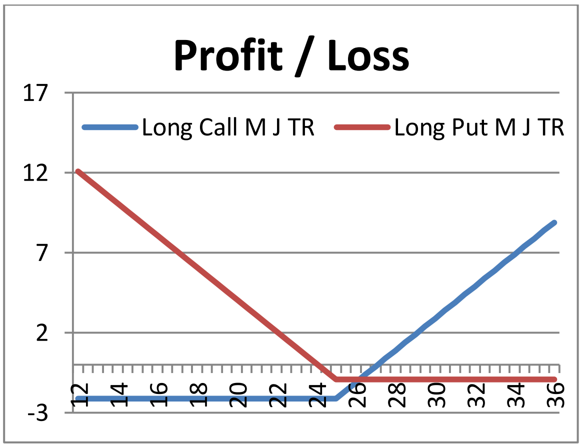

Illustration 12: Profit / Loss of an Option regarding Merton Jump Model in the Case of Total Ruin;
Source: own illustration

3.3.3 Log–Normal distributed Jumps

If you look again at equation (27), you can see that the formula of the option price with log-normal distributed jumps consists of an infinite sum. To calculate the option price, we have to approximate the infinite sum to a finite sum. In the table below you can see that the cut-off point of the calculation after the 10th item is possible because the value of the Poisson loading decreases very fast and the change in the sum is so small that it can be neglected for pricing an option.

n	Poisson-Loading	Black-Scholes-Value	Product	Sum
0	0,89182501	0,88	0,78180091	0,781800908
1	0,10210089	3,96	0,40471249	1,18651339806789000
2	0,00584453	5,66	0,03309141	1,21960480869617000
3	0,00022304	6,95	0,0015508	1,22115561069015000
4	6,3836E-06	8,02	5,1199E-05	1,22120680984683000
5	1,4617E-07	8,94	1,3066E-06	1,22120811647742000
6	2,789E-09	9,75	2,7193E-08	1,22120814367030000
7	4,5614E-11	10,48	4,779E-10	1,22120814414820000
8	6,5277E-13	11,14	7,2697E-12	1,22120814415547000
9	8,3036E-15	11,74	9,7487E-14	1,22120814415557000
10	9,5064E-17	12,30	1,169E-15	1,22120814415557000
11	9,894E-19	12,81	1,2676E-17	1,22120814415557000
12	9,4393E-21	13,29	1,2546E-19	1,22120814415557000
13	8,3128E-23	13,74	1,1421E-21	1,22120814415557000
14	6,7978E-25	14,16	9,6251E-24	1,22120814415557000
15	5,1883E-27	14,55	7,5509E-26	1,22120814415557000
16	3,7124E-29	14,93	5,5408E-28	1,22120814415557000
17	2,5001E-31	15,28	3,8191E-30	1,22120814415557000
18	1,5901E-33	15,61	2,4818E-32	1,22120814415557000
19	9,5815E-36	15,92	1,5255E-34	1,22120814415557000
20	5,4847E-38	16,22	8,8955E-37	1,22120814415557000
21	2,9901E-40	16,50	4,9341E-39	1,22120814415557000
22	1,556E-42	16,77	2,6094E-41	1,22120814415557000
23	7,7452E-45	17,03	1,3187E-43	1,22120814415557000
24	3,6946E-47	17,27	6,3805E-46	1,22120814415557000
25	1,6919E-49	17,50	2,9612E-48	1,22120814415557000
26	7,45E-52	17,72	1,3204E-50	1,22120814415557000
27	3,159E-54	17,94	5,6658E-53	1,22120814415557000
28	1,2916E-56	18,14	2,3428E-55	1,22120814415557000
29	5,099E-59	18,33	9,3474E-58	1,22120814415557000
30	1,9459E-61	18,52	3,6032E-60	1,22120814415557000

Table 3: Calculation of the Approximated Infinite Sum; Source: own table

As already shown also in the previous part, we would like to show the option price of a long call and put option regarding the option price and the jump intensity below.

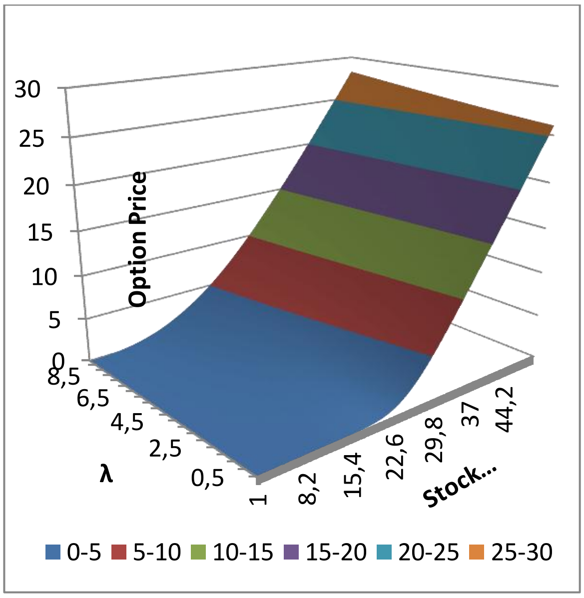

Illustration 13: Call-Option Prices regarding Stock Prices and Jump Intensities in the Case of LOG-Normal Distributed Jumps;
Source: own illustration

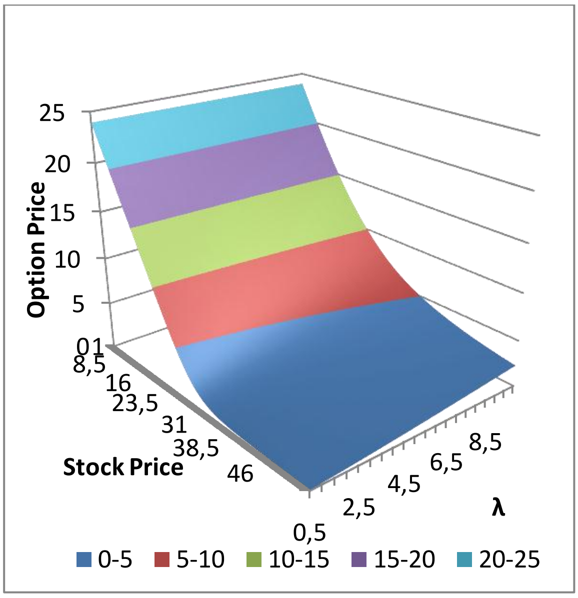

Illustration 14: Put-Option Prices regarding Stock Prices and Jump Intensities in the Case of LOG-Normal Distributed Jumps;
Source: own illustration

In illustrations 13 and 14 you can see again that the option price of a call option increases if the jump intensity increases and the stock price also increases, but the option price of a put option increases if the jump intensity increases and the stock price decreases because you gain a profit if the stock price is below the strike price.

The illustrations below show the option price and the profit / loss statement regarding the parameters of the example:

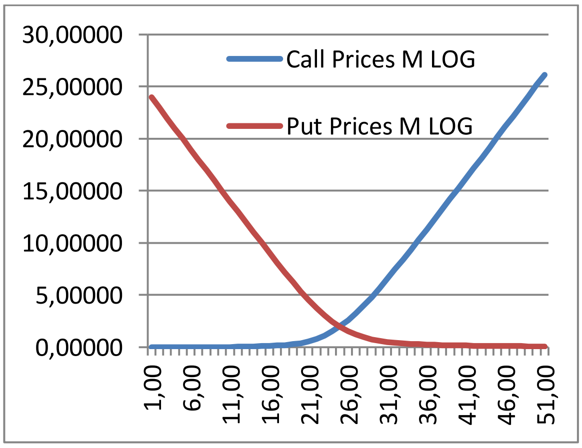

Illustration 15: Option Price regarding the Merton Jump Model in the Case of LOG-Normal Distributed Jumps;
Source: own illustration

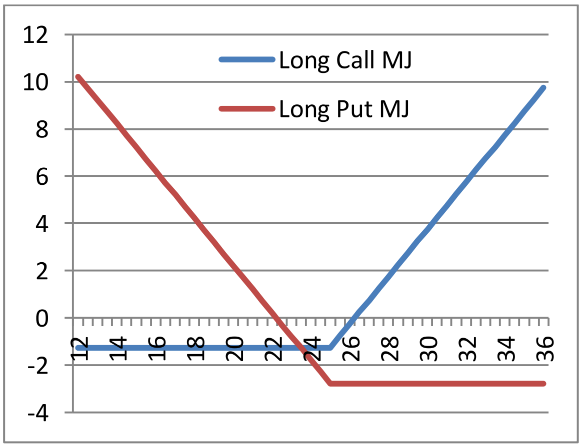

Illustration 16: Profit / Loss of an Option regarding Merton Jump Model in the Case of LOG-Normal Distributed Jumps;
Source: own illustration

All in all, the two shown closed solutions of the Merton Jump Model are very easy to calculate because they are only an advanced form of the Black-Scholes equation with varying parameters, but it is also important to keep in mind that further assumptions have to be made obtain these solutions.

3.4 Kou Model

Now let us look at the last of our models which is the most complex of all three. All assumptions which have been defined in the previous parts also pertain in this part. But also regarding this model some parameters have to be defined before calculation:

Special Parameters for the Kou Model		
Variable	**Value**	**Declaration**
$1/\eta_1$	0,21774	Mean of the positive random parameter
$1/\eta_2$	0,25403	Mean of the negative random parameter
p	0,53846	Probability of an upward jump
q	0,46154	Probability of a downward jump
ς	0,05639	Expected value of the jump distribution

Table 4: Parameters of the Kou Model; Source: own table

Due to the fact that the complete analytical solution of the Kou model is very complex, we tried to calculate the option price only with numerical functions. To calculate the integral which is needed to obtain the option price you have to solve the Hh Function, which is an infinite function. Here the question was where to cut off the infinite sum? Through our investigations we have seen that there is no difference if we stop the sum after item 50 or any figure bigger than 50. The same problem reoccurred for the calculation of the option price with the Kou equation. But here Mr Kou already calls the readers' attention to the fact that most of the time the calculation can be cut off after the 15^{th} item. We have also tried out and noted that if we cut off the sum after the 15^{th}, the 50^{th} or the 51^{st} item the difference between the 15^{th} and 50^{th} item is about € 0.04, which we think is an amount which cannot be neglected in our complex financial world but between the 50^{th} and 51^{st} item there is no numerical difference and so we decided to cut all sums off after the 50^{th} item calculated.

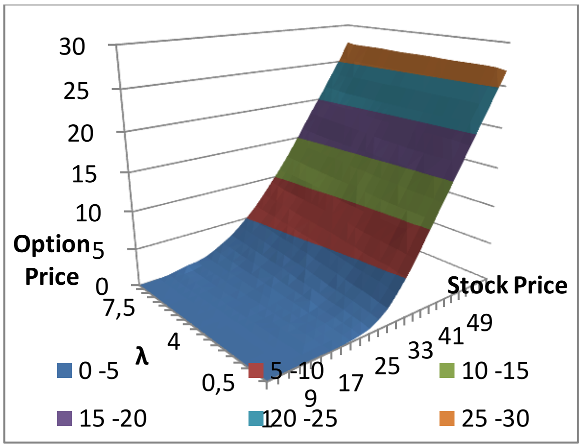

Illustration 17: Call-Option Prices regarding tock Prices and Jump Intensities in the Case of the Kou Model; Source: own illustration

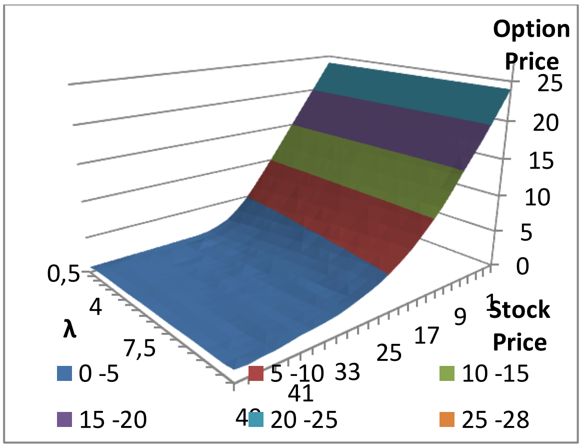

Illustration 18: Put-Option Prices regarding Stock Prices and Jump Intensities in the Kou Model; Source: own illustration

Let us look first at the illustration of the call option prices. The call option price increases if the stock prices increase and if the jump intensity increases.

Now we will come to the illustration of the put option price. The gain of the option contract for the long position is at the peak if the stock defaults. Here you can see again the feature that the option price increases if stock prices decrease and if the jump intensity increases.

Here are the option price and the profit / loss statement regarding the parameters of my example calculated by the Kou model:

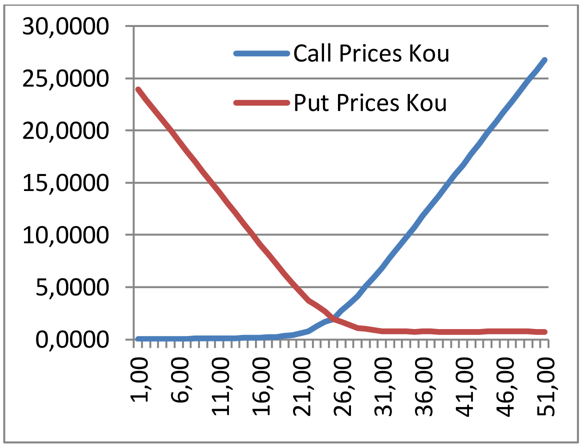

Illustration 19: Option Price regarding to Kou's double exponential jump diffusion model; Source: own illustration

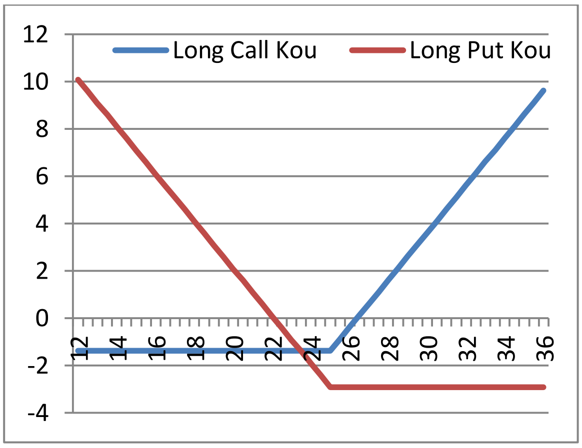

Illustration 20: Profit / Loss Statement regarding Koru's double exponential jump diffusion model; Source: own illustration

The following illustrations should show the difference between the Kou model (red curve) and the Black Scholes approach (green curve).

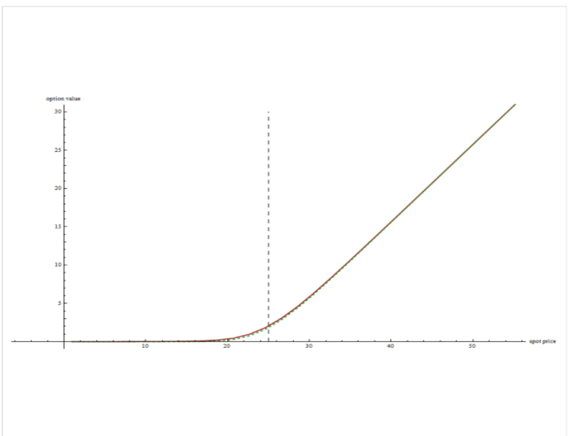

Illustration 21: European style Call: Kou Model vs. Black-Scholes with a jump intensity of 0.47; Source: own illustration

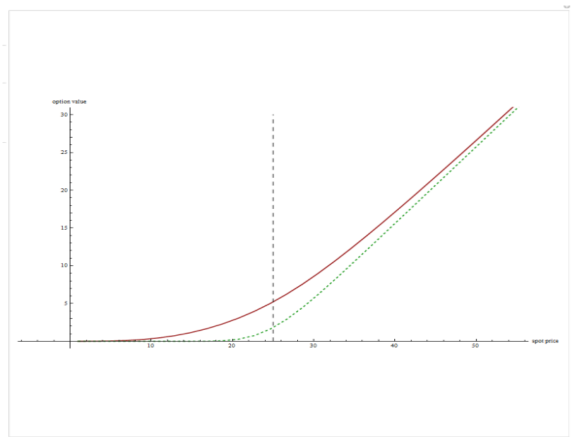

Illustration 22: European style Call: Kou Model vs. Black-Scholes with a jump intensity of 10; Source: own illustration

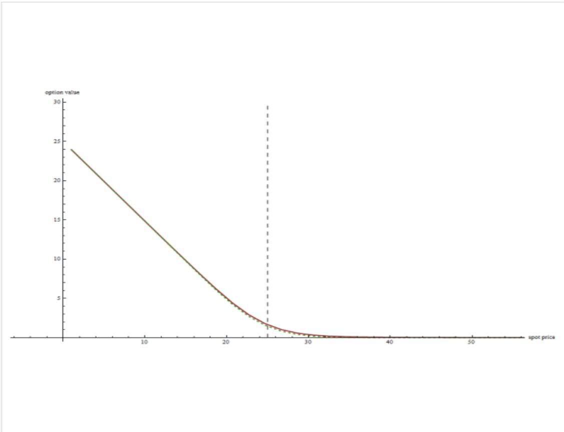

Illustration 23: European style Put: Kou Model vs. Black-Scholes with a jump intensity of 0.47;
Source: own illustration

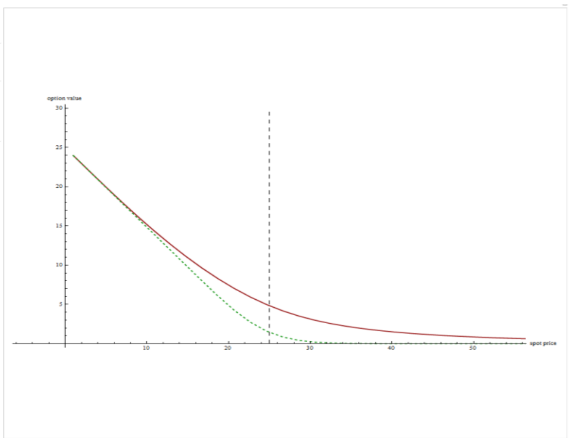

Illustration 24: European style Put: Kou Model vs. Black-Scholes with a jump intensity of 10;
Source: own illustration

If you look at the above illustrations, you can see why the Black-Scholes approach is used more often than the more complex Kou model. If the jump intensity of the underlying asset is small like in our example the difference between the models is very small. If the jump intensity increases, however, the difference between the option prices calculated increases also for at the money options. But with increasing or decreasing option prices the option price calculated by the Kou model and the option price of the Black-Scholes approach approximate. In reality the likelihood of a jump-intensity higher than five is very low, and consequently in most cases it is enough to evaluate the price of an option with the Black-Scholes formula. Theoretical stock data fits the Kou model better, however, because more factors of the underlying are considered. If someone looks only at the formula of the Kou model they would think that the pricing formula for this double exponential jump diffusion model appears very long but in the time of computer programming a solution of the model can be achieved within good time.

