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Market Modelling for Anticipating Risk in a Context of Macroeconomic Stresstest

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An intelligent and extensive risk management in companies becomes more and more important. Market simulations considering interdependencies of market and risk drivers significantly redound to anticipate the situation of the company in appropriate market scenarios. Simulations offer the possibility to companies to be alerted early. Full market simulations are not presentable and less promising due to their complexity. So an abstract reproduction of the company specific market factors is an adequate base to model the market dynamics and to illustrate the consequences of market developments. Empirical methods combined with a system dynamic approach are used to meet the high requirements of risk management and the quantification of risks. The model turns one's attention in the context of company-wide stress test. Market risk stress tests in conjunction with modeling market interdependencies and company relevant risk factors provide economic interpretable results by generating hypothetical, but real plausible scenarios. Those scenarios show the consequences for the company's financial efficiency and capacity. This article supplies a company specific framework for market simulation in the context of market risk stress tests.

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Economics: Quantitative Economics, Financial Economics.
Finance: Stock markets, Financial Modelling, Quantitative Finance, European Financial Markets, Capital Markets, Risk Management Process, Risk Analysis, Risk Management and Insurance.

1. Introduction

Risk management in companies has become eminent and turned out to be an important factor, which needs to be considered strongly by management. On one hand someone might think about risk as a characteristic to be avoided, but on the other hand risk is a fundamental factor of reinvestment and making profit.

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Investments might only be profitable if companies take chances. So there are instruments, tools, techniques and methodologies which are accumulated in risk management.[1] By now lots of risk types have been classified, which companies need to deal with. In common the two major risks are typically financial risks and non-financial risks, in the latter case especially the operational risk. Furthermore business and strategic risks exist as well as legal risks. Operational risk is mainly determined by organisational business processes, environmental circumstances and the behaviour of staff members. Whereas financial risks emerge from changing market prices, interest rates, supply and demand of products or commodities.[2] At this point companies need a sense for their actual risk under given conditions and they need to handle the uncertainty in changing environmental conditions.

This paper focuses on particular financial risks in the context of sales and product management. A market simulation model is developed and a quantitative method for measuring risks in a macroeconomic view is proposed. The effects are clarified by stress test scenarios. The developed simulation model in this article connects environmental market conditions, company specific parameters and relevant risk factors and shows effects of interdependencies of those three dimensions.

After this introduction, chapter two describes basic information about risk and theoretical dependencies as found in other studies. Chapter three picks up the results of chapter two and proposes a market simulation model. The developed model using a sample industrial company is illustrated in chapter four. At last chapter 5 concludes the article.

2. Risk Measurement and Adjustment

2.1 Introduction to Risk and Alternative Models

At first it is necessary to know how risk in context of product and strategic planning can be measured and additionally, how risk can be adjusted by management.

In the nature of risk there is uncertainty of predicting price developments in the future. This uncertainty leads similarly to the constitution of risk measurement methods, which are shortly described in the following section.

Setting a high value on an enduring strategy you need to explore the connectivity between different factors, which have great effect on failure or success of a company. With a global view there is uncertainty in the development of commodity prices, currency exchange rates, interest rates and stock prices. These are the basic financial risk factors, which are proposed e.g. by (Wiedemann & Hager 2003).[3] A global operating company depends on the global economic activity and is highly dependent on commodity prices. Beyond that commodity prices are mainly traded in USD and currency exchange rates strongly influence commodity prices which are to be paid effectively in the domestic currency of the specific company. So there are also exchange rate risks which have to be considered.

Calculating the volatility measured by the standard deviation of time series of the regarded risk factor is a good indicator for the expected variation, but there is no appropriate way to predict the future trend with high certainty.

The Random-Walk-Model, Variance-Covariance-Model, Modern Simulation and Monte-Carlo-Simulation are common approaches to measure risk. These models are e.g. described in (Hager 2004)[4]. In his work, he picks up a cash flow at risk model for mapping different exposure factors and getting to an aggregated risk measure.[5]

Here in the following analysis another framework for measuring risks of company's product portfolio is developed and introduced. This framework will take place in risk management to anticipate different market scenarios and its impact on the company. The simulation model is at first based on a short theoretical overview of selected factors and secondly on empirical interdependencies.

2.2 Theoretical Interdependencies of Risk Factors and Background Information

Sales Risk
Sales risk is the risk of a company that sales fall below an expected level.[6] Both sales of a company and the strongly linked business volume depend on the present economic situation. Product prices and interest rates influence the demand of consumers. Rising interest rates reduce demand due to more expensive financing, which in turn reduces economic growth and associated inflation. An upward revaluation of the domestic currency reduces the number of exports which decrease national income. The income elasticity of demand declares the effects of changing income on demand. A further aspect is the company's individual price policy. Sales and product prices stay in a direct connection that is declared by the price elasticity of demand.