3.5 Comparison of all Models for a European Call and Put

In the previous parts we only looked at the option prices and option price changes regarding one special model. Now we want to compete all models. To achieve this we calculated the option prices for each model with the same fundamental parameters.

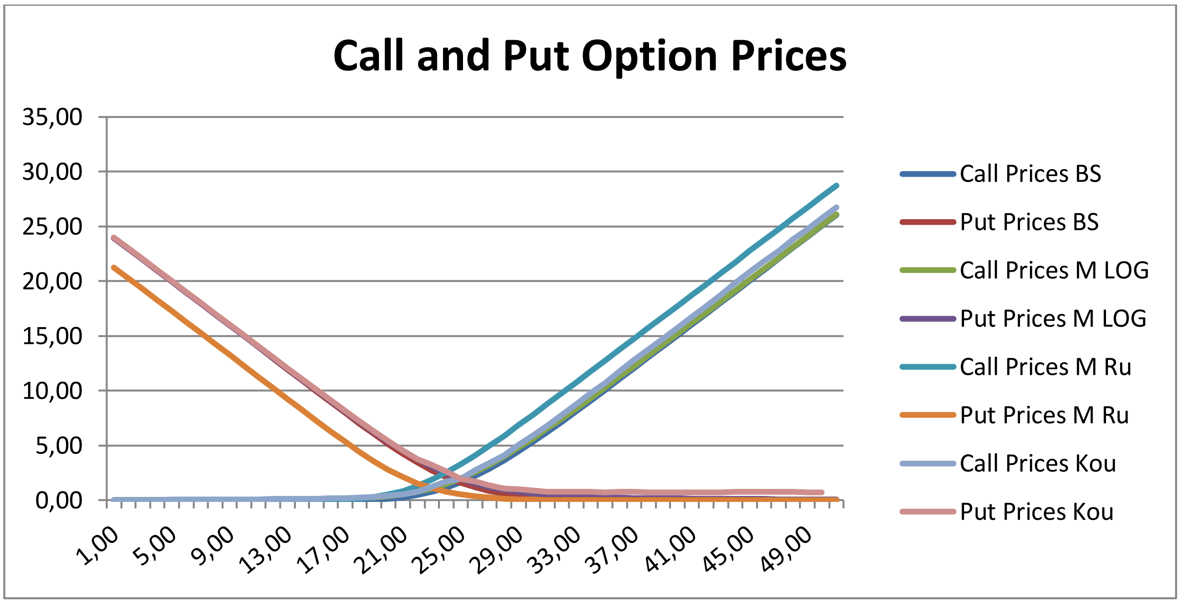

Illustration 25: Option price comparison of all models; Source: own illustration

In the above illustration you can see the option prices of a European style call and put options with the OMV AG stock as underlying. The difference between the option price regarding the Merton-Jump model with log-normally distributed jumps and the Black-Scholes model at strike price is only about € 0.40 and with increasing and decreasing stock prices both option price curves approximate.

If you look at the Merton-Jump model in which the fact of a total ruin is considered you see that the call option price is about € 1.20 more expensive and the put option price about € 1.20 cheaper than the prices regarding the Black-Scholes approach. This difference exists because of the jump intensity of the underlying stock. The OMV AG stock has got a low jump intensity of about 0.47 a year and this feature affects that a high increase or a sharp decrease is almost unlikely. Due to that attribute, the possibility of a high difference between current stock price and strike price is very low. This results in low option prices in the case of a put option because the profits which can be gained from the option contract will be small too. In the case of a call option the price is higher compared to the other models because in the case of a total ruin the long position of the contract would not benefit from the default and the jump intensity is not high. Consequently, the possibility of a profit is high and this likelihood has to be paid for a higher option price.

Now let us look at the option price graphs calculated regarding the Kou model. Here you see that the option price is about € 0.40 more expensive than the prices regarding to the Black-Scholes Model if the current value of the OMV AG stock is about € 23.44. This difference is caused by the parameters the Kou model considers. Kou says that the option price is driven by two parts, a continuous part replicated by a Brownian motion and a jump part of which the logarithm of jump sizes are double exponential distributed. As I already mentioned before the graphs of the Kou model, the Merton model with log-normally distributed jumps and the Black-Scholes model approximate with increasing or decreasing stock prices.

With all these parameters, this model can replicate stock price returns in the best way compared to the other two models and so the option prices have to be more expensive. This is also a solution to a part of the research question because the double exponential jump diffusion model fits stock data better for pricing European options regarding accuracy and applicability. Now the final question is if the effort which is needed to get a solution is appropriate to the solution you obtain by the model. If you only looked at the equation of the model the answer would be no because for human eyes the formula appears very long but if you think of solving the model by computer programming it is not so long because the model has a defined closed form solution and does not have to be solved by an approximation.

The illustration below shows the Pay-Off profiles of each model when the current stock price is € 23.44 and the strike price is € 25.00.

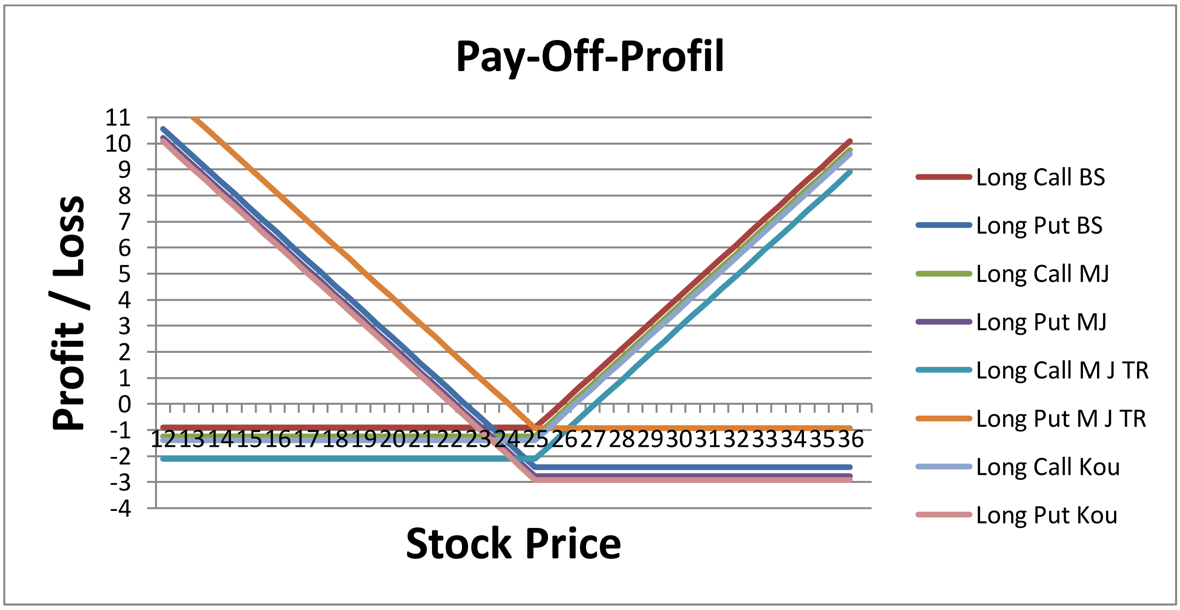

Illustration 26: Pay-off-Profile of all models; Source: own illustration

Finally here is a short comparison of all models in figures only.

Stock	**23,44**	**Call Price**			
Strike	**25,000**	**Black Scho-les**	**Merton LOG**	**Merton Ruin**	**Kou**
Risk-Free Interest Rate	**0,00602**	**€ 0,9141**	**€ 1,2561**	**€ 2,1028**	**€ 1,3960**
Duration	**0,242**	**Put Price**			
Dividend Yield	**0,000**	**Black Scho-les**	**Merton LOG**	**Merton Ruin**	**Kou**
Trading Days	**248,00**	**€ 2,4377**	**€ 2,7798**	**€ 0,9234**	**€ 2,9196**

Table 5: Option Prices; Source: own table

4. Conclusion

In this paper we have depicted three different models to calculate an option price of a European style call and put option with a stock as underlying asset.

The first model is the Black-Scholes model which is one of the best known equations to evaluate option prices. The second model has been the Merton-Jump-Diffusion model, which has a similarity to the Black-Scholes model because it is only an advanced form of the Black-Scholes equation and a Poisson weight, which should replicate the jump process. Both models are constructed regarding normal distribution. But not all stock return distributions can be well replicated by a normal distribution and so I have chosen the Kou model as my third model because regarding that model also this fact is considered.

The Kou model is a double exponential jump diffusion model which does not assume a normal distribution of the stock returns but a distribution which has got a higher peak and two heavier tails. It also considers the empirical abnormity called volatility smile.

With the empirical study we aspired to show that the Kou model fits stock data better and the option price calculation is more accurate. Although the calculation seems to be long the effort–solution and applicability–solution ratio are very good. It has also to be mentioned, however, that more assumptions have to be made than regarding the Black-Scholes model to obtain a solution: for example, jump intensity and how jumps are determined. A further disadvantage is that the riskless hedging arguments are not adaptable here, but this argument is a special property of the continuous Brownian motion.

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6. Appendix

6.1 Data:

OMV AG:

OMV AG						
Ric:	OMVV.VI			Volatility	0,02087311	
Zeitraum:	01.01.2011 - 31.12.2011			Variance	0,00043569	
Periodizität:	täglich					
Date	**Open**	**High**	**Low**	**Close**	**Return**	**Return in %**
03.01.2011	30,90438	31,25218	30,84476	31,25218		
04.01.2011	30,91432	31,3913	30,40753	30,80501	-0,01431	-1,43084
05.01.2011	30,80501	30,92426	30,60627	30,92426	0,00387	0,38711
07.01.2011	30,70564	31,14287	30,28828	30,74042	-0,00594	-0,59448
10.01.2011	30,6162	30,72054	30,10941	30,1591	-0,01891	-1,89106
11.01.2011	30,40256	30,95407	30,31809	30,70564	0,01812	1,81219
12.01.2011	30,52677	31,30186	30,52677	31,30186	0,01942	1,94173
13.01.2011	31,123	31,2969	30,80501	31,13293	-0,00540	-0,53968
14.01.2011	31,10312	31,17765	30,51187	31,09319	-0,00128	-0,12765
17.01.2011	30,80998	31,00375	30,24853	30,5069	-0,01886	-1,88559
18.01.2011	30,54664	31,52048	30,54664	31,48073	0,03192	3,19216
19.01.2011	31,53042	32,76262	31,53042	32,21111	0,02320	2,32009
20.01.2011	31,92293	31,97262	31,20249	31,59998	-0,01897	-1,89726
21.01.2011	31,8484	31,8484	31,11306	31,43105	-0,00535	-0,53459
24.01.2011	31,4062	32,0869	31,18262	32,0869	0,02087	2,08663
25.01.2011	32,14155	32,18627	31,26212	31,51054	-0,01796	-1,79625
26.01.2011	31,55029	31,89809	31,45092	31,79872	0,00915	0,91455
27.01.2011	31,97759	32,83715	31,86828	32,79243	0,03125	3,12500
28.01.2011	32,29558	32,7179	31,94281	31,99746	-0,02424	-2,42425
31.01.2011	31,79872	32,1962	31,42111	32,1962	0,00621	0,62111
01.02.2011	32,58872	33,73645	32,51419	33,72652	0,04753	4,75311
02.02.2011	33,83582	34,24822	33,53274	33,57746	-0,00442	-0,44197
03.02.2011	33,76627	33,94513	33,12035	33,70168	0,00370	0,36995
04.02.2011	32,86199	33,09054	32,21608	32,43469	-0,03759	-3,75943
07.02.2011	32,77752	33,03092	32,59866	32,84212	0,01256	1,25616
08.02.2011	32,99117	33,39362	32,78249	33,39362	0,01679	1,67925
09.02.2011	33,28928	33,28928	32,79243	33,18991	-0,00610	-0,61003
10.02.2011	33,09054	33,83582	32,69306	33,83582	0,01946	1,94610
11.02.2011	33,88551	34,03457	32,71293	33,38866	-0,01322	-1,32156
14.02.2011	33,68677	34,46683	33,55759	34,46683	0,03229	3,22915
15.02.2011	34,283	34,77985	33,81098	34,36249	-0,00303	-0,30273
16.02.2011	34,14388	34,52148	33,17004	33,78614	-0,01677	-1,67726
17.02.2011	34,01469	34,48174	33,59734	34,19356	0,01206	1,20588
18.02.2011	34,32274	34,38237	33,33897	33,76627	-0,01250	-1,24962
21.02.2011	33,48803	33,53771	31,59998	32,36514	-0,04149	-4,14950
22.02.2011	31,79872	32,544	31,36149	31,70929	-0,02026	-2,02641

23.02.2011	30,80501	30,80501	29,21507	29,88583	-0,05751	-5,75055
24.02.2011	29,8113	30,89444	29,71193	30,75532	0,02909	2,90937
25.02.2011	30,98388	31,04847	30,55658	31,04847	0,00953	0,95317
28.02.2011	31,30186	31,30186	30,54664	30,60627	-0,01424	-1,42422
01.03.2011	30,95407	31,4708	30,82985	30,97891	0,01218	1,21753
02.03.2011	31,06834	31,28696	30,44727	30,49199	-0,01572	-1,57178
03.03.2011	30,55658	30,89444	30,32803	30,44727	-0,00147	-0,14666
04.03.2011	30,60627	31,09815	30,48205	30,48205	0,00114	0,11423
07.03.2011	30,70564	30,8547	30,44727	30,59633	0,00375	0,37491
08.03.2011	30,80501	30,80501	30,45721	30,60627	0,00032	0,03249
09.03.2011	30,54664	30,84973	30,24853	30,51683	-0,00292	-0,29223
10.03.2011	30,28331	30,84476	29,92558	30,2386	-0,00912	-0,91173
11.03.2011	29,8113	30,16904	29,68709	30,05973	-0,00592	-0,59153
14.03.2011	29,3691	30,27338	29,16042	29,8113	-0,00826	-0,82645
15.03.2011	29,32438	29,32438	28,15677	29,0064	-0,02700	-2,69998
16.03.2011	29,0064	29,17533	28,54432	28,83746	-0,00582	-0,58242
17.03.2011	29,06602	30,10941	28,97658	30,05973	0,04238	4,23848
18.03.2011	30,2386	31,10312	30,174	30,174	0,00380	0,38014
21.03.2011	30,40753	30,92426	30,24853	30,6162	0,01466	1,46550
22.03.2011	30,40753	30,75036	30,40753	30,56155	-0,00179	-0,17850
23.03.2011	30,21872	31,02363	30,21872	30,5069	-0,00179	-0,17882
24.03.2011	30,34294	31,0286	30,34294	31,0286	0,01710	1,71010
25.03.2011	31,0286	31,0286	30,54168	30,65595	-0,01201	-1,20099
28.03.2011	30,37275	31,27205	30,37275	31,05344	0,01297	1,29662
29.03.2011	31,00375	31,77885	30,8696	31,09319	0,00128	0,12801
30.03.2011	31,45092	32,51419	31,40124	31,69935	0,01949	1,94949
31.03.2011	31,45092	31,94778	31,17765	31,68941	-0,00031	-0,03136
01.04.2011	32,28564	32,28564	31,30683	31,59998	-0,00282	-0,28221
04.04.2011	31,66457	32,6235	31,55029	31,79872	0,00629	0,62892
05.04.2011	31,70929	32,1813	31,32174	31,89809	0,00312	0,31250
06.04.2011	32,01237	32,30551	31,61985	31,79872	-0,00312	-0,31152
07.04.2011	31,88318	32,09683	31,5801	31,5801	-0,00688	-0,68751
08.04.2011	31,68941	32,17633	31,68941	32,09186	0,01621	1,62051
11.04.2011	32,14652	32,39495	31,98752	31,99249	-0,00310	-0,30964
12.04.2011	31,61985	31,72419	30,72054	30,94413	-0,03277	-3,27689
13.04.2011	30,80501	32,59369	30,80501	31,76891	0,02665	2,66538
14.04.2011	32,01734	32,29558	30,95407	31,0286	-0,02330	-2,33030
15.04.2011	31,25218	31,66954	30,8547	31,46583	0,01409	1,40912
18.04.2011	31,6447	31,6447	30,18891	30,5069	-0,03048	-3,04753
19.04.2011	30,43237	30,73545	29,62746	30,69073	0,00603	0,60258
20.04.2011	30,79507	31,63973	30,79507	31,63973	0,03092	3,09214
21.04.2011	31,37142	31,70432	31,11306	31,23727	-0,01272	-1,27201
26.04.2011	31,30186	31,30186	31,07331	31,10312	-0,00429	-0,42945
27.04.2011	31,0435	31,55526	31,0435	31,55526	0,01454	1,45368
28.04.2011	31,30683	31,55029	30,80501	30,80501	-0,02378	-2,37758
29.04.2011	30,65595	30,71061	30,30319	30,59633	-0,00677	-0,67742