Interest Rate Risk
The hazard of changing interest rates and thereby the according effects on future operating results are described as interest rate risk.[7] Interest rates and the adjustment of interest rates are mainly managed by the monetary and tax policy. The central bank adjusts the short time rate, whereas the long term interest rate is primarily determined by macroeconomic factors. Beyond that, the rate of price increase influences the value of interest rates. Moreover, there are business cycles, exchange rates und commodity prices, which have a positive effect on long term interest rates.[8] A currency depreciation leads to increasing exports, higher demand of products and following higher interest rates.[9]

Rising commodity prices cause a higher real interest rate as well as higher expectation of inflation and have increasing effects on long term interest rates.[10]

Commodity Price Risk
Companies require commodities for their production. Those commodities are traded at commodity markets and therefore they undergo price formation processes and variations. Those variations contain extensive risks at the time of buying as well as at the time of resale of the manufactured products. So companies are faced to changing commodity prices and they have to deal with them. Commodity price formation is also influenced by commodity reserves, tax and subvention policy, business cycles and conveyor technique. Above that they are driven by the inflation and expectations of the market.[11]

Exchange Rate Risk
Exchange rates are influenced by the price level and inflation, interest rates and commodity prices. They are also faced with deviations depending on imports, exports and the monetary policy.[12] Commodities are mainly traded in USD. Companies registered in a Non-USD currency area (i.e. European Monetary Union) are confronted the Domestic/USD-exchange rates deviations at trading.[13] In the international trading there are further risks. On one hand there are transaction risks, which are caused by a time gap between selling goods into a foreign currency country and receiving the money. On the other hand there are translation risks. These are value changing balance sheet items due to deviating exchange rates, which are originally expressed in a foreign currency. Above that there is economic exchange rate risk, which quantifies the impact of future exchange rate deviations on expected cash flows.[14]

These coherences are considered in the developed simulation model, which is explained in chapter 3.

3. Simulation model construction

3.1 Construction

Simultaneous deviations of different risk drivers have various effects on the development of the considered company's cash flows. Every risk factor influences the economical business objectives in an individual manner. For measuring the effects and risks by an integrated view, interdependencies have to be constituted by a market model. At this point it is necessary to know that modelling a complete market is highly ineffective and not promising. The reason why is the huge complexity of markets, their high connectivity of almost unlimited factors and the insufficient data availability. So an appropriate trade-off needs to be met by modelling an abstract view of the company relevant factors, which are representable for the market dynamic and show the consequences of market movements. To cope with the high economic dynamics, elements of a system dynamics approach[15] are used for the model. For quantification the theoretical analysis is supported by empirical coherences. The resulting scheme is an approximative view of the risk relevant factors in the company's environment.