02.05.2011	30,80501	31,16275	30,79507	31,00375	0,01332	1,33160
03.05.2011	31,25218	31,25218	30,38765	30,80501	-0,00641	-0,64102
04.05.2011	30,5069	30,89941	29,8113	29,8113	-0,03226	-3,22581
05.05.2011	30,24853	30,24853	29,71193	29,82124	0,00033	0,03334
06.05.2011	30,01004	30,40753	29,49828	30,11935	0,01000	0,99966
09.05.2011	30,41746	30,45224	29,72187	29,77155	-0,01155	-1,15474
10.05.2011	29,86595	30,54664	29,86595	30,38765	0,02069	2,06943
11.05.2011	30,55658	30,55658	29,95042	30,5069	0,00392	0,39243
12.05.2011	30,08954	30,4125	29,8113	29,8113	-0,02280	-2,28014
13.05.2011	30,14916	30,14916	29,66721	29,66721	-0,00483	-0,48334
16.05.2011	29,76161	29,81627	29,47841	29,76161	0,00318	0,31820
17.05.2011	28,81759	29,64734	28,51948	29,28463	-0,01603	-1,60267
18.05.2011	29,5579	29,75168	29,06602	29,34426	0,00204	0,20362
19.05.2011	29,5	30,06	29,075	29,99	0,02201	2,20057
20.05.2011	29,99	30,015	29,415	29,43	-0,01867	-1,86729
23.05.2011	28,39	28,405	27,9	28,265	-0,03959	-3,95855
24.05.2011	28,26	28,675	28,26	28,515	0,00884	0,88449
25.05.2011	28,48	28,5	27,95	28,405	-0,00386	-0,38576
26.05.2011	28,47	28,9	27,86	28,16	-0,00863	-0,86252
27.05.2011	28,325	28,67	28,22	28,4	0,00852	0,85227
30.05.2011	28,6	28,675	28,31	28,4	0,00000	0,00000
31.05.2011	28,66	29,215	28,55	28,865	0,01637	1,63732
01.06.2011	29	29	28,56	28,62	-0,00849	-0,84878
03.06.2011	28,5	28,5	27,87	27,91	-0,02481	-2,48078
06.06.2011	27,81	28,055	27,43	27,85	-0,00215	-0,21498
07.06.2011	28,32	28,45	27,96	28,09	0,00862	0,86176
08.06.2011	28,12	28,135	27,85	28,105	0,00053	0,05340
09.06.2011	28,31	28,545	28,1	28,54	0,01548	1,54777
10.06.2011	28,59	28,6	28,22	28,28	-0,00911	-0,91100
14.06.2011	28,625	28,87	28,35	28,87	0,02086	2,08628
15.06.2011	28,75	28,875	28,405	28,635	-0,00814	-0,81399
16.06.2011	28,48	28,6	28,125	28,595	-0,00140	-0,13969
17.06.2011	28,71	28,88	28,32	28,6	0,00017	0,01749
20.06.2011	28,45	28,6	28,25	28,4	-0,00699	-0,69930
21.06.2011	28,71	28,89	28,53	28,89	0,01725	1,72535
22.06.2011	28,945	29,2	28,765	28,99	0,00346	0,34614
24.06.2011	28,89	28,915	28,245	28,245	-0,02570	-2,56985
27.06.2011	28,24	28,385	28,05	28,355	0,00389	0,38945
28.06.2011	28,48	28,56	28,165	28,5	0,00511	0,51137
29.06.2011	28,7	29,33	28,7	29,3	0,02807	2,80702
30.06.2011	29,485	30,125	29,4	30,125	0,02816	2,81570
01.07.2011	30,195	30,25	29,985	30,2	0,00249	0,24896
04.07.2011	30,05	30,26	30	30,235	0,00116	0,11589
05.07.2011	30,285	30,285	29,73	29,755	-0,01588	-1,58756
06.07.2011	29,655	29,99	29,51	29,99	0,00790	0,78978
07.07.2011	29,695	30,15	29,695	30,15	0,00534	0,53351

08.07.2011	30,23	30,46	29,745	29,745	-0,01343	-1,34328
11.07.2011	29,5	30,005	29,5	29,95	0,00689	0,68919
12.07.2011	29,3	29,98	29,2	29,725	-0,00751	-0,75125
13.07.2011	29,59	29,79	29,11	29,77	0,00151	0,15139
14.07.2011	29,475	29,545	28,83	29,07	-0,02351	-2,35136
15.07.2011	28,7	29,17	28,545	29,125	0,00189	0,18920
18.07.2011	28,74	28,9	28,3	28,34	-0,02695	-2,69528
19.07.2011	28,355	28,5	28,145	28,16	-0,00635	-0,63514
20.07.2011	28,25	28,425	28,04	28,28	0,00426	0,42614
21.07.2011	28,455	29,075	28,105	28,8	0,01839	1,83876
22.07.2011	28,96	28,96	28,04	28,535	-0,00920	-0,92014
25.07.2011	28,5	28,765	28,28	28,595	0,00210	0,21027
26.07.2011	28,795	28,92	28,59	28,735	0,00490	0,48960
27.07.2011	28,51	28,56	28,3	28,4	-0,01166	-1,16583
28.07.2011	28,28	28,39	28	28,26	-0,00493	-0,49296
29.07.2011	28,2	28,3	27,535	27,81	-0,01592	-1,59236
01.08.2011	28,35	28,35	27,51	27,545	-0,00953	-0,95289
02.08.2011	27,44	27,49	27,065	27,065	-0,01743	-1,74260
03.08.2011	26,795	26,795	25,675	26,01	-0,03898	-3,89802
04.08.2011	26,29	26,4	24,635	24,9	-0,04268	-4,26759
05.08.2011	23	24,33	22,505	23,775	-0,04518	-4,51807
08.08.2011	23,3	23,7	22,65	22,935	-0,03533	-3,53312
09.08.2011	22,5	23,09	20,81	22,71	-0,00981	-0,98103
10.08.2011	23,5	24,49	22,5	22,5	-0,00925	-0,92470
11.08.2011	23,19	23,905	22,75	23,905	0,06244	6,24444
12.08.2011	24,22	24,64	23,61	24,61	0,02949	2,94917
16.08.2011	24,89	24,89	24,185	24,5	-0,00447	-0,44697
17.08.2011	24,385	24,72	24,3	24,595	0,00388	0,38776
18.08.2011	24,33	24,425	23,8	24,19	-0,01647	-1,64668
19.08.2011	24	24,4	23,615	24,035	-0,00641	-0,64076
22.08.2011	24	25,565	24	25,27	0,05138	5,13834
23.08.2011	25,505	26,1	24,9	25,25	-0,00079	-0,07915
24.08.2011	25,25	25,73	25,25	25,7	0,01782	1,78218
25.08.2011	25,55	25,82	25,42	25,75	0,00195	0,19455
26.08.2011	25,75	25,915	25,54	25,775	0,00097	0,09709
29.08.2011	25,9	26,465	25,85	26,4	0,02425	2,42483
30.08.2011	26,68	26,7	26,345	26,66	0,00985	0,98485
31.08.2011	26,65	27,59	26,635	27,5	0,03151	3,15079
01.09.2011	27,49	27,49	26,94	27,285	-0,00782	-0,78182
02.09.2011	27,1	27,28	26,99	27,25	-0,00128	-0,12828
05.09.2011	27,25	27,25	26,4	26,4	-0,03119	-3,11927
06.09.2011	26,6	26,775	25,8	25,8	-0,02273	-2,27273
07.09.2011	26,42	26,56	25,895	26,2	0,01550	1,55039
08.09.2011	26,05	26,395	25,66	26,365	0,00630	0,62977
09.09.2011	25,98	26,365	25,295	25,455	-0,03452	-3,45155
12.09.2011	25,09	25,11	24,4	24,725	-0,02868	-2,86781

13.09.2011	25	25,115	24,055	24,62	-0,00425	-0,42467
14.09.2011	24,76	25,46	24,4	25,46	0,03412	3,41186
15.09.2011	25,285	25,9	25,285	25,72	0,01021	1,02121
16.09.2011	25,8	25,95	25,405	25,665	-0,00214	-0,21384
19.09.2011	25,3	25,795	25,15	25,3	-0,01422	-1,42217
20.09.2011	25,105	25,77	25,105	25,43	0,00514	0,51383
21.09.2011	25,25	25,345	24,755	25,04	-0,01534	-1,53362
22.09.2011	24,485	24,71	22,75	22,97	-0,08267	-8,26677
23.09.2011	23,1	23,11	21,33	22,7	-0,01175	-1,17545
26.09.2011	22,135	22,705	21,97	22,405	-0,01300	-1,29956
27.09.2011	22,87	23,395	22,635	23,23	0,03682	3,68221
28.09.2011	22,89	23,485	22,7	22,885	-0,01485	-1,48515
29.09.2011	22,8	22,9	22,575	22,85	-0,00153	-0,15294
30.09.2011	22,965	22,965	22,17	22,52	-0,01444	-1,44420
03.10.2011	22,25	22,335	21,67	21,87	-0,02886	-2,88632
04.10.2011	21,64	22,2	21,15	22,2	0,01509	1,50892
05.10.2011	22,51	22,805	21,95	22,79	0,02658	2,65766
06.10.2011	22,6	23,865	22,585	23,7	0,03993	3,99298
07.10.2011	23,76	24,305	23,57	24,07	0,01561	1,56118
10.10.2011	24,08	24,42	23	24,12	0,00208	0,20773
11.10.2011	23,75	23,875	22,95	23,135	-0,04084	-4,08375
12.10.2011	23,36	24,5	23,01	24,44	0,05641	5,64080
13.10.2011	24,225	24,74	24	24,5	0,00245	0,24550
14.10.2011	24,58	24,98	24,355	24,775	0,01122	1,12245
17.10.2011	24,99	25,595	24,585	25,12	0,01393	1,39253
18.10.2011	24,94	25,14	24,48	25,125	0,00020	0,01990
19.10.2011	25,17	25,745	25,06	25,335	0,00836	0,83582
20.10.2011	25,01	25,2	24,605	24,74	-0,02349	-2,34853
21.10.2011	25,18	25,79	24,89	25,495	0,03052	3,05174
24.10.2011	25,5	25,57	24,865	25,035	-0,01804	-1,80428
25.10.2011	24,75	25,39	24,565	24,695	-0,01358	-1,35810
27.10.2011	25,4	26,105	25,02	26,1	0,05689	5,68941
28.10.2011	26,05	26,195	25,36	26	-0,00383	-0,38314
31.10.2011	25,57	25,74	25,275	25,275	-0,02788	-2,78846
02.11.2011	24,56	25,09	24,345	25,09	-0,00732	-0,73195
03.11.2011	24,82	25,49	24,62	25,17	0,00319	0,31885
04.11.2011	25,01	25,35	24,765	25,005	-0,00656	-0,65554
07.11.2011	24,9	25,195	24,755	25,09	0,00340	0,33993
08.11.2011	24,76	25,4	24,76	25,325	0,00937	0,93663
09.11.2011	25,44	25,44	24,105	24,42	-0,03574	-3,57354
10.11.2011	24,03	24,54	23,7	23,97	-0,01843	-1,84275
11.11.2011	24,1	24,48	23,555	24,14	0,00709	0,70922
14.11.2011	24,24	24,48	23,79	24,065	-0,00311	-0,31069
15.11.2011	24	24,17	23,165	23,895	-0,00706	-0,70642
16.11.2011	23,55	23,765	22,97	23,38	-0,02155	-2,15526
17.11.2011	23,2	23,485	22,82	23,125	-0,01091	-1,09068

18.11.2011	23	23,17	22,555	22,73	-0,01708	-1,70811
21.11.2011	22,66	22,8	22	22	-0,03212	-3,21161
22.11.2011	22	22,15	21,24	21,24	-0,03455	-3,45455
23.11.2011	21,155	22,03	21,155	21,59	0,01648	1,64783
24.11.2011	21,98	22,2	21,52	21,615	0,00116	0,11579
25.11.2011	21,5	21,925	21,1	21,925	0,01434	1,43419
28.11.2011	22,08	22,815	22,08	22,73	0,03672	3,67161
29.11.2011	22,73	22,985	22,37	22,985	0,01122	1,12187
30.11.2011	23	24,6	22,615	24,6	0,07026	7,02632
01.12.2011	24,39	24,39	23,56	23,73	-0,03537	-3,53659
02.12.2011	23,9	24,15	23,38	23,705	-0,00105	-0,10535
05.12.2011	23,89	24,16	23,22	23,46	-0,01034	-1,03354
06.12.2011	23,235	24,305	23,04	24,01	0,02344	2,34442
07.12.2011	24,01	24,43	23,48	23,65	-0,01499	-1,49938
09.12.2011	24,58	24,7	23,56	24,575	0,03911	3,91121
12.12.2011	24,75	24,75	23,735	23,8	-0,03154	-3,15361
13.12.2011	24,08	24,56	23,865	24,17	0,01555	1,55462
14.12.2011	24,4	24,4	23,375	23,375	-0,03289	-3,28920
15.12.2011	23,7	23,7	23,2	23,605	0,00984	0,98396
16.12.2011	23,72	23,83	23,225	23,27	-0,01419	-1,41919
19.12.2011	23,395	23,495	23	23,225	-0,00193	-0,19338
20.12.2011	23,11	23,47	22,915	23,41	0,00797	0,79656
21.12.2011	23,54	23,7	23,085	23,245	-0,00705	-0,70483
22.12.2011	23,335	23,77	23,325	23,77	0,02259	2,25855
23.12.2011	23,77	23,995	23,77	23,77	0,00000	0,00000
27.12.2011	23,835	23,92	23,72	23,72	-0,00210	-0,21035
28.12.2011	23,78	23,78	23,295	23,395	-0,01370	-1,37015
29.12.2011	23,54	23,54	23,195	23,44	0,00192	0,19200

<u>MSCI World Index:</u>

MSCI World Index						
Ric:	.MSCIWO					
Zeitraum:	01.01.2011 - 31.12.2011					
Periodizität:	täglich					
Date	**Open**	**High**	**Low**	**Close**	**Return**	**Return in %**
03.01.2011	1.277,20	1.291,03	1.276,06	1.287,94		
04.01.2011	1.287,55	1.295,99	1.284,81	1.289,26	0,001025	0,102489
05.01.2011	1.289,00	1.289,59	1.277,39	1.285,14	-0,003196	-0,319563
06.01.2011	1.285,70	1.290,66	1.280,92	1.283,66	-0,001152	-0,115163
07.01.2011	1.282,88	1.285,82	1.274,33	1.281,41	-0,001753	-0,175280
10.01.2011	1.278,96	1.280,33	1.269,52	1.275,61	-0,004526	-0,452626
11.01.2011	1.275,54	1.285,17	1.274,10	1.282,23	0,005190	0,518967
12.01.2011	1.283,50	1.301,27	1.283,43	1.298,46	0,012658	1,265764
13.01.2011	1.300,90	1.308,52	1.300,66	1.305,34	0,005299	0,529858

14.01.2011	1.305,32	1.309,20	1.298,91	1.309,00	0,002804	0,280387
17.01.2011	1.309,40	1.310,28	1.305,02	1.307,42	-0,001207	-0,120703
18.01.2011	1.306,77	1.317,14	1.306,42	1.316,17	0,006693	0,669257
19.01.2011	1.316,13	1.321,73	1.306,54	1.308,81	-0,005592	-0,559198
20.01.2011	1.307,71	1.307,85	1.290,44	1.295,09	-0,010483	-1,048280
21.01.2011	1.296,86	1.309,67	1.293,84	1.302,54	0,005752	0,575250
24.01.2011	1.302,81	1.312,58	1.300,65	1.312,18	0,007401	0,740092
25.01.2011	1.311,36	1.315,45	1.304,10	1.310,93	-0,000953	-0,095261
26.01.2011	1.311,49	1.320,59	1.309,94	1.318,32	0,005637	0,563722
27.01.2011	1.318,79	1.323,94	1.315,85	1.321,14	0,002139	0,213909
28.01.2011	1.320,72	1.321,65	1.300,92	1.302,13	-0,014389	-1,438909
31.01.2011	1.301,09	1.308,91	1.295,34	1.308,08	0,004569	0,456944
01.02.2011	1.307,43	1.332,39	1.307,39	1.330,27	0,016964	1,696379
02.02.2011	1.331,52	1.337,95	1.330,19	1.332,77	0,001879	0,187932
03.02.2011	1.332,89	1.333,51	1.320,70	1.329,93	-0,002131	-0,213090
04.02.2011	1.330,43	1.334,53	1.325,96	1.331,65	0,001293	0,129330
07.02.2011	1.331,95	1.342,22	1.331,95	1.339,44	0,005850	0,584989
08.02.2011	1.339,91	1.347,36	1.338,16	1.347,36	0,005913	0,591292
09.02.2011	1.345,02	1.346,54	1.339,59	1.342,34	-0,003726	-0,372580
10.02.2011	1.342,71	1.342,90	1.328,52	1.337,85	-0,003345	-0,334491
11.02.2011	1.337,44	1.342,72	1.330,81	1.340,99	0,002347	0,234705
14.02.2011	1.340,65	1.346,75	1.340,42	1.344,83	0,002864	0,286356
15.02.2011	1.345,82	1.348,19	1.341,10	1.344,27	-0,000416	-0,041641
16.02.2011	1.343,47	1.355,10	1.343,38	1.352,03	0,005773	0,577265
17.02.2011	1.354,14	1.360,95	1.352,17	1.359,68	0,005658	0,565816
18.02.2011	1.360,32	1.365,07	1.357,36	1.362,62	0,002162	0,216227
21.02.2011	1.364,17	1.364,84	1.357,76	1.358,10	-0,003317	-0,331714
22.02.2011	1.358,40	1.358,55	1.335,01	1.338,12	-0,014712	-1,471173
23.02.2011	1.337,15	1.338,29	1.325,43	1.329,90	-0,006143	-0,614295
24.02.2011	1.330,09	1.332,71	1.321,20	1.327,06	-0,002135	-0,213550
25.02.2011	1.327,32	1.342,21	1.327,25	1.341,30	0,010730	1,073049
28.02.2011	1.341,63	1.355,14	1.339,68	1.351,65	0,007716	0,771639
01.03.2011	1.352,22	1.357,81	1.339,22	1.340,89	-0,007961	-0,796064
02.03.2011	1.339,59	1.342,13	1.330,05	1.337,94	-0,002200	-0,220003
03.03.2011	1.337,42	1.353,23	1.337,27	1.352,05	0,010546	1,054606
04.03.2011	1.352,46	1.357,09	1.343,69	1.348,44	-0,002670	-0,267002
07.03.2011	1.348,74	1.352,95	1.333,70	1.338,87	-0,007097	-0,709709
08.03.2011	1.337,04	1.343,52	1.328,95	1.341,05	0,001628	0,162824
09.03.2011	1.341,21	1.344,96	1.335,14	1.339,58	-0,001096	-0,109616
10.03.2011	1.339,13	1.339,35	1.312,82	1.313,55	-0,019431	-1,943146
11.03.2011	1.313,98	1.319,36	1.306,57	1.315,07	0,001157	0,115717
14.03.2011	1.318,32	1.318,64	1.294,85	1.301,31	-0,010463	-1,046332
15.03.2011	1.301,84	1.302,02	1.251,34	1.271,87	-0,022623	-2,262336
16.03.2011	1.271,96	1.282,74	1.254,67	1.260,15	-0,009215	-0,921478
17.03.2011	1.262,69	1.282,90	1.255,36	1.279,69	0,015506	1,550609
18.03.2011	1.279,18	1.294,66	1.278,24	1.287,13	0,005814	0,581391
21.03.2011	1.288,78	1.309,28	1.287,87	1.307,42	0,015764	1,576375

22.03.2011	1.310,06	1.310,10	1.310,01	1.310,09	0,002042	0,204219
23.03.2011	1.310,06	1.313,84	1.301,40	1.311,62	0,001168	0,116786
24.03.2011	1.311,54	1.324,04	1.308,55	1.324,04	0,009469	0,946921
25.03.2011	1.323,04	1.329,65	1.321,64	1.325,85	0,001367	0,136703
28.03.2011	1.321,87	1.328,29	1.320,80	1.321,61	-0,003198	-0,319795
29.03.2011	1.320,37	1.325,02	1.312,85	1.323,81	0,001665	0,166464
30.03.2011	1.325,08	1.338,66	1.324,95	1.335,98	0,009193	0,919316
31.03.2011	1.336,54	1.340,49	1.333,95	1.334,93	-0,000786	-0,078594
01.04.2011	1.333,68	1.346,61	1.333,13	1.341,45	0,004884	0,488415
04.04.2011	1.344,83	1.349,06	1.342,55	1.345,62	0,003109	0,310858
05.04.2011	1.344,10	1.346,90	1.338,85	1.343,64	-0,001471	-0,147144
06.04.2011	1.343,65	1.351,36	1.341,93	1.348,86	0,003885	0,388497
07.04.2011	1.348,98	1.351,77	1.341,98	1.345,20	-0,002713	-0,271340
08.04.2011	1.345,21	1.357,46	1.344,39	1.351,43	0,004631	0,463128
11.04.2011	1.351,99	1.354,96	1.345,13	1.348,65	-0,002057	-0,205708
12.04.2011	1.346,22	1.346,22	1.329,56	1.333,85	-0,010974	-1,097394
13.04.2011	1.333,38	1.343,17	1.332,25	1.338,75	0,003674	0,367358
14.04.2011	1.337,68	1.340,36	1.327,44	1.336,54	-0,001651	-0,165079
15.04.2011	1.336,45	1.340,67	1.333,12	1.338,04	0,001122	0,112230
18.04.2011	1.338,29	1.338,66	1.309,06	1.316,91	-0,015792	-1,579176
19.04.2011	1.318,06	1.325,00	1.314,53	1.324,45	0,005726	0,572552
20.04.2011	1.325,27	1.352,55	1.325,27	1.350,22	0,019457	1,945713
21.04.2011	1.351,32	1.360,95	1.351,30	1.360,95	0,007947	0,794685
22.04.2011	1.359,09	1.361,03	1.358,55	1.361,03	0,000059	0,005878
25.04.2011	1.360,78	1.361,49	1.355,18	1.357,50	-0,002594	-0,259362
26.04.2011	1.357,85	1.368,46	1.355,02	1.366,69	0,006770	0,676980
27.04.2011	1.369,86	1.377,98	1.364,59	1.371,38	0,003432	0,343165
28.04.2011	1.376,81	1.385,59	1.376,81	1.384,94	0,009888	0,988785
29.04.2011	1.385,11	1.390,18	1.383,31	1.388,62	0,002657	0,265715
02.05.2011	1.389,76	1.397,57	1.387,41	1.391,86	0,002333	0,233325
03.05.2011	1.388,59	1.389,84	1.377,85	1.382,99	-0,006373	-0,637277
04.05.2011	1.382,27	1.382,35	1.366,34	1.371,36	-0,008409	-0,840932
05.05.2011	1.369,46	1.373,07	1.349,18	1.355,45	-0,011602	-1,160162
06.05.2011	1.353,41	1.367,16	1.348,57	1.359,27	0,002818	0,281825
09.05.2011	1.356,27	1.359,00	1.348,12	1.353,77	-0,004046	-0,404629
10.05.2011	1.358,16	1.368,80	1.355,09	1.366,36	0,009300	0,929995
11.05.2011	1.367,19	1.372,30	1.350,67	1.357,35	-0,006594	-0,659416
12.05.2011	1.354,30	1.354,89	1.339,13	1.351,14	-0,004575	-0,457509
13.05.2011	1.352,00	1.357,60	1.337,35	1.343,17	-0,005899	-0,589872
16.05.2011	1.339,67	1.345,28	1.332,13	1.336,65	-0,004854	-0,485419
17.05.2011	1.334,02	1.335,93	1.322,64	1.329,33	-0,005476	-0,547638
18.05.2011	1.332,01	1.343,51	1.331,72	1.341,98	0,009516	0,951607
19.05.2011	1.341,96	1.350,11	1.341,17	1.345,73	0,002794	0,279438
20.05.2011	1.348,32	1.351,34	1.333,50	1.336,65	-0,006747	-0,674727
23.05.2011	1.335,77	1.335,77	1.310,84	1.313,69	-0,017177	-1,717727
24.05.2011	1.312,60	1.321,99	1.311,89	1.315,76	0,001576	0,157571
25.05.2011	1.315,78	1.323,62	1.310,10	1.320,26	0,003420	0,342008

26.05.2011	1.320,23	1.330,03	1.319,29	1.326,96	0,005075	0,507476
27.05.2011	1.328,85	1.341,59	1.327,55	1.338,47	0,008674	0,867396
30.05.2011	1.339,47	1.340,09	1.338,00	1.338,29	-0,000134	-0,013448
31.05.2011	1.340,09	1.356,49	1.339,83	1.354,61	0,012195	1,219467
01.06.2011	1.355,61	1.357,02	1.332,11	1.335,59	-0,014041	-1,404094
02.06.2011	1.331,16	1.332,12	1.320,48	1.325,36	-0,007660	-0,765954
03.06.2011	1.326,91	1.328,03	1.314,06	1.320,11	-0,003961	-0,396119
06.06.2011	1.322,86	1.322,86	1.308,23	1.309,78	-0,007825	-0,782511
07.06.2011	1.309,87	1.319,53	1.308,47	1.311,90	0,001619	0,161859
08.06.2011	1.311,82	1.312,21	1.300,18	1.301,84	-0,007668	-0,766827
09.06.2011	1.301,97	1.311,00	1.299,37	1.307,93	0,004678	0,467799
10.06.2011	1.308,29	1.310,68	1.286,08	1.288,49	-0,014863	-1,486318
13.06.2011	1.287,70	1.293,62	1.284,21	1.288,49	0,000000	0,000000
14.06.2011	1.289,72	1.308,21	1.288,39	1.305,84	0,013465	1,346537
15.06.2011	1.304,76	1.305,44	1.277,32	1.283,97	-0,016748	-1,674784
16.06.2011	1.280,52	1.280,52	1.267,55	1.273,56	-0,008108	-0,810767
17.06.2011	1.275,37	1.286,61	1.268,50	1.280,58	0,005512	0,551211
20.06.2011	1.279,37	1.282,61	1.271,68	1.281,55	0,000757	0,075747
21.06.2011	1.282,75	1.304,10	1.282,43	1.301,77	0,015778	1,577777
22.06.2011	1.301,80	1.306,95	1.296,66	1.299,53	-0,001721	-0,172073
23.06.2011	1.296,16	1.296,16	1.268,82	1.281,57	-0,013820	-1,382038
24.06.2011	1.284,17	1.293,03	1.274,54	1.275,45	-0,004775	-0,477539
27.06.2011	1.274,66	1.283,78	1.270,20	1.281,77	0,004955	0,495511
28.06.2011	1.282,56	1.296,78	1.281,31	1.296,43	0,011437	1,143731
29.06.2011	1.296,33	1.316,40	1.296,33	1.314,00	0,013553	1,355260
30.06.2011	1.316,17	1.332,67	1.316,17	1.331,18	0,013075	1,307458
01.07.2011	1.330,56	1.346,10	1.329,34	1.343,81	0,009488	0,948782
04.07.2011	1.346,18	1.349,23	1.346,18	1.348,18	0,003252	0,325195
05.07.2011	1.348,99	1.349,06	1.342,90	1.345,93	-0,001669	-0,166892
06.07.2011	1.345,32	1.347,75	1.335,38	1.341,98	-0,002935	-0,293477
07.07.2011	1.342,94	1.354,06	1.341,06	1.352,39	0,007757	0,775719
08.07.2011	1.352,29	1.354,49	1.336,29	1.343,13	-0,006847	-0,684714
11.07.2011	1.341,56	1.341,91	1.312,68	1.314,81	-0,021085	-2,108508
12.07.2011	1.315,56	1.316,47	1.297,20	1.307,28	-0,005727	-0,572706
13.07.2011	1.308,02	1.328,92	1.307,47	1.320,34	0,009990	0,999021
14.07.2011	1.323,96	1.325,34	1.309,23	1.310,83	-0,007203	-0,720269
15.07.2011	1.311,72	1.315,72	1.305,61	1.313,17	0,001785	0,178513
18.07.2011	1.313,77	1.313,77	1.292,26	1.297,04	-0,012283	-1,228325
19.07.2011	1.299,52	1.316,54	1.297,37	1.316,54	0,015034	1,503423
20.07.2011	1.315,41	1.327,10	1.315,41	1.324,12	0,005758	0,575752
21.07.2011	1.325,46	1.346,35	1.319,16	1.343,72	0,014802	1,480228
22.07.2011	1.344,30	1.351,07	1.341,13	1.348,69	0,003699	0,369869
25.07.2011	1.347,97	1.347,97	1.336,81	1.340,94	-0,005746	-0,574632
26.07.2011	1.341,45	1.349,01	1.338,90	1.342,40	0,001089	0,108879
27.07.2011	1.342,43	1.343,37	1.317,40	1.318,96	-0,017461	-1,746126
28.07.2011	1.318,06	1.321,15	1.309,83	1.312,62	-0,004807	-0,480682
29.07.2011	1.312,99	1.314,86	1.296,21	1.306,05	-0,005005	-0,500526

01.08.2011	1.305,92	1.319,43	1.290,58	1.297,23	-0,006753	-0,675319
02.08.2011	1.296,23	1.296,76	1.268,94	1.269,44	-0,021423	-2,142257
03.08.2011	1.266,56	1.266,56	1.245,52	1.262,71	-0,005302	-0,530155
04.08.2011	1.263,99	1.264,11	1.205,98	1.208,40	-0,043011	-4,301067
05.08.2011	1.205,80	1.213,52	1.175,95	1.194,05	-0,011875	-1,187521
08.08.2011	1.195,88	1.197,78	1.132,62	1.132,91	-0,051204	-5,120389
09.08.2011	1.132,29	1.170,95	1.113,16	1.164,91	0,028246	2,824584
10.08.2011	1.171,56	1.179,44	1.127,53	1.130,33	-0,029685	-2,968470
11.08.2011	1.128,44	1.173,61	1.120,68	1.166,54	0,032035	3,203489
12.08.2011	1.166,25	1.187,73	1.159,59	1.180,82	0,012241	1,224133
15.08.2011	1.182,53	1.204,80	1.182,53	1.204,80	0,020308	2,030792
16.08.2011	1.204,45	1.205,28	1.189,06	1.196,58	-0,006823	-0,682271
17.08.2011	1.195,99	1.211,87	1.190,96	1.200,34	0,003142	0,314229
18.08.2011	1.199,51	1.199,51	1.141,45	1.147,86	-0,043721	-4,372095
19.08.2011	1.146,98	1.154,71	1.128,95	1.131,69	-0,014087	-1,408708
22.08.2011	1.128,84	1.149,13	1.124,57	1.131,33	-0,000318	-0,031811
23.08.2011	1.130,41	1.158,48	1.130,41	1.157,75	0,023353	2,335304
24.08.2011	1.158,36	1.172,40	1.154,12	1.168,58	0,009354	0,935435
25.08.2011	1.167,81	1.178,79	1.152,32	1.154,64	-0,011929	-1,192901
26.08.2011	1.155,39	1.168,82	1.135,27	1.163,02	0,007258	0,725767
29.08.2011	1.166,39	1.191,23	1.165,94	1.190,92	0,023989	2,398927
30.08.2011	1.191,10	1.201,05	1.182,92	1.196,18	0,004417	0,441675
31.08.2011	1.196,56	1.218,25	1.195,74	1.211,22	0,012573	1,257336
01.09.2011	1.210,79	1.218,73	1.203,17	1.203,17	-0,006646	-0,664619
02.09.2011	1.202,75	1.202,88	1.172,36	1.175,26	-0,023197	-2,319705
05.09.2011	1.172,96	1.172,96	1.151,89	1.153,57	-0,018455	-1,845549
06.09.2011	1.152,51	1.157,78	1.125,65	1.141,91	-0,010108	-1,010775
07.09.2011	1.140,59	1.175,24	1.140,59	1.173,44	0,027612	2,761163
08.09.2011	1.174,88	1.180,55	1.164,70	1.169,62	-0,003255	-0,325539
09.09.2011	1.166,22	1.168,61	1.130,83	1.134,68	-0,029873	-2,987295
12.09.2011	1.132,53	1.132,53	1.107,30	1.122,68	-0,010576	-1,057567
13.09.2011	1.123,41	1.138,26	1.118,56	1.134,65	0,010662	1,066199
14.09.2011	1.134,87	1.155,09	1.126,51	1.145,07	0,009183	0,918345
15.09.2011	1.147,22	1.170,68	1.147,20	1.169,47	0,021309	2,130874
16.09.2011	1.170,21	1.183,33	1.169,41	1.176,03	0,005609	0,560938
19.09.2011	1.173,35	1.173,76	1.146,27	1.156,53	-0,016581	-1,658121
20.09.2011	1.156,37	1.172,09	1.152,34	1.161,94	0,004678	0,467779
21.09.2011	1.161,75	1.163,14	1.132,86	1.137,18	-0,021309	-2,130919
22.09.2011	1.133,21	1.133,21	1.080,01	1.089,33	-0,042078	-4,207777
23.09.2011	1.090,15	1.098,20	1.079,62	1.094,92	0,005132	0,513159
26.09.2011	1.095,08	1.111,28	1.084,13	1.109,43	0,013252	1,325211
27.09.2011	1.111,21	1.151,48	1.110,72	1.140,16	0,027699	2,769891
28.09.2011	1.138,14	1.144,85	1.119,22	1.122,45	-0,015533	-1,553291
29.09.2011	1.119,36	1.140,65	1.115,87	1.129,70	0,006459	0,645909
30.09.2011	1.127,56	1.129,25	1.103,26	1.104,06	-0,022696	-2,269629
03.10.2011	1.102,53	1.102,53	1.072,72	1.074,81	-0,026493	-2,649313
04.10.2011	1.072,79	1.077,37	1.042,30	1.074,50	-0,000288	-0,028842