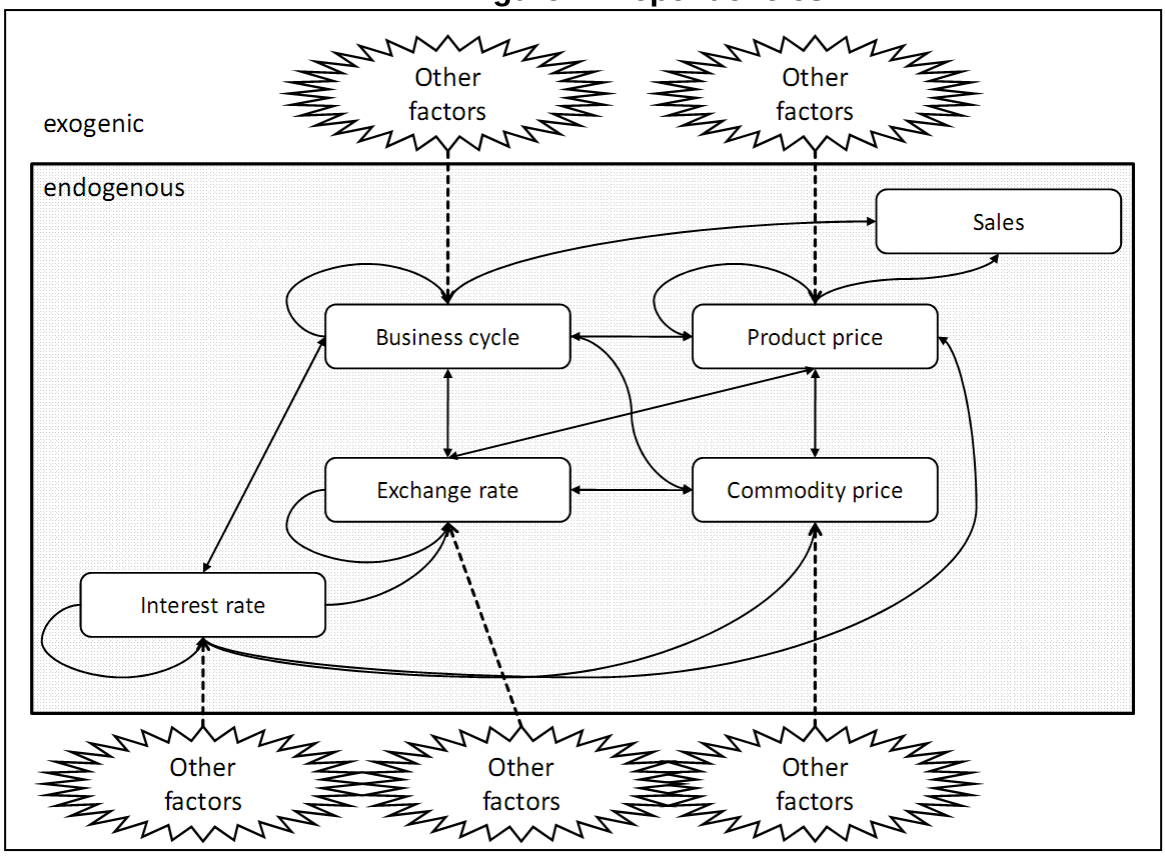
It is supposed that there are exogenic and endogenous market factors. Endogenous factors are those, which coherences are modelled and reviewed in detail and have direct impact on the company. Exogenic factors influence the endogenous factors. They have indirect impact on the company and are hardly controllable by the company itself. Examples for exogenous factors are the tax and monetary policy or an environmental disaster, which can influence commodity prices. The scope of the endogenous factors is determined by the variables

- exchange rate
- business cycle
- longeterm interest rate
- commodity prices
- product prices and

- sales.

The theoretical dependencies of these factors as suggested in studies mentioned above are summarized in figure 1.

Figure 1: Dependencies



These factors can be treated as several dependent random variables. In our model the exogenic factors are aggregated into one single variable per endogenous factor. Since there are lots of external factors, the assumption of aggregating all exogenic factors in one variable per endogenous factor is valid and therefore a random walk process is acceptable for modelling the exogenic variable. In a Monte-Carlo-Simulation[16] algorithm a normal distribution is used for generating random rates of return.[17] The exogenic rates of returns are interpretable as the environmental influence. The endogenous variables are calculated by the influence of each single risk factor with regression methods. The rate of return of a factor corresponds to the weighted summation of the rate of returns of the other factors of the prior period plus the rate of return of the residual environmental factor of the prior period.

$$\tilde{r}_{i,t} = a_{x,i} r_{x,t-1} + \sum_{j=1}^{n} a_{j,i} r_{j,t-1} \qquad (1)$$

with $\tilde{r}_{i,t}$: rate of return of parameter i in period t,
$a_{x,i}$: factor of influence of the exogenic system,
$r_{x,t-1}$: rate of return of the exogenic system in period t-1,
$a_{j,i}$: factor of influence of parameter j in period t-1 on parameter i in period t
$r_{j,t-1}$: rate of return of parameter j in period t-1.

The rate of change of each factor is expressed by the discrete rate of return $r_{j,t}$.

$$r_{i,t} = \frac{S_{i,t}}{S_{i,t-1}} - 1 \tag{2}$$

with $r_{i,t}$: rate of return of parameter i in period t,
$S_{i,t}$: value / price of parameter i at the end of period t,
$S_{i,t-1}$: value / price of parameter i at the end of period t-1.

For parametrization of the model the coefficients $a_{j,i}$ respectively $a_{x,i}$ have to be estimated. First the empirical historic correlations between the rates of return of period *t* and the rates of return of period *t-1* for all factors are calculated. This timeshift is motivated by the influence to be measured up to the next period. Therefore historical time series for the regarded factors are used. The correlation coefficient $\rho_{R_i^t,R_j^{t-1}}$ is calculated for series[18] R_i^t and R_j^{t-1}:[19]

$$\rho_{R_i^t,R_j^{t-1}} = \frac{Cov(R_i^t, R_j^{t-1})}{\sqrt{Var(R_i^t)}\sqrt{Var(R_j^{t-1})}} \tag{3}$$

with R_i^t: rates of return series of factor i till period t,
R_j^{t-1}: rates of return series of factor j till period t-1,

This correlation describes the coherence of two variables with a time shift of one period. The correlations are the basis to identify the exogenic influence factors. The coefficient of determination R^2 is calculated, which measures the adjustment goodness of a linear approximation.[20] The coefficient of determination describes the relative part of the whole deviation of the endogenous factor, which is explained by the exogenic influence. R^2 is limited to [0, 1]. The correlation of the exogenic factor is calculated by

$$\rho_{x,i}^2 = 1 - \sum_{j=1}^{n} \rho_{j,i}^2 \tag{4}$$

The correlations are adjusted to calculate the factors of influence $a_{j,i}$ respectively $a_{x,i}$.

$$a_{j,i} = \rho_{j,i} \frac{\sigma(i)}{\sigma(j)} \tag{5}$$

with $\sigma(i)$: standard deviation of the rate of return of parameter i,
$\sigma(j)$: standard deviation of the rate of return of parameter j.

The expected values of the environmental factors μ_x are calibrated so that the expected values of the market factors $\bar{x}_{j,t}$ are matched using the formula below. Setting $\bar{x}_{j,t}$ can be used to anticipate a trend or downturn of an according factor. Otherwise it can be defined to consider expert estimations or any other market movement.[21]

$$\bar{x}_{i,t} = a_{x,i}\mu_x + \sum_{j=1}^{n} a_{j,i}\bar{x}_{j,t-1} \tag{5}$$

This framework leads to an integrated market model by using regression instruments. One benefit is the simulation of external factors which implicitly influence the endogenous development of the relevant market factors considering market expectations, deviations and coherences. The proposed linear approach is suitable and efficient to model the coherences between the exogenic and endogenous view. This also causes a short computing time.

3.2 Parametrization and Exposure Map

Factors of influence not based on theoretical studies as mentioned in chapter 2.2 are supposed to be independent and determined as random and environmental. In those cases these factors of influence are defined as zero in the model. To take care of the development of sales, there are the income elasticity of demand and the price elasticity of demand of the regarded products. Sales are directly influenced by these parameters. The elasticities are economic values and are estimated from internal processes in the company.

When measuring the empirical correlations there are uncertainties due to choice of the right time frame. The user needs to deal with a trade-off between short time series and long time series. Short time series assure a reference to present market conditions. Long time series reduce the standard error of the correlation coefficients. As there are continuous movements in markets correlations are not constant and long time series can contain correlation breakdowns.[22]

By resolving formula (2) one gets the simulated value of the market factors, which are used to evaluate the simulated market scenario. Each scenario is indicated by a vector of all regarded market factors. Those market factors lead to a resulting cash flow. The cash flows are calculated by a so-called exposure mapping. The exposure mapping establishes a relation between market factors and the consequences of these factors for the company's economic development. Although the market factors are valid for each company, the exposure mapping needs to be accomplished individually for each company. In this model the result is aggregated to the cash flow. A repeated simulation leads to a cash flow distribution considering sales and costs. A quantile of the cash flow distribution represents the cash flow at risk under a given time horizon.

The results provide information about the equity requirements, liquidity reserves as well as the probability of cost recovery in a certain market scenario. The company is able to respond to scenarios in time and can evaluate necessary protection activities.

4. Example Simulation

The example is based on a fictive company. The company's relevant factors are simulated as proposed in the developed model. The results of the simulation are aggregated and demonstrated via the expected cash flows of the company.

4.1 Data and Parametrization

It is assumed that the sample industrial company produces three comsumer products made out of the commodities aluminium, nickel, copper and zinc. The commodities are quoted in USD per ton. So the company is faced to exchange rate risk besides the commodity price risk. The company is settled in Germany and transacts its business in EUR on the German market. The company's sales volume results from the product of sales and product prices. The connection is declared by the price elasticity of demand as mentioned above. Sales are additionally influenced by the economic situation and product prices are supposed to develop similarly to the consumer price index. Sales are subject to random deviations caused by the development of gross domestic product.
The requested amounts of commodities for production are shown in table 1.

Table 1: Consumption of commodities in tons per product.

Consumption (in tons)	Product 1	Product 2	Product 3
Aluminium	0.1	0.03	0.01
Copper	0	0.05	0.01
Nickel	0	0	0.005
Zinc	0	0	0.005

First a standard scenario is defined which contains feasible use of estimations by the management about the company's prospective development. It is presumed that the expected sales are reached on average with a 5% standard deviation of the relative sales' change. Fixed costs e.g. for staff are determined to an overall of 9.0 Mio. EUR p.a. and need to be earned. It is assumed that all income is represented by the expected cash flows and the company has no other costs. Interest and taxes are not regarded in this sample. This is the basic scenario and acts as a benchmark. It is compared with two stress scenarios. A stress scenario represents special market conditions, which have huge effect on the company. Stress scenarios show effects of hypothetical, but plausible and really possible parametrizations of the model. Stress scenario 1 represents falling sales of 20% p.a. on average per product. Stress scenario 2 represents an additional increase of commodity prices of 20% p.a. on average.