05.10.2011	1.076,40	1.099,20	1.074,26	1.096,16	0,020158	2,015821
06.10.2011	1.097,50	1.126,04	1.097,50	1.123,85	0,025261	2,526091
07.10.2011	1.125,28	1.137,06	1.120,31	1.126,15	0,002047	0,204654
10.10.2011	1.122,84	1.156,83	1.122,52	1.156,54	0,026986	2,698575
11.10.2011	1.156,35	1.161,67	1.150,94	1.159,28	0,002369	0,236914
12.10.2011	1.159,19	1.183,03	1.155,69	1.175,71	0,014173	1,417259
13.10.2011	1.175,43	1.179,43	1.160,76	1.169,21	-0,005529	-0,552857
14.10.2011	1.169,87	1.188,23	1.167,75	1.186,40	0,014702	1,470223
17.10.2011	1.187,41	1.195,83	1.169,34	1.171,84	-0,012272	-1,227242
18.10.2011	1.170,10	1.185,31	1.155,08	1.177,54	0,004864	0,486415
19.10.2011	1.179,30	1.187,09	1.170,46	1.174,97	-0,002183	-0,218252
20.10.2011	1.172,89	1.173,08	1.156,44	1.166,92	-0,006851	-0,685124
21.10.2011	1.169,21	1.194,71	1.168,75	1.194,33	0,023489	2,348919
24.10.2011	1.193,32	1.214,94	1.193,32	1.211,89	0,014703	1,470280
25.10.2011	1.213,20	1.214,01	1.193,26	1.195,81	-0,013269	-1,326853
26.10.2011	1.195,44	1.208,69	1.186,13	1.200,43	0,003863	0,386349
27.10.2011	1.202,26	1.257,55	1.202,01	1.250,82	0,041977	4,197663
28.10.2011	1.251,75	1.257,20	1.247,67	1.254,20	0,002702	0,270223
31.10.2011	1.253,27	1.253,68	1.213,98	1.217,30	-0,029421	-2,942114
01.11.2011	1.213,83	1.213,83	1.170,52	1.174,77	-0,034938	-3,493798
02.11.2011	1.174,30	1.193,71	1.171,15	1.189,30	0,012368	1,236838
03.11.2011	1.187,44	1.210,51	1.179,61	1.206,76	0,014681	1,468090
04.11.2011	1.209,42	1.215,33	1.192,12	1.203,07	-0,003058	-0,305777
07.11.2011	1.204,53	1.208,87	1.193,93	1.204,97	0,001579	0,157929
08.11.2011	1.205,72	1.218,77	1.202,53	1.215,69	0,008896	0,889649
09.11.2011	1.216,71	1.221,28	1.178,01	1.180,59	-0,028872	-2,887249
10.11.2011	1.178,66	1.186,55	1.167,81	1.178,92	-0,001415	-0,141455
11.11.2011	1.179,95	1.207,76	1.178,66	1.205,46	0,022512	2,251213
14.11.2011	1.206,21	1.208,94	1.190,80	1.194,56	-0,009042	-0,904219
15.11.2011	1.194,04	1.195,42	1.183,57	1.191,20	-0,002813	-0,281275
16.11.2011	1.191,36	1.194,04	1.176,86	1.178,95	-0,010284	-1,028375
17.11.2011	1.176,85	1.179,13	1.157,15	1.162,67	-0,013809	-1,380890
18.11.2011	1.160,82	1.164,20	1.154,56	1.157,50	-0,004447	-0,444666
21.11.2011	1.157,04	1.157,08	1.125,61	1.130,98	-0,022911	-2,291145
22.11.2011	1.131,46	1.136,60	1.123,58	1.127,25	-0,003298	-0,329802
23.11.2011	1.127,33	1.127,76	1.102,69	1.102,89	-0,021610	-2,161011
24.11.2011	1.103,11	1.106,93	1.098,15	1.099,84	-0,002765	-0,276546
25.11.2011	1.099,92	1.107,65	1.093,72	1.097,81	-0,001846	-0,184572
28.11.2011	1.099,27	1.135,83	1.099,27	1.132,35	0,031463	3,146264
29.11.2011	1.131,43	1.144,20	1.130,97	1.139,70	0,006491	0,649093
30.11.2011	1.139,55	1.184,60	1.133,69	1.184,60	0,039396	3,939633
01.12.2011	1.183,85	1.192,91	1.181,51	1.184,46	-0,000118	-0,011818
02.12.2011	1.184,31	1.197,98	1.183,55	1.187,64	0,002685	0,268477
05.12.2011	1.186,58	1.206,41	1.186,58	1.199,33	0,009843	0,984305
06.12.2011	1.197,36	1.199,01	1.189,98	1.193,68	-0,004711	-0,471096
07.12.2011	1.194,39	1.202,17	1.185,16	1.197,31	0,003041	0,304102
08.12.2011	1.198,39	1.202,81	1.172,36	1.174,60	-0,018968	-1,896752

09.12.2011	1.173,98	1.189,97	1.167,80	1.187,29	0,010804	1,080368
12.12.2011	1.187,72	1.190,14	1.162,51	1.168,92	-0,015472	-1,547221
13.12.2011	1.167,13	1.178,01	1.153,05	1.159,39	-0,008153	-0,815282
14.12.2011	1.157,41	1.157,57	1.138,30	1.139,04	-0,017552	-1,755233
15.12.2011	1.139,92	1.150,89	1.136,72	1.142,85	0,003345	0,334492
16.12.2011	1.143,67	1.153,75	1.142,22	1.146,48	0,003176	0,317627
19.12.2011	1.145,78	1.148,14	1.132,62	1.135,30	-0,009752	-0,975159
20.12.2011	1.134,31	1.163,90	1.133,71	1.163,90	0,025192	2,519158
21.12.2011	1.163,16	1.173,25	1.156,71	1.164,16	0,000223	0,022339
22.12.2011	1.164,24	1.173,85	1.162,93	1.173,46	0,007989	0,798859
23.12.2011	1.173,35	1.182,24	1.173,33	1.182,24	0,007482	0,748215
26.12.2011	1.182,90	1.183,84	1.182,77	1.182,85	0,000516	0,051597
27.12.2011	1.182,73	1.185,64	1.181,41	1.183,59	0,000626	0,062561
28.12.2011	1.183,67	1.185,36	1.166,94	1.167,96	-0,013206	-1,320559
29.12.2011	1.167,44	1.179,10	1.165,44	1.177,56	0,008219	0,821946
30.12.2011	1.178,51	1.185,60	1.178,11	1.182,59	0,004272	0,427154

6.2 Programming Codes

6.2.1 Mathematica 9 Codes

Kou Model:

```
Manipulate[
 Module[{g1, g2},
  g1 = ListLinePlot[
    Transpose[
     Table[{Tooltip[
        Kou[type, r, \[Sigma], x, $strike,
         T, \[Lambda], \[Eta]1, \[Eta]2, p], "Kou Model"],
       Tooltip[priceBS[type, x, $strike, r, 0, \[Sigma], T],
        "Black-Scholes Model"]}, {x, 1, 71, ControlActive[20, 2]}]],
    Joined -> True, DataRange -> {1, 70}, PerformanceGoal -> "Speed",
    PlotStyle -> {Directive[Thick, RGBColor[0.6, 0.1, 0.1]],
      Directive[Thick, RGBColor[0.1, 0.6, 0.1], Dashed]}];
  g2 = Graphics[{Dashing[0.01], Line[{{$strike, 0}, {$strike, v}}]}];
  Show[g1, g2, AxesLabel -> {"spot price", "option value"},
   PlotRange -> {{$strike - h, $strike + h}, {0, v}},
   ImageSize -> {480, 480}]], Style["option specs", Bold],
 {{type, "call", "option type"}, {"call", "put"}}, {{T, 0.24,
   "duration (years)"}, 0.05, 1, 0.05, Appearance -> "Labeled",
  ImageSize -> Tiny},
 Delimiter,
 Style["general parameters", Bold],
 {{r, 0.00602, "risk\[Hyphen]free interest rate"}, 0.01, 0.8, 0.01,
  Appearance -> "Labeled",
  ImageSize -> Tiny}, {{\[Sigma], 0.33, "volatility"}, 0.1, 0.8, 0.1,
  Appearance -> "Labeled", ImageSize -> Tiny},
 Delimiter,
 Style["Kou jump parameters", Bold],
 {{\[Lambda], 0.47, "jump intensity"}, 0.01, 10, 0.01,
  Appearance -> "Labeled", ImageSize -> Tiny},
 {{\[Eta]1, 4.59, "\!\(\*SubscriptBox[\(\[Eta]\), \(1\)]\)"}, 1.1, 10,
   0.1, Appearance -> "Labeled", ImageSize -> Tiny},
 {{\[Eta]2, 3.94, "\!\(\*SubscriptBox[\(\[Eta]\), \(2\)]\)"}, 0.1, 10,
   0.1, Appearance -> "Labeled",
  ImageSize -> Tiny}, {{p, 0.54, "probability of up jump"}, 0.05,
```

```
  0.95, 0.05, Appearance -> "Labeled", ImageSize -> Tiny},
 Delimiter,
 {{v, 30, "range of option values"}, 20, 80, .01,
  Appearance -> "Labeled", ImageSize -> Tiny},
 {{h, 30, "range of spot prices"}, 5, 40, .01,
  Appearance -> "Labeled", ImageSize -> Tiny},
 SynchronousUpdating -> False,
 TrackedSymbols -> True,
 Initialization :> (
   d1[S_, k_, r_, \[Delta]_, \[Sigma]_,
     T_] := (Log[
       S/k] + (r - \[Delta] + \[Sigma]^2/2) T)/(\[Sigma] Sqrt[T]);
   d2[S_, k_, r_, \[Delta]_, \[Sigma]_,
     T_] := (Log[
       S/k] + (r - \[Delta] - \[Sigma]^2/2) T)/(\[Sigma] Sqrt[T]);
   \[ScriptCapitalN][z_] := (1 + Erf[z/Sqrt[2]])/2 ;
   priceBS["call", S_, k_, r_, q_, \[Sigma]_, T_] :=
    S Exp[-q T] \[ScriptCapitalN][d1[S, k, r, q, \[Sigma], T]] -
     k Exp[-r T] \[ScriptCapitalN][d2[S, k, r, q, \[Sigma], T]];
   priceBS["put", S_, k_, r_, q_, \[Sigma]_, T_] :=
    k Exp[-r T] \[ScriptCapitalN][-d2[S, k, r, q, \[Sigma], T]] -
     S Exp[-q T] \[ScriptCapitalN][-d1[S, k, r, q, \[Sigma], T]];
   $strike = 25;
   Hh[n_Integer, x_] :=
    2^(-n/2) Sqrt[
      Pi] Exp[-x^2/2] (Hypergeometric1F1[1/2 n + 1/2, 1/2, 1/2 x^2]/(
       Sqrt[2] Gamma[1 + 1/2 n]) -
       x Hypergeometric1F1[1/2 n + 1, 3/2, 1/2 x^2]/
        Gamma[1/2 + 1/2 n]);
   \[CapitalPhi][x_] = CDF[NormalDistribution[0, 1], x];
   Do[With[{n = j},
     ff[n, c_, \[Alpha]_, \[Beta]_, \[Delta]_] = -Exp[\[Alpha] c]/\
\[Alpha] Sum[(\[Beta]/\[Alpha])^(n - i)
           Hh[i, \[Beta] c - \[Delta]], {i, 0,
          n}] + (\[Beta]/\[Alpha])^(n + 1) (\!\(TraditionalForm\`
\*FractionBox[
SqrtBox[\(2\ \[Pi]\)], \(\[Beta]\)]\)) Exp[(\[Alpha] \
\[Delta])/\[Beta] + \[Alpha]^2/(
          2 \[Beta]^2)] \[CapitalPhi][-\[Beta] c + \[Delta] + \
\[Alpha]/\[Beta]]], {j, 0, 15}];
   Do[With[{n = j},
     gg[n, c_, \[Alpha]_, \[Beta]_, \[Delta]_] = -Exp[\[Alpha] c]/\
\[Alpha] Sum[(\[Beta]/\[Alpha])^(n - i)
           Hh[i, \[Beta] c - \[Delta]], {i, 0,
          n}] - (\[Beta]/\[Alpha])^(n + 1) (\!\(TraditionalForm\`
\*FractionBox[
SqrtBox[\(2\ \[Pi]\)], \(\[Beta]\)]\)) Exp[(\[Alpha] \
\[Delta])/\[Beta] + \[Alpha]^2/(
          2 \[Beta]^2)] \[CapitalPhi][\[Beta] c - \[Delta] - \
\[Alpha]/\[Beta]]], {j, 0, 15}];
   Do[With[{n = j},
     II[n] = Compile[{c, \[Alpha], \[Beta], \[Delta]},
       Evaluate[
        Piecewise[
         Evaluate[{{ff[n, c, \[Alpha], \[Beta], \[Delta]], \[Beta] >
             0}, {gg[n, c, \[Alpha], \[Beta], \[Delta]], \[Beta] <
             0}}]]]]],
    {j, 0, 15}];
   PP[n_, n_, p_, \[Eta]1_, \[Eta]2_] := p^n;
   QQ[n_, n_, p_, \[Eta]1_, \[Eta]2_] := (1 - p)^n;
   PP[n_, k_, p_, \[Eta]1_, \[Eta]2_] /;
     1 <= k < n = \!\(TraditionalForm\`
\*UnderoverscriptBox[\(\[Sum]\), \(i = k\), \(n - 1\)]
```

```
\*SuperscriptBox[\(p\), \(i\)]\ \*
TemplateBox[{"n","i"},
"Binomial"]\
\*SuperscriptBox[\((1 - p)\), \(n - i\)]\ \*
TemplateBox[{RowBox[{
RowBox[{"-", "k"}], "+", "n", "-", "1"}],RowBox[{"i", "-", "k"}]},
"Binomial"]\
\*SuperscriptBox[\((
\*FractionBox[\(\[Eta]1\), \(\[Eta]1 + \[Eta]2\)])\), \(i - k\)]\
\*SuperscriptBox[\((
\*FractionBox[\(\[Eta]2\), \(\[Eta]1 + \[Eta]2\)])\), \(n - i\)]\);
  QQ[n_, k_, p_, \[Eta]1_, \[Eta]2_] /;
    1 <= k < n = \!\(TraditionalForm\`
\*UnderoverscriptBox[\(\[Sum]\), \(i = k\), \(n - 1\)]
\*SuperscriptBox[\(p\), \(n - i\)]\ \*
TemplateBox[{"n","i"},
"Binomial"]\
\*SuperscriptBox[\((1 - p)\), \(i\)]\ \*
TemplateBox[{RowBox[{
RowBox[{"-", "k"}], "+", "n", "-", "1"}],RowBox[{"i", "-", "k"}]},
"Binomial"]\
\*SuperscriptBox[\((
\*FractionBox[\(\[Eta]2\), \(\[Eta]1 + \[Eta]2\)])\), \(i - k\)]\
\*SuperscriptBox[\((
\*FractionBox[\(\[Eta]1\), \(\[Eta]1 + \[Eta]2\)])\), \(n - i\)]\);
  \[CapitalUpsilon][\[Mu]_, \[Sigma]_, \[Lambda]_,
    p_, \[Eta]1_, \[Eta]2_, a_, T_] :=
   With[{w = 15}, Exp[(\[Sigma] \[Eta]1)^2 T/2]/\!\(TraditionalForm\`
\*SqrtBox[\(2\ \[Pi]\ T\)]\ \[Sigma]\) Sum[
      Exp[-\[Lambda] T] (\[Lambda] T)^n/
       n! PP[n, k, p, \[Eta]1, \[Eta]2]*(\[Sigma] Sqrt[T] \[Eta]1)^
       k*II[k - 1][
        a - \[Mu] T, -\[Eta]1, -1/(\[Sigma] Sqrt[
          T]), -\[Sigma] \[Eta]1 Sqrt[T]], {n, 1, w}, {k, 1, n}] +
     Exp[(\[Sigma] \[Eta]2)^2 T/2]/\!\(TraditionalForm\`
\*SqrtBox[\(2\ \[Pi]\ T\)]\ \[Sigma]\) Sum[
      Exp[-\[Lambda] T] (\[Lambda] T)^n/
       n! QQ[n, k, p, \[Eta]1, \[Eta]2]*(\[Sigma] Sqrt[T] \[Eta]2)^
       k*
       II[k - 1][a - \[Mu] T, \[Eta]2,
        1/(\[Sigma] Sqrt[T]), -\[Sigma] \[Eta]2 Sqrt[T]], {n, 1,
       w}, {k, 1, n}] +
     Exp[-\[Lambda] T] \[CapitalPhi][-((a - \[Mu] T)/(\[Sigma] Sqrt[
          T]))]];
  KouEC[r_, \[Sigma]_, s_, k_, T_, \[Lambda]_, \[Eta]1_, \[Eta]2_,
    p_] := Module[{pp, eta1 = \[Eta]1 - 1,
     eta2 = \[Eta]2 + 1, \[Zeta] =
      p \[Eta]1/(\[Eta]1 - 1) + (1 - p) \[Eta]2/(\[Eta]2 + 1) - 1,
     lambda}, lambda = \[Lambda] (\[Zeta] + 1);
    pp = p/(1 + \[Zeta])*\[Eta]1/(\[Eta]1 - 1);
    s \[CapitalUpsilon][
      r + 1/2 \[Sigma]^2 - \[Lambda] \[Zeta], \[Sigma], lambda, pp,
      eta1, eta2, Log[k/s], T] -
     k Exp[- r T]*\[CapitalUpsilon][
      r - 1/2 \[Sigma]^2 - \[Lambda] \[Zeta], \[Sigma], \[Lambda],
      p, \[Eta]1, \[Eta]2, Log[k/s], T]];
  Kou["call", r_, \[Sigma]_, s_, k_,
    T_, \[Lambda]_, \[Eta]1_, \[Eta]2_, p_] :=
   KouEC[r, \[Sigma], s, k, T, \[Lambda], \[Eta]1, \[Eta]2, p];
  Kou["put", r_, \[Sigma]_, s_, k_,
    T_, \[Lambda]_, \[Eta]1_, \[Eta]2_, p_] :=
   KouEC[r, \[Sigma], s, k, T, \[Lambda], \[Eta]1, \[Eta]2, p] +
    k Exp[-r T] - s
```

```
   )]
```

Density of the Kou Jump Diffusion Process:

```
g[x_, \[CapitalDelta]t_, \[Mu]_, \[Sigma]_, \[Eta]1_, \[Eta]2_,
  p_, \[Lambda]_] :=
 With[{\[Phi] = PDF[NormalDistribution[0, 1]], \[CapitalPhi] =
    CDF[NormalDistribution[0, 1]]}, (
    1 - \[Lambda] \[CapitalDelta]t)/(\[Sigma] Sqrt[\[CapitalDelta]t]) \
\[Phi][(x - \[Mu] \[CapitalDelta]t)/(\[Sigma] \
Sqrt[\[CapitalDelta]t])] + \[Lambda] \[CapitalDelta]t (p \[Eta]1 Exp[\
\[Sigma]^2 \[Eta]1^2 \[CapitalDelta]t/
         2] Exp[-(x - \[Mu] \[CapitalDelta]t) \[Eta]1] \[CapitalPhi][(
       x - \[Mu] \[CapitalDelta]t - \[Sigma]^2 \[Eta]1 \
\[CapitalDelta]t)/(\[Sigma] Sqrt[\[CapitalDelta]t])]) + \[Lambda] \
\[CapitalDelta]t ((1 -
        p) \[Eta]2  Exp[\[Sigma]^2 \[Eta]2^2 \[CapitalDelta]t/
         2] Exp[(x - \[Mu] \[CapitalDelta]t) \[Eta]2] \
\[CapitalPhi][-((
        x - \[Mu] \[CapitalDelta]t + \[Sigma]^2 \[Eta]2 \
\[CapitalDelta]t)/(\[Sigma] Sqrt[\[CapitalDelta]t]))])]
expect[\[CapitalDelta]t_, \[Mu]_, \[Sigma]_, \[Eta]1_, \[Eta]2_,
  p_, \[Lambda]_] := \[Mu] \[CapitalDelta]t + \[Lambda] (p/\[Eta]1 - \
(1 - p)/\[Eta]2) \[CapitalDelta]tvar[\[CapitalDelta]t_, \[Mu]_, \[Sigma]_, \[Eta]1_, \[Eta]2_,
  p_, \[Lambda]_] := \[Sigma]^2 \[CapitalDelta]t + (p (1 -
        p) (1/\[Eta]1 + 1/\[Eta]2)^2 + (p/\[Eta]1^2 + (
       1 - p)/\[Eta]2^2)) \[Lambda] \[CapitalDelta]t + (p/\[Eta]1 - \
(1 - p)/\[Eta]2)^2 \[Lambda] \[CapitalDelta]t (1 - \[Lambda] \
\[CapitalDelta]t)
Manipulate[
 Module[{u =
    expect[1/250, \[Mu], \[Sigma], \[Eta]1, \[Eta]2, p, \[Lambda]],
   s = Sqrt[
     var[1/250, \[Mu], \[Sigma], \[Eta]1, \[Eta]2, p, \[Lambda]]]},
  Plot[{Tooltip[
     g[x, 1/250, \[Mu], \[Sigma], \[Eta]1, \[Eta]2, p, \[Lambda]],
     "Kou jump diffusion"],
    Tooltip[PDF[NormalDistribution[u, s]][x],
     "normal distribution with the same mean and variance"],
    Tooltip[PDF[NormalDistribution[\[Mu]/250, \[Sigma]/Sqrt[250]]][x],
      "continuous component"]}, {x, -0.2, 0.2},
   PlotStyle -> {Red, Green, Blue}, PlotRange -> All,
   ImageSize -> {500, 350},
   Epilog ->
    Inset[Framed[
      Style[Column[{Grid[{{Graphics[{GrayLevel[0.9],
             Directive[GrayLevel[0.85], EdgeForm[Opacity[0.7]], Red],
              Rectangle[{0, 0}, {1, 1}]}, {ImageSize -> 7}],
           Style["Kou jump diffusion", 10]}}],
         Grid[{{Graphics[{GrayLevel[0.9],
             Directive[GrayLevel[0.85], EdgeForm[Opacity[0.7]],
              Green], Rectangle[{0, 0}, {1, 1}]}, {ImageSize -> 7}],
           Style["normal distribution (same mean, variance)", 10]}}],

         Grid[{{Graphics[{GrayLevel[0.9],
             Directive[GrayLevel[0.85], EdgeForm[Opacity[0.7]],
              Blue], Rectangle[{0, 0}, {1, 1}]}, {ImageSize -> 7}],
           Style["continuous component", 10]}}]}], "TR",
       ShowStringCharacters -> False], FrameStyle -> Thickness[0.001],
       RoundingRadius -> 4], ImageScaled[{0.79, 0.90}]]
   ]], {{\[Mu], 0.15, "drift of diffusion"}, 0.01, 0.8, .01,
  Appearance -> "Labeled",
  ImageSize -> Small}, {{\[Sigma], 0.2, "volatility of diffusion"},
  0.01, 0.8, .01, Appearance -> "Labeled",
```

```
  ImageSize -> Small}, {{\[Lambda], 70, "jump intensity"}, 0, 100,
  0.01, Appearance -> "Labeled",
  ImageSize -> Small}, {{\[Eta]1, 50, "positive jump size parameter"},
   1.1, 100, 0.1, Appearance -> "Labeled",
  ImageSize -> Small}, {{\[Eta]2, 50, "negative jump size parameter"},
   0.1, 100, 0.1, Appearance -> "Labeled",
  ImageSize -> Small}, {{p, 0.3, "probability of positive jump"}, 0,
  1, 0.01, Appearance -> "Labeled", ImageSize -> Small},
 SaveDefinitions -> True]
```

6.2.2 VBA Codes

<u>Calculation of Jump Parameters:</u>

```
Public Sub JumpEstimation_Click()
        Dim i As Integer
        Dim zeile As Integer
        Dim Ende As Integer
        Dim mü As Double
        Dim var As Double
        Dim myrange  As Range

        mü = 0
        var = 0
        zeile = 3

        'Jumps ausgeben
        For i = 8 To 254
                If Workbooks("Modellierung.xlsm").Worksheets("OMV").Cells(i, 8) = "JUMP"
                Then
                Workbooks("Modellierung.xlsm").Worksheets("Parameter Merton LOG").Cells(zeile, 1) =
                Workbooks("Modellierung.xlsm").Worksheets("OMV").Cells(i, 6)

                zeile = zeile + 1
                Ende = zeile - 1
                End If
        Next

        'Erwartungswert berechnen
        Set myrange = Range(Cells(3, 1), Cells(Ende, 1))
        mü = Application.Average(myrange)
        Cells(4, 6) = mü
        'Varianz berechnen
        var = Application.var(myrange)
        Cells(5, 6) = var
End Sub
```

<u>Calculation Merton Jump Diffusion Model:</u>

```
Private Sub MertonJump_Click()
    Dim anfang As Double
    Dim Ende As Double
    Dim zeile As Integer
    Dim zähler As Double
    Dim i As Integer
    Dim zeilenanfang As Integer
    Dim zeilenende As Integer
        anfang = txt1
        Ende = txt2
        zähler = anfang
        zeile = 3
        Range("D3: E5000").Clear
        Range("G3: H5000").Clear
        'Anfangswert überprüfen
```

```
        If anfang = 0 Then
        anfang = 1
        txt1 = 1
        zähler = anfang
        End If
        If Ende - anfang < 50 Then
        Ende = anfang + 50
        txt2 = Ende
        End If
        If Ende - anfang > 50 Then
        Ende = anfang + 50
        txt2 = Ende
        End If
            Do Until zähler > Ende
            Cells(1, 2).NumberFormat = "0.00"
            Cells(1, 2) = zähler
            Cells(zeile, 4) = zähler
            Cells(zeile, 4).NumberFormat = "0.00"
            Cells(zeile, 7) = zähler
            Cells(zeile, 7).NumberFormat = "0.00"
            Cells(zeile, 4).HorizontalAlignment = -4152
            Cells(zeile, 7).HorizontalAlignment = -4152
            Cells(zeile, 5) = Cells(130, 19)
            Cells(zeile, 8) = Cells(131, 19)
            Cells(zeile, 5).NumberFormat = "0.00000"
            Cells(zeile, 8).NumberFormat = "0.00000"
            zeile = zeile + 1
            zähler = zähler + 1
            Loop

End Sub
```

<u>Option Prices Kou Model:</u>

```
Public Sub KouOptionPrice_Click()
    Dim n As Integer
    Dim k As Integer
    Dim i As Integer
    Dim zeile As Integer
    Dim zeile1 As Integer
    Dim ZeileE As Integer
    Dim zeileN As Integer
    Dim zeileS As Integer
    Dim p As Double
    Dim q As Double
    Dim multi1 As Double
    Dim multi2 As Double
    Dim pi As Double
    Dim pin As Double
    Dim phochn As Double
    Dim qhochn As Double
    Dim Integ1 As Double
    Dim Integ2 As Double
    Dim Integ3 As Double
    Dim Integ4 As Double
    Dim Erg1 As Double
    Dim Erg2 As Double
    Dim Erg3 As Double
    Dim Erg4 As Double
    Dim Prod1 As Double
    Dim Prod2 As Double
    Dim Prod3 As Double
    Dim Prod4 As Double
    Dim SummeP As Double
```

```
Dim SummeQ As Double
Dim Summe1 As Double
Dim Summe2 As Double
Dim Summe3 As Double
Dim Summe4 As Double
Dim SolSum1 As Double
Dim SolSum2 As Double
Dim SolSum3 As Double
Dim SolSum4 As Double
Dim myrangeP As Range
Dim myrangeQ As Range
Dim myrange1 As Range
Dim myrange2 As Range
Dim myrange3 As Range
Dim myrange4 As Range
Dim solutionrange1 As Range
Dim solutionrange2 As Range
Dim solutionrange3 As Range
Dim solutionrange4 As Range

Dim anfang As Double
Dim Ende As Double
Dim zähler As Double
Dim zeilenzähler As Integer

' Anfangswerte definieren
anfang = Workbooks("Modellierung.xlsm").Worksheets("Merton LOG Option Price").txt1
Ende = Workbooks("Modellierung.xlsm").Worksheets("Merton LOG Option Price").txt2

zähler = anfang
zeilenzähler = 7
Cells(1, 2) = zähler

n = 1
Cells(2, 5).Value = n
k = 1
Cells(3, 5).Value = k
i = k
Cells(4, 5).Value = i
zeile = 4
zeile1 = zeile
ZeileE = zeile
zeileN = zeile
zeileS = zeile
p = Cells(12, 2).Value
q = Cells(13, 2).Value
multi1 = Cells(5, 5).Value
multi2 = Cells(6, 5).Value

'Bereiche löschen
Range("O4: O5000").Clear
Range("P4: P5000").Clear
Range("Q4: Q5000").Clear
Range("R4: R5000").Clear
Range("S4: S5000").Clear
Range("U4: U5000").Clear
Range("V4: V5000").Clear
Range("W4: W5000").Clear
Range("X4: X5000").Clear
Range("Y4: Y5000").Clear
Range("AA4: AA5000").Clear
Range("AB4: AB5000").Clear
Range("AC4: AC5000").Clear
```

```
Range("AD4: AD5000").Clear
Range("AE4: AE5000").Clear
Range("AF4: AF5000").Clear
Range("AH4: AH5000").Clear
Range("AI4: AI5000").Clear
Range("AJ4: AJ5000").Clear
Range("AK4: AK5000").Clear
Range("AM4: AM5000").Clear
Range("AN4: AN5000").Clear


Do Until zähler > Ende
        Cells(1, 2) = zähler
        Cells(zeilenzähler, 7) = zähler
        Cells(zeilenzähler, 10) = zähler

        Call Tabelle14.Integral1_Click
        Call Tabelle15.Integral2_Click
        Call Tabelle16.Integral3_Click
        Call Tabelle17.Integral4_Click

    Do Until n > 15
        Cells(zeileN, 15) = n
        pi = Cells(7, 5).Value
        Cells(zeileN, 21) = pi

         Do Until k > n
            If k = n Then
                phochn = p ^ n
                qhochn = q ^ n
                Cells(zeile, 16) = phochn
                Cells(zeile1, 17) = phochn
                Cells(zeile, 29) = qhochn
                Cells(zeile1, 30) = qhochn
                Integ1 = Cells(zeileS, 20).Value
                Integ2 = Cells(zeileS, 26).Value
                Integ3 = Cells(zeileS, 33).Value
                Integ4 = Cells(zeileS, 38).Value
                multi1 = multi1 ^ k
                multi2 = multi2 ^ k
                Prod1 = phochn * multi1 * Integ1
                Prod2 = phochn * multi1 * Integ2
                Prod3 = qhochn * multi2 * Integ3
                Prod4 = qhochn * multi2 * Integ4
                Cells(zeileS, 18) = Prod1
                Cells(zeileS, 24) = Prod2
                Cells(zeileS, 31) = Prod3
                Cells(zeileS, 36) = Prod4
                Set myrange1 = Range(Cells(4, 18), Cells(zeileS, 18))
                Summe1 = Application.WorksheetFunction.Sum(myrange1)
                Set myrange2 = Range(Cells(4, 24), Cells(zeileS, 24))
                Summe2 = Application.WorksheetFunction.Sum(myrange2)
                Set myrange3 = Range(Cells(4, 31), Cells(zeileS, 31))
                Summe3 = Application.WorksheetFunction.Sum(myrange3)
                Set myrange4 = Range(Cells(4, 36), Cells(zeileS, 36))
                Summe4 = Application.WorksheetFunction.Sum(myrange4)
                Cells(ZeileE, 19) = Summe1
                Cells(ZeileE, 25) = Summe2
                Cells(ZeileE, 32) = Summe3
                Cells(ZeileE, 37) = Summe4
                pin = Cells(ZeileE, 21).Value
                Erg1 = Summe1 * pin
                Cells(zeileN, 22) = Erg1
```

```
        Erg2 = Summe2 * pin
        Cells(zeileN, 27) = Erg2
        Erg3 = Summe3 * pin
        Cells(zeileN, 34) = Erg3
        Erg4 = Summe4 * pin
        Cells(zeileN, 39) = Erg4
        multi1 = Cells(5, 5).Value
        multi2 = Cells(6, 5).Value
        k = k + 1
        Cells(3, 5) = k
        i = k
        Cells(4, 5) = i
        zeile = 4
        Range("P4: P5000").Clear
        Range("AC4: AC5000").Clear
        ZeileE = ZeileE + 1
    Else
            Do Until i > n - 1
               Cells(zeile, 16) = Cells(3, 13).Value
               Cells(zeile, 29) = Cells(3, 14).Value
               zeile = zeile + 1
               i = i + 1
               Cells(4, 5) = i
            Loop

        Set myrangeP = Range(Cells(4, 16), Cells(zeile - 1, 16))
        SummeP = Application.WorksheetFunction.Sum(myrangeP)
        Cells(zeile1, 17) = SummeP
        Integ1 = Cells(zeileS, 20).Value
        Integ2 = Cells(zeileS, 26).Value
        multi1 = multi1 ^ k
        Prod1 = SummeP * multi1 * Integ1
        Prod2 = SummeP * multi1 * Integ2
        Cells(zeileS, 18) = Prod1
        Cells(zeileS, 24) = Prod2

        Set myrangeQ = Range(Cells(4, 29), Cells(zeile - 1, 29))
        SummeQ = Application.WorksheetFunction.Sum(myrangeQ)
        Cells(zeile1, 30) = SummeQ
        Integ3 = Cells(zeileS, 33).Value
        Integ4 = Cells(zeileS, 38).Value
        multi2 = multi2 ^ k
        Prod3 = SummeQ * multi2 * Integ3
        Prod4 = SummeQ * multi2 * Integ4
        Cells(zeileS, 31) = Prod3
        Cells(zeileS, 36) = Prod4

        multi1 = Cells(5, 5).Value
        multi2 = Cells(6, 5).Value
        zeileS = zeileS + 1

        k = k + 1
        Cells(3, 5) = k
        i = k
        Cells(4, 5) = i
        zeile1 = zeile1 + 1
        zeile = 4
        Range("P4: P5000").Clear
        Range("AC4:Ac5000").Clear
    End If
  Loop
  n = n + 1
  Cells(2, 5) = n
```

```
            k = 1
            Cells(3, 5) = k
            i = k
            Cells(4, 5) = i
            zeile = 4
            zeile1 = zeile
            zeileS = zeile
            zeileN = zeileN + 1
            Range("P4: P5000").Clear
            Range("Q4: Q5000").Clear
            Range("R4: R5000").Clear
            Range("X4: X5000").Clear
            Range("AC4: AC5000").Clear
            Range("AD4: AD5000").Clear
            Range("AE4: AE5000").Clear
            Range("AJ4: AJ5000").Clear
        Loop
        Set solutionrange1 = Range(Cells(4, 22), Cells(ZeileE - 1, 22))
        SolSum1 = Application.WorksheetFunction.Sum(solutionrange1)
        Cells(4, 23) = SolSum1

        Set solutionrange2 = Range(Cells(4, 27), Cells(ZeileE - 1, 27))
        SolSum2 = Application.WorksheetFunction.Sum(solutionrange2)
        Cells(4, 28) = SolSum2

        Set solutionrange3 = Range(Cells(4, 34), Cells(ZeileE - 1, 34))
        SolSum3 = Application.WorksheetFunction.Sum(solutionrange3)
        Cells(4, 35) = SolSum3

        Set solutionrange4 = Range(Cells(4, 39), Cells(ZeileE - 1, 39))
        SolSum4 = Application.WorksheetFunction.Sum(solutionrange4)
        Cells(4, 40) = SolSum4

        Cells(zeilenzähler, 8) = Cells(8, 5).Value
        Cells(zeilenzähler, 11) = Cells(9, 5).Value

        zähler = zähler + 1
        zeilenzähler = zeilenzähler + 1

        p = Cells(12, 2).Value
        q = Cells(13, 2).Value
        multi1 = Cells(5, 5).Value
        multi2 = Cells(6, 5).Value
        n = 1
        Cells(2, 5) = n
        k = 1
        Cells(3, 5) = k
        i = k
        Cells(4, 5) = i
        zeile = 4
        zeile1 = zeile
        ZeileE = zeile
        zeileN = zeile
        zeileS = zeile
    Loop

    Cells(1, 2).Value = 23.44

    Call Tabelle14.Integral1_Click
    Call Tabelle15.Integral2_Click
    Call Tabelle16.Integral3_Click
    Call Tabelle17.Integral4_Click
```

```
Do Until n = 51
        Cells(zeileN, 15).Value = n
        pi = Cells(7, 5).Value
        Cells(zeileN, 21).Value = pi

         Do Until k = n + 1
            If k = n Then
                phochn = p ^ n
                qhochn = q ^ n
                Cells(zeile, 16) = phochn
                Cells(zeile1, 17) = phochn
                Cells(zeile, 29) = qhochn
                Cells(zeile1, 30) = qhochn
                Integ1 = Cells(zeileS, 20).Value
                Integ2 = Cells(zeileS, 26).Value
                Integ3 = Cells(zeileS, 33).Value
                Integ4 = Cells(zeileS, 38).Value
                multi1 = multi1 ^ k
                multi2 = multi2 ^ k
                Prod1 = phochn * multi1 * Integ1
                Prod2 = phochn * multi1 * Integ2
                Prod3 = qhochn * multi2 * Integ3
                Prod4 = qhochn * multi2 * Integ4
                Cells(zeileS, 18) = Prod1
                Cells(zeileS, 24) = Prod2
                Cells(zeileS, 31) = Prod3
                Cells(zeileS, 36) = Prod4
                Set myrange1 = Range(Cells(4, 18), Cells(zeileS, 18))
                Summe1 = Application.WorksheetFunction.Sum(myrange1)
                Set myrange2 = Range(Cells(4, 24), Cells(zeileS, 24))
                Summe2 = Application.WorksheetFunction.Sum(myrange2)
                Set myrange3 = Range(Cells(4, 31), Cells(zeileS, 31))
                Summe3 = Application.WorksheetFunction.Sum(myrange3)
                Set myrange4 = Range(Cells(4, 36), Cells(zeileS, 36))
                Summe4 = Application.WorksheetFunction.Sum(myrange4)
                Cells(ZeileE, 19) = Summe1
                Cells(ZeileE, 25) = Summe2
                Cells(ZeileE, 32) = Summe3
                Cells(ZeileE, 37) = Summe4
                pin = Cells(ZeileE, 21).Value
                Erg1 = Summe1 * pin
                Cells(zeileN, 22) = Erg1
                Erg2 = Summe2 * pin
                Cells(zeileN, 27) = Erg2
                Erg3 = Summe3 * pin
                Cells(zeileN, 34) = Erg3
                Erg4 = Summe4 * pin
                Cells(zeileN, 39) = Erg4
                multi1 = Cells(5, 5).Value
                multi2 = Cells(6, 5).Value
                k = k + 1
                Cells(3, 5) = k
                i = k
                Cells(4, 5) = i
                zeile = 4
                Range("P4: P5000").Clear
                Range("AC4: AC5000").Clear
                ZeileE = ZeileE + 1
            Else
                    Do Until i > n - 1
                       Cells(zeile, 16).Value = Cells(3, 13)
                       Cells(zeile, 29).Value = Cells(3, 14)
                       zeile = zeile + 1
```

```
            i = i + 1
            Cells(4, 5) = i
          Loop

        Set myrangeP = Range(Cells(4, 16), Cells(zeile - 1, 16))
        SummeP = Application.WorksheetFunction.Sum(myrangeP)
        Cells(zeile1, 17) = SummeP
        Integ1 = Cells(zeileS, 20).Value
        Integ2 = Cells(zeileS, 26).Value
        multi1 = multi1 ^ k
        Prod1 = SummeP * multi1 * Integ1
        Prod2 = SummeP * multi1 * Integ2
        Cells(zeileS, 18) = Prod1
        Cells(zeileS, 24) = Prod2

        Set myrangeQ = Range(Cells(4, 29), Cells(zeile - 1, 29))
        SummeQ = Application.WorksheetFunction.Sum(myrangeQ)
        Cells(zeile1, 30) = SummeQ
        Integ3 = Cells(zeileS, 33).Value
        Integ4 = Cells(zeileS, 38).Value
        multi2 = multi2 ^ k
        Prod3 = SummeQ * multi2 * Integ3
        Prod4 = SummeQ * multi2 * Integ4
        Cells(zeileS, 31) = Prod3
        Cells(zeileS, 36) = Prod4

        multi1 = Cells(5, 5).Value
        multi2 = Cells(6, 5).Value
        zeileS = zeileS + 1

        k = k + 1
        Cells(3, 5) = k
        i = k
        Cells(4, 5) = i
        zeile1 = zeile1 + 1
        zeile = 4
        Range("P4: P5000").Clear
        Range("AC4:Ac5000").Clear
      End If
    Loop
    n = n + 1
    Cells(2, 5) = n
    k = 1
    Cells(3, 5) = k
    i = k
    Cells(4, 5) = i
    zeile = 4
    zeile1 = zeile
    zeileS = zeile
    zeileN = zeileN + 1
    Range("P4: P5000").Clear
    Range("Q4: Q5000").Clear
    Range("R4: R5000").Clear
    Range("X4: X5000").Clear
    Range("AC4: AC5000").Clear
    Range("AD4: AD5000").Clear
    Range("AE4: AE5000").Clear
    Range("AJ4: AJ5000").Clear
  Loop
  Set solutionrange1 = Range(Cells(4, 22), Cells(ZeileE - 1, 22))
  SolSum1 = Application.WorksheetFunction.Sum(solutionrange1)
  Cells(4, 23) = SolSum1
```

```
    Set solutionrange2 = Range(Cells(4, 27), Cells(ZeileE - 1, 27))
    SolSum2 = Application.WorksheetFunction.Sum(solutionrange2)
    Cells(4, 28) = SolSum2

    Set solutionrange3 = Range(Cells(4, 34), Cells(ZeileE - 1, 34))
    SolSum3 = Application.WorksheetFunction.Sum(solutionrange3)
    Cells(4, 35) = SolSum3

    Set solutionrange4 = Range(Cells(4, 39), Cells(ZeileE - 1, 39))
    SolSum4 = Application.WorksheetFunction.Sum(solutionrange4)
    Cells(4, 40) = SolSum4

End Sub
```

<u>Integral Calculations (Integral1, Integral2, Integral3 and Integral4 are the same but on different spread-sheets:</u>

```
Dim n As Integer
  Dim i As Integer
  Dim k As Integer
  Dim x As Double
  Dim zeile As Integer
  Dim zeileI As Integer
  Dim zeileN As Integer
  Dim zeileK As Integer
  Dim zeileform As Integer
  Dim myrange As Range
  Dim produktrange1 As Range
  Dim produktrange2 As Range
  Dim beta As Double
  Dim multi As Double
  Dim multi1 As Double
  Dim multi2 As Double
  Dim multi3 As Double
  Dim multi4 As Double
  Dim multi5 As Double
  Dim Produkt1 As Double
  Dim Produkt2 As Double
  Dim Summe As Double
  Dim Summe1 As Double
  Dim Summe2 As Double
  Dim H As Double
  Dim F1 As Double
  Dim F2 As Double
  Dim nenner1 As Double
  Dim nnern2 As Double
  n = 0
  Cells(8, 2) = n
  k = 0
  Cells(2, 13) = k
  i = 0
  Cells(9, 2) = i
  x = Cells(7, 2).Value
  zeile = 3
  zeileI = zeile
  zeileN = zeile
  zeileK = zeile
  beta = Cells(4, 2).Value
  multi = Cells(12, 2).Value
  multi1 = Cells(3, 13).Value
  multi2 = Cells(4, 13).Value
  multi3 = Cells(3, 14).Value
  multi4 = Cells(4, 14).Value
  multi5 = Cells(10, 2).Value
```

```
Range("E1: E5000").Clear
Range("F3: F5000").Clear
Range("G3: G5000").Clear
Range("H3:H5000").Clear
Range("Q3: Q5000").Clear
Range("R3: R5000").Clear
Range("S3: S5000").Clear
Range("T3: T5000").Clear
Range("U3: u5000").Clear
Range("V3: V5000").Clear
If beta > 0 Then
   zeileform = 14
   Else
   zeileform = 15
End If
   Do Until n = 51
      Cells(zeileN, 17).Value = n

      Dim parnenner1 As Integer
      Dim parnenner2 As Integer
      Dim gammavert1 As Double
      Dim gammavert2 As Double

      parnenner1 = Cells(10, 13).Value
      parnenner2 = Cells(10, 14).Value

         Do Until k = 51
            Cells(2, 13).Value = k
            Cells(zeileK, 18).Value = k

            Dim gamma1 As Integer
            Dim gamma2 As Integer
            Dim gamma3 As Integer
            Dim gamma4 As Integer
            Dim gamma5 As Integer
            Dim gamma6 As Integer
            Dim gamma7 As Integer
            Dim gamma8 As Integer

            gamma1 = Cells(6, 13).Value
            gamma2 = Cells(7, 13).Value
            gamma3 = Cells(8, 13).Value
            gamma4 = Cells(9, 13).Value
            gamma5 = Cells(6, 14).Value
            gamma6 = Cells(7, 14).Value
            gamma7 = Cells(8, 14).Value
            gamma8 = Cells(9, 14).Value

            '1Fi1

            If gamma1 Mod 2 <> 0 Then
               Cells(20, 12) = gamma1
               gammavert1 = Cells(18, 12).Value
               Cells(22, 12) = gammavert1
            Else
               Cells(20, 12) = gamma1 / 2
               gammavert2 = Cells(19, 12).Value
               Cells(22, 12) = gammavert2
            End If

            If gamma2 Mod 2 <> 0 Then
               Cells(20, 12) = gamma2
```

```
    gammavert1 = Cells(18, 12).Value
    Cells(23, 12) = gammavert1
Else
    Cells(20, 12) = gamma2 / 2
    ammavert2 = Cells(19, 12).Value
    Cells(23, 12) = gammavert2
End If

If gamma3 Mod 2 <> 0 Then
    Cells(20, 12) = gamma3
    gammavert1 = Cells(18, 12).Value
    Cells(24, 12) = gammavert1
Else
    Cells(20, 12) = gamma3 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(24, 12) = gammavert2
End If

If gamma4 Mod 2 <> 0 Then
    Cells(20, 12) = gamma4
    gammavert1 = Cells(18, 12).Value
    Cells(25, 12) = gammavert1
Else
    Cells(20, 12) = gamma4 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(25, 12) = gammavert2
End If

'1Fi2

If gamma5 Mod 2 <> 0 Then
    Cells(20, 12) = gamma5
    gammavert1 = Cells(18, 12).Value
    Cells(22, 13) = gammavert1
Else
    Cells(20, 12) = gamma5 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(22, 13) = gammavert2
End If

If gamma6 Mod 2 <> 0 Then
    Cells(20, 12) = gamma6
    gammavert1 = Cells(18, 12).Value
    Cells(23, 13) = gammavert1
Else
    Cells(20, 12) = gamma6 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(23, 13) = gammavert2
End If

If gamma7 Mod 2 <> 0 Then
    Cells(20, 12) = gamma7
    gammavert1 = Cells(18, 12).Value
    Cells(24, 13) = gammavert1
Else
    Cells(20, 12) = gamma7 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(24, 13) = gammavert2
End If

If gamma8 Mod 2 <> 0 Then
    Cells(20, 12) = gamma8
    gammavert1 = Cells(18, 12).Value
```

```
            Cells(25, 13) = gammavert1
        Else
            Cells(20, 12) = gamma8 / 2
            gammavert2 = Cells(19, 12).Value
            Cells(25, 13) = gammavert2
        End If

        multi1 = Cells(3, 13).Value
        multi2 = Cells(4, 13).Value
        multi3 = Cells(3, 14).Value
        multi4 = Cells(4, 14).Value
        Produkt1 = multi1 * multi2
        Cells(zeile, 19) = Produkt1
        Produkt2 = multi3 * multi4
        Cells(zeile, 21) = Produkt2
        zeileK = zeileK + 1
        zeile = zeile + 1
        k = k + 1

    Loop

  Set produktrange1 = Range(Cells(3, 19), Cells(zeile - 1, 19))
  Summe1 = Application.WorksheetFunction.Sum(produktrange1)
  Cells(zeileN, 20) = Summe1
  Set produktrange2 = Range(Cells(3, 21), Cells(zeile - 1, 21))
  Summe2 = Application.WorksheetFunction.Sum(produktrange2)
  Cells(zeileN, 22).Value = Summe2

  zeileN = zeileN + 1
  n = n + 1
  Cells(8, 2) = n
  k = 0
  Cells(2, 13) = k
  zeile = 3
  zeileK = zeile
  Range("S3: S5000").Clear
  Range("U3: u5000").Clear
Loop
n = 0
Cells(8, 2) = n
zeile = 3
zeileN = zeile
multi5 = Cells(10, 2).Value
Do Until n = 51
  Cells(zeileN, 4) = n

  parnenner1 = Cells(10, 13).Value
  parnenner2 = Cells(10, 14).Value

  If parnenner1 Mod 2 <> 0 Then
    Cells(20, 12) = parnenner1
    gammavert1 = Cells(18, 12).Value
    Cells(26, 12) = gammavert1
  Else
    Cells(20, 12) = parnenner1 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(26, 12) = gammavert2
  End If

  If parnenner2 Mod 2 <> 0 Then
    Cells(20, 12) = parnenner2
    gammavert1 = Cells(18, 12).Value
    Cells(26, 13) = gammavert1
```

```
        Else
            Cells(20, 12) = parnenner2 / 2
            gammavert2 = Cells(19, 12).Value
            Cells(26, 13) = gammavert2
        End If

        nenner1 = Cells(5, 13).Value
        nenner2 = Cells(5, 14).Value
        F1 = Cells(zeileN, 20).Value
        F2 = Cells(zeileN, 22).Value
        multi5 = Cells(10, 2).Value
        H = multi5 * ((F1 / nenner1) - x * (F2 / nenner2))
        Cells(zeileN, 6) = H
        zeileN = zeileN + 1
        n = n + 1
        Cells(8, 2) = n
    Loop

    n = 0
    Cells(8, 2) = n
    zeile = 3
    zeileI = zeile
    zeileN = zeile
        Do Until n = 51
            Do Until i > n
                Cells(zeile, 5) = Cells(zeileform, 2).Value * Cells(zeile, 6).Value
                zeile = zeile + 1
                i = i + 1
                Cells(9, 2).Value = i
            Loop

        Set myrange = Range(Cells(3, 5), Cells(zeile - 1, 5))
        Summe = Application.WorksheetFunction.Sum(myrange)
        Cells(zeileI, 7) = Summe
        Erg = multi * Summe + Cells(zeileform, 3).Value
        Cells(zeileI, 8).Value = Erg
        n = n + 1
        Cells(8, 2).Value = n
        i = 0
        Cells(9, 2).Value = i
        zeileI = zeileI + 1
        zeile = 3
        zeileN = zeileN + 1
        Range("E1: E5000").Clear
    Loop

End Sub
```

<u>Calculation of Merton Jump Model with different Jump Intensities:</u>

```
Public Sub MertonJumpdifLambada_Click()
    Dim anfangST As Double
    Dim EndeST As Double
    Dim lambada As Double
    Dim CallPr As Double
    Dim PutPr As Double
    Dim spalte As Integer
    Dim spalteput As Integer
    Dim zeile As Integer
    Dim zeileput As Integer
    Dim zähler As Double

    anfangST = Workbooks("Modellierung.xlsm").Worksheets("Merton LOG Option Price").txt1
    EndeST = Workbooks("Modellierung.xlsm").Worksheets("Merton LOG Option Price").txt2
```

```
    zähler = anfangST
    lambada = 0.5
    spalte = 17
    zeile = 2
    zeileput = 27
    spalteput = 17

    Do Until lambada > 10
        Cells(zeile, 16) = lambada
        Cells(7, 2) = lambada
        Cells(26, spalteput) = lambada

        Do Until zähler > EndeST
            Cells(1, 2) = zähler
            Cells(1, spalte) = zähler
            Cells(zeileput, 16) = zähler
            CallPr = Cells(130, 13).Value
            Cells(zeile, spalte) = CallPr
            PutPr = Cells(131, 13).Value
            Cells(zeileput, spalteput) = PutPr

            zähler = zähler + 0.1
            spalte = spalte + 1
            zeileput = zeileput + 1
        Loop

        lambada = lambada + 0.5
        zeile = zeile + 1
        zähler = anfangST
        spalte = 17
        zeileput = 27
        spalteput = spalteput + 1
    Loop
End Sub
```

<u>Merton Ruin with different Jump Intensities:</u>

```
Public Sub MertonRuindifLambada_Click()
    Dim anfangST As Double
    Dim EndeST As Double
    Dim lambada As Double
    Dim CallPr As Double
    Dim PutPr As Double
    Dim spalte As Integer
    Dim spalteput As Integer
    Dim zeile As Integer
    Dim zeileput As Integer
    Dim zähler As Double

    anfangST = Workbooks("Modellierung.xlsm").Worksheets("Merton LOG Option Price").txt1
    EndeST = Workbooks("Modellierung.xlsm").Worksheets("Merton LOG Option Price").txt2
    zähler = anfangST
    lambada = 0
    spalte = 6
    zeile = 2
    zeileput = 25
    spalteput = 6

    Do Until lambada > 10
        Cells(zeile, 5) = lambada
        Cells(9, 2) = lambada
        Cells(24, spalteput) = lambada

        Do Until zähler > EndeST
            Cells(3, 2) = zähler
```

```
            Cells(1, spalte) = zähler
            Cells(zeileput, 5) = zähler
            CallPr = Cells(16, 2).Value
            Cells(zeile, spalte) = CallPr
            PutPr = Cells(17, 2).Value
            Cells(zeileput, spalteput) = PutPr

            zähler = zähler + 0.1
            spalte = spalte + 1
            zeileput = zeileput + 1
        Loop

        lambada = lambada + 0.5
        zeile = zeile + 1
        zähler = anfangST
        spalte = 6
        zeileput = 25
        spalteput = spalteput + 1
    Loop
End Sub
```

<u>Kou Model with different Jump Intensities:</u>

```
Private Sub Koudif_Click()
    Dim n As Integer
    Dim k As Integer
    Dim i As Integer
    Dim zeile As Integer
    Dim zeile1 As Integer
    Dim ZeileE As Integer
    Dim zeileN As Integer
    Dim zeileS As Integer
    Dim zeilecall As Integer
    Dim spaltecall As Integer
    Dim zeileput As Integer
    Dim spalteput As Integer
    Dim zähler As Double
    Dim anfangP As Double
    Dim endeP As Double
    Dim lambada As Double
    Dim CallPr As Double
    Dim PutPr As Double
    Dim p As Double
    Dim q As Double
    Dim multi1 As Double
    Dim multi2 As Double
    Dim pi As Double
    Dim pin As Double
    Dim phochn As Double
    Dim qhochn As Double
    Dim Integ1 As Double
    Dim Integ2 As Double
    Dim Integ3 As Double
    Dim Integ4 As Double
    Dim Erg1 As Double
    Dim Erg2 As Double
    Dim Erg3 As Double
    Dim Erg4 As Double
    Dim Prod1 As Double
    Dim Prod2 As Double
    Dim Prod3 As Double
    Dim Prod4 As Double
    Dim SummeP As Double
    Dim SummeQ As Double
    Dim Summe1 As Double
```

```
Dim Summe2 As Double
Dim Summe3 As Double
Dim Summe4 As Double
Dim SolSum1 As Double
Dim SolSum2 As Double
Dim SolSum3 As Double
Dim SolSum4 As Double
Dim myrangeP As Range
Dim myrangeQ As Range
Dim myrange1 As Range
Dim myrange2 As Range
Dim myrange3 As Range
Dim myrange4 As Range
Dim solutionrange1 As Range
Dim solutionrange2 As Range
Dim solutionrange3 As Range
Dim solutionrange4 As Range
' Anfangswerte definieren
p = Cells(12, 2).Value
q = Cells(13, 2).Value
multi1 = Cells(5, 5).Value
multi2 = Cells(6, 5).Value
n = 1
Cells(2, 5).Value = n
k = 1
Cells(3, 5).Value = k
i = k
Cells(4, 5).Value = i
zeile = 4
zeile1 = zeile
ZeileE = zeile
zeileN = zeile
zeileS = zeile
zeilecall = 58
spaltecall = 2
zeileput = 84
spalteput = 2
lambada = 0.5
anfangP = Workbooks("Modellierung.xlsm").Worksheets("Merton LOG Option Price").txt1
endeP = Workbooks("Modellierung.xlsm").Worksheets("Merton LOG Option Price").txt2
zähler = anfangP
'Bereiche löschen
Range("O4: O55").Clear
Range("P4: P55").Clear
Range("Q4: Q55").Clear
Range("R4: R55").Clear
Range("S4: S55").Clear
Range("U4: U55").Clear
Range("V4: V55").Clear
Range("W4: W55").Clear
Range("X4: X55").Clear
Range("Y4: Y55").Clear
Range("AA4: AA55").Clear
Range("AB4: AB55").Clear
Range("AC4: AC55").Clear
Range("AD4: AD55").Clear
Range("AE4: AE55").Clear
Range("AF4: AF55").Clear
Range("AH4: AH55").Clear
Range("AI4: AI55").Clear
Range("AJ4: AJ55").Clear
Range("AK4: AK55").Clear
Range("AM4: AM55").Clear
```

```
Range("AN4: AN55").Clear

Do Until lambada > 10
   Cells(zeilecall, 1) = lambada
   Cells(83, spalteput) = lambada
   Cells(7, 2) = lambada

   Do Until zähler > endeP
      Cells(1, 2) = zähler
      Cells(57, spaltecall) = zähler
      Cells(zeileput, 1) = zähler

      Call Tabelle13.In1dif_Click
      Call Tabelle20.In2dif_Click
      Call Tabelle21.In3dif_Click
      Call Tabelle22.In4dif_Click
      Do Until n > 50
      Cells(zeileN, 15).Value = n
      pi = Cells(7, 5).Value
      Cells(zeileN, 21).Value = pi

       Do Until k > n
         If k = n Then
            phochn = p ^ n
            qhochn = q ^ n
            Cells(zeile, 16).Value = phochn
            Cells(zeile1, 17).Value = phochn
            Cells(zeile, 29).Value = qhochn
            Cells(zeile1, 30).Value = qhochn
            Integ1 = Cells(zeileS, 20).Value
            Integ2 = Cells(zeileS, 26).Value
            Integ3 = Cells(zeileS, 33).Value
            Integ4 = Cells(zeileS, 38).Value
            multi1 = multi1 ^ k
            multi2 = multi2 ^ k
            Prod1 = phochn * multi1 * Integ1
            Prod2 = phochn * multi1 * Integ2
            Prod3 = qhochn * multi2 * Integ3
            Prod4 = qhochn * multi2 * Integ4
            Cells(zeileS, 18) = Prod1
            Cells(zeileS, 24) = Prod2
            Cells(zeileS, 31) = Prod3
            Cells(zeileS, 36) = Prod4
            Set myrange1 = Range(Cells(4, 18), Cells(zeileS, 18))
            Summe1 = Application.WorksheetFunction.Sum(myrange1)
            Set myrange2 = Range(Cells(4, 24), Cells(zeileS, 24))
            Summe2 = Application.WorksheetFunction.Sum(myrange2)
            Set myrange3 = Range(Cells(4, 31), Cells(zeileS, 31))
            Summe3 = Application.WorksheetFunction.Sum(myrange3)
            Set myrange4 = Range(Cells(4, 36), Cells(zeileS, 36))
            Summe4 = Application.WorksheetFunction.Sum(myrange4)
            Cells(ZeileE, 19) = Summe1
            Cells(ZeileE, 25) = Summe2
            Cells(ZeileE, 32) = Summe3
            Cells(ZeileE, 37) = Summe4
            pin = Cells(ZeileE, 21).Value
            Erg1 = Summe1 * pin
            Cells(zeileN, 22) = Erg1
            Erg2 = Summe2 * pin
            Cells(zeileN, 27) = Erg2
            Erg3 = Summe3 * pin
            Cells(zeileN, 34) = Erg3
            Erg4 = Summe4 * pin
```

```
      Cells(zeileN, 39) = Erg4
      multi1 = Cells(5, 5).Value
      multi2 = Cells(6, 5).Value
      k = k + 1
      Cells(3, 5).Value = k
      i = k
      Cells(4, 5).Value = i
      zeile = 4
      Range("P4: P55").Clear
      Range("AC4: AC55").Clear
      ZeileE = ZeileE + 1
    Else
        Do Until i > n - 1
          Cells(zeile, 16).Value = Cells(3, 13)
          Cells(zeile, 29).Value = Cells(3, 14)
          zeile = zeile + 1
          i = i + 1
          Cells(4, 5).Value = i
        Loop

      Set myrangeP = Range(Cells(4, 16), Cells(zeile - 1, 16))
      SummeP = Application.WorksheetFunction.Sum(myrangeP)
      Cells(zeile1, 17) = SummeP
      Integ1 = Cells(zeileS, 20).Value
      Integ2 = Cells(zeileS, 26).Value
      multi1 = multi1 ^ k
      Prod1 = SummeP * multi1 * Integ1
      Prod2 = SummeP * multi1 * Integ2
      Cells(zeileS, 18) = Prod1
      Cells(zeileS, 24) = Prod2

      Set myrangeQ = Range(Cells(4, 29), Cells(zeile - 1, 29))
      SummeQ = Application.WorksheetFunction.Sum(myrangeQ)
      Cells(zeile1, 30) = SummeQ
      Integ3 = Cells(zeileS, 33).Value
      Integ4 = Cells(zeileS, 38).Value
      multi2 = multi2 ^ k
      Prod3 = SummeQ * multi2 * Integ3
      Prod4 = SummeQ * multi2 * Integ4
      Cells(zeileS, 31) = Prod3
      Cells(zeileS, 36) = Prod4

      multi1 = Cells(5, 5).Value
      multi2 = Cells(6, 5).Value
      zeileS = zeileS + 1

      k = k + 1
      Cells(3, 5).Value = k
      i = k
      Cells(4, 5).Value = i
      zeile1 = zeile1 + 1
      zeile = 4
      Range("P4: P55").Clear
      Range("AC4:Ac55").Clear
    End If
  Loop
  n = n + 1
  Cells(2, 5).Value = n
  k = 1
  Cells(3, 5).Value = k
  i = k
  Cells(4, 5).Value = i
  zeile = 4
```

```
        zeile1 = zeile
        zeileS = zeile
        zeileN = zeileN + 1
        Range("P4: P55").Clear
        Range("Q4: Q55").Clear
        Range("R4: R55").Clear
        Range("X4: X55").Clear
        Range("AC4: AC55").Clear
        Range("AD4: AD55").Clear
        Range("AE4: AE55").Clear
        Range("AJ4: AJ55").Clear
    Loop
    Set solutionrange1 = Range(Cells(4, 22), Cells(ZeileE - 1, 22))
    SolSum1 = Application.WorksheetFunction.Sum(solutionrange1)
    Cells(4, 23) = SolSum1

    Set solutionrange2 = Range(Cells(4, 27), Cells(ZeileE - 1, 27))
    SolSum2 = Application.WorksheetFunction.Sum(solutionrange2)
    Cells(4, 28) = SolSum2

    Set solutionrange3 = Range(Cells(4, 34), Cells(ZeileE - 1, 34))
    SolSum3 = Application.WorksheetFunction.Sum(solutionrange3)
    Cells(4, 35) = SolSum3

    Set solutionrange4 = Range(Cells(4, 39), Cells(ZeileE - 1, 39))
    SolSum4 = Application.WorksheetFunction.Sum(solutionrange4)
    Cells(4, 40) = SolSum4

       CallPr = Cells(8, 5).Value
       PutPr = Cells(9, 5).Value
       Cells(zeilecall, spaltecall) = CallPr
       Cells(zeileput, spalteput) = PutPr

       zähler = zähler + 1
       spaltecall = spaltecall + 1
       zeileput = zeileput + 1
       p = Cells(12, 2).Value
       q = Cells(13, 2).Value
       multi1 = Cells(5, 5).Value
       multi2 = Cells(6, 5).Value
       n = 1
       Cells(2, 5).Value = n
       k = 1
       Cells(3, 5).Value = k
       i = k
       Cells(4, 5).Value = i
       zeile = 4
       zeile1 = zeile
       ZeileE = zeile
       zeileN = zeile
       zeileS = zeile
    Loop

    lambada = lambada + 0.5
    zeilecall = zeilecall + 1
    zähler = anfangP
    spaltecall = 2
    zeileput = 84
    spalteput = spalteput + 1

  Loop
End Sub
```

Integral Calculations with different jump intensities (In1dif, In2dif, In3dif and In4dif are the same but on different spreadsheets):

```
Public Sub In1dif_Click()
Dim n As Integer
    Dim i As Integer
    Dim k As Integer
    Dim x As Double
    Dim zeile As Integer
    Dim zeileI As Integer
    Dim zeileN As Integer
    Dim zeileK As Integer
    Dim zeileform As Integer
    Dim myrange As Range
    Dim produktrange1 As Range
    Dim produktrange2 As Range
    Dim beta As Double
    Dim multi As Double
    Dim multi1 As Double
    Dim multi2 As Double
    Dim multi3 As Double
    Dim multi4 As Double
    Dim multi5 As Double
    Dim Produkt1 As Double
    Dim Produkt2 As Double
    Dim Summe As Double
    Dim Summe1 As Double
    Dim Summe2 As Double
    Dim H As Double
    Dim F1 As Double
    Dim F2 As Double
    Dim nenner1 As Double
    Dim nnern2 As Double
    n = 0
    Cells(8, 2) = n
    k = 0
    Cells(2, 13) = k
    i = 0
    Cells(9, 2) = i
    x = Cells(7, 2).Value
    zeile = 3
    zeileI = zeile
    zeileN = zeile
    zeileK = zeile
    beta = Cells(4, 2).Value
    multi = Cells(12, 2).Value
    multi1 = Cells(3, 13).Value
    multi2 = Cells(4, 13).Value
    multi3 = Cells(3, 14).Value
    multi4 = Cells(4, 14).Value
    multi5 = Cells(10, 2).Value

    Range("E1: E5000").Clear
    Range("F3: F5000").Clear
    Range("G3: G5000").Clear
    Range("H3:H5000").Clear
    Range("Q3: Q5000").Clear
    Range("R3: R5000").Clear
    Range("S3: S5000").Clear
    Range("T3: T5000").Clear
    Range("U3: u5000").Clear
    Range("V3: V5000").Clear
    If beta > 0 Then
        zeileform = 14
```

```
    Else
    zeileform = 15
End If
    Do Until n = 51
        Cells(zeileN, 17).Value = n

        Dim parnenner1 As Integer
        Dim parnenner2 As Integer
        Dim gammavert1 As Double
        Dim gammavert2 As Double

        parnenner1 = Cells(10, 13).Value
        parnenner2 = Cells(10, 14).Value

            Do Until k = 51
                Cells(2, 13).Value = k
                Cells(zeileK, 18).Value = k

                Dim gamma1 As Integer
                Dim gamma2 As Integer
                Dim gamma3 As Integer
                Dim gamma4 As Integer
                Dim gamma5 As Integer
                Dim gamma6 As Integer
                Dim gamma7 As Integer
                Dim gamma8 As Integer

                gamma1 = Cells(6, 13).Value
                gamma2 = Cells(7, 13).Value
                gamma3 = Cells(8, 13).Value
                gamma4 = Cells(9, 13).Value
                gamma5 = Cells(6, 14).Value
                gamma6 = Cells(7, 14).Value
                gamma7 = Cells(8, 14).Value
                gamma8 = Cells(9, 14).Value

                '1Fi1

                If gamma1 Mod 2 <> 0 Then
                    Cells(20, 12) = gamma1
                    gammavert1 = Cells(18, 12).Value
                    Cells(22, 12) = gammavert1
                Else
                    Cells(20, 12) = gamma1 / 2
                    gammavert2 = Cells(19, 12).Value
                    Cells(22, 12) = gammavert2
                End If

                If gamma2 Mod 2 <> 0 Then
                    Cells(20, 12) = gamma2
                    gammavert1 = Cells(18, 12).Value
                    Cells(23, 12) = gammavert1
                Else
                    Cells(20, 12) = gamma2 / 2
                    ammavert2 = Cells(19, 12).Value
                    Cells(23, 12) = gammavert2
                End If

                If gamma3 Mod 2 <> 0 Then
                    Cells(20, 12) = gamma3
                    gammavert1 = Cells(18, 12).Value
                    Cells(24, 12) = gammavert1
                Else
```

```
    Cells(20, 12) = gamma3 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(24, 12) = gammavert2
End If

If gamma4 Mod 2 <> 0 Then
    Cells(20, 12) = gamma4
    gammavert1 = Cells(18, 12).Value
    Cells(25, 12) = gammavert1
Else
    Cells(20, 12) = gamma4 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(25, 12) = gammavert2
End If

'1Fi2

If gamma5 Mod 2 <> 0 Then
    Cells(20, 12) = gamma5
    gammavert1 = Cells(18, 12).Value
    Cells(22, 13) = gammavert1
Else
    Cells(20, 12) = gamma5 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(22, 13) = gammavert2
End If

If gamma6 Mod 2 <> 0 Then
    Cells(20, 12) = gamma6
    gammavert1 = Cells(18, 12).Value
    Cells(23, 13) = gammavert1
Else
    Cells(20, 12) = gamma6 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(23, 13) = gammavert2
End If

If gamma7 Mod 2 <> 0 Then
    Cells(20, 12) = gamma7
    gammavert1 = Cells(18, 12).Value
    Cells(24, 13) = gammavert1
Else
    Cells(20, 12) = gamma7 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(24, 13) = gammavert2
End If

If gamma8 Mod 2 <> 0 Then
    Cells(20, 12) = gamma8
    gammavert1 = Cells(18, 12).Value
    Cells(25, 13) = gammavert1
Else
    Cells(20, 12) = gamma8 / 2
    gammavert2 = Cells(19, 12).Value
    Cells(25, 13) = gammavert2
End If

multi1 = Cells(3, 13).Value
multi2 = Cells(4, 13).Value
multi3 = Cells(3, 14).Value
multi4 = Cells(4, 14).Value
Produkt1 = multi1 * multi2
Cells(zeile, 19) = Produkt1
```

```
            Produkt2 = multi3 * multi4
            Cells(zeile, 21) = Produkt2
            zeileK = zeileK + 1
            zeile = zeile + 1
            k = k + 1

        Loop

    Set produktrange1 = Range(Cells(3, 19), Cells(zeile - 1, 19))
    Summe1 = Application.WorksheetFunction.Sum(produktrange1)
    Cells(zeileN, 20) = Summe1
    Set produktrange2 = Range(Cells(3, 21), Cells(zeile - 1, 21))
    Summe2 = Application.WorksheetFunction.Sum(produktrange2)
    Cells(zeileN, 22).Value = Summe2

    zeileN = zeileN + 1
    n = n + 1
    Cells(8, 2) = n
    k = 0
    Cells(2, 13) = k
    zeile = 3
    zeileK = zeile
    Range("S3: S5000").Clear
    Range("U3: u5000").Clear
Loop
n = 0
Cells(8, 2) = n
zeile = 3
zeileN = zeile
multi5 = Cells(10, 2).Value
Do Until n = 51
    Cells(zeileN, 4) = n

    parnenner1 = Cells(10, 13).Value
    parnenner2 = Cells(10, 14).Value

    If parnenner1 Mod 2 <> 0 Then
        Cells(20, 12) = parnenner1
        gammavert1 = Cells(18, 12).Value
        Cells(26, 12) = gammavert1
    Else
        Cells(20, 12) = parnenner1 / 2
        gammavert2 = Cells(19, 12).Value
        Cells(26, 12) = gammavert2
    End If

    If parnenner2 Mod 2 <> 0 Then
        Cells(20, 12) = parnenner2
        gammavert1 = Cells(18, 12).Value
        Cells(26, 13) = gammavert1
    Else
        Cells(20, 12) = parnenner2 / 2
        gammavert2 = Cells(19, 12).Value
        Cells(26, 13) = gammavert2
    End If

    nenner1 = Cells(5, 13).Value
    nenner2 = Cells(5, 14).Value
    F1 = Cells(zeileN, 20).Value
    F2 = Cells(zeileN, 22).Value
    multi5 = Cells(10, 2).Value
    H = multi5 * ((F1 / nenner1) - x * (F2 / nenner2))
    Cells(zeileN, 6) = H
```

```
        zeileN = zeileN + 1
        n = n + 1
        Cells(8, 2) = n
    Loop

    n = 0
    Cells(8, 2) = n
    zeile = 3
    zeileI = zeile
    zeileN = zeile
        Do Until n = 51
            Do Until i > n
                Cells(zeile, 5) = Cells(zeileform, 2).Value * Cells(zeile, 6).Value
                zeile = zeile + 1
                i = i + 1
                Cells(9, 2).Value = i
            Loop

        Set myrange = Range(Cells(3, 5), Cells(zeile - 1, 5))
        Summe = Application.WorksheetFunction.Sum(myrange)
        Cells(zeileI, 7) = Summe
        Erg = multi * Summe + Cells(zeileform, 3).Value
        Cells(zeileI, 8).Value = Erg
        n = n + 1
        Cells(8, 2).Value = n
        i = 0
        Cells(9, 2).Value = i
        zeileI = zeileI + 1
        zeile = 3
        zeileN = zeileN + 1
        Range("E1: E5000").Clear
    Loop

End Sub
```

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