Basic data are the quarterly collected time series from 1st quarter 2004 up to 4th quarter 2010 of the factors gross domestic product, consumer price index, exchange rates (EUR/USD), interest rates (12-month-EURIBOR), aluminium-, nickel-, copper- and zinc price.[23]

The cash flow at risk at confidence level 95% after four quarters is used as risk measure. 50.0000 iterations per quarter and per scenario were implemented. Whereas a number of 10.000 iterations already leads to stable risk forecasts in many cases according to the literature.[24] Further parameters are listed in table 2.

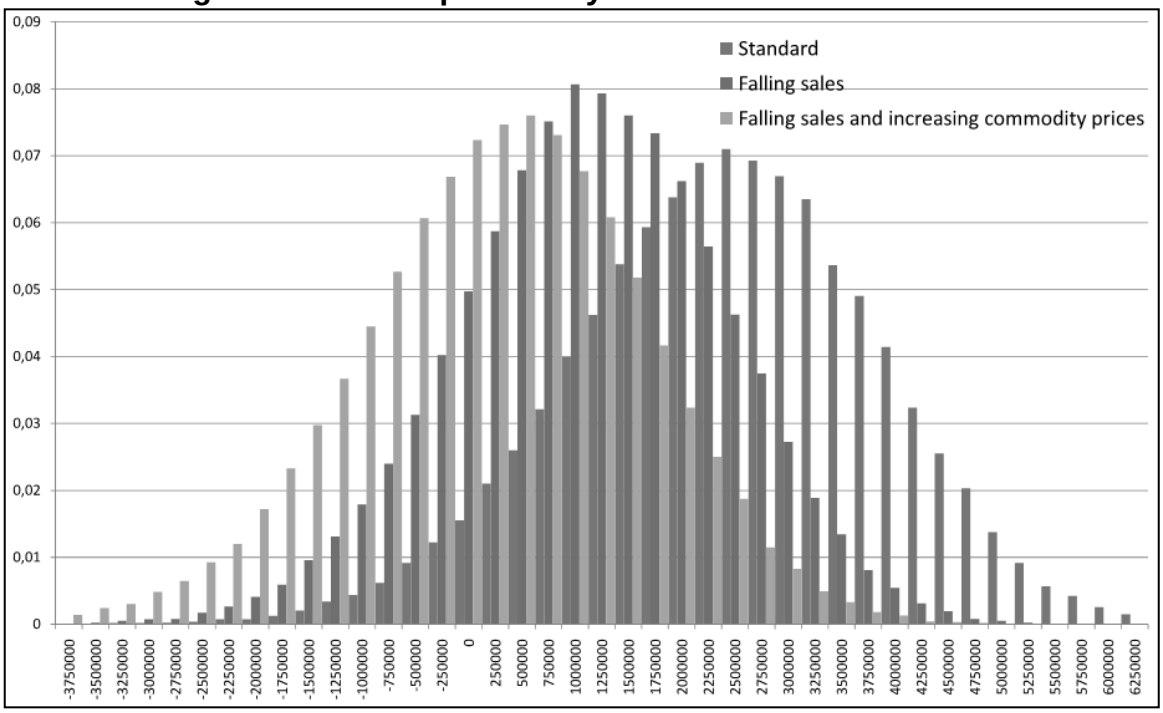
Table 2: Parametrization

	Product 1	Product 2	Product 3
Income elasticity of demand	1.2	0.5	1
Price elasticity of demand	-2	-1	-1.5
Price at beginning of simulation	400	900	400
Expected number of sales per quarter	6000	2000	1500

4.2 Empirical Simulation Results

The empirical results of the simulation are three relative probability distributions of the expected operational cash flows after deduction of fixed costs. The results are shown in figure 2.

Figure 2: Relative probability distribution of cash flows



The results confirm that falling sales as well as falling sales combined with rising commodity prices lead to an explicit reduction of the expected cash flow surpluses. Moreover, the results can be ordered by the concept of stochastic dominance.[25] Thus, the standard scenario distribution dominates the distribution of scenario two. Scenario three is also dominated. That means that the probability of making a higher profit in the standard scenario is in every case higher than in scenario two respectively three. The company is now aware of possible consequences on extraordinary market movements. The expected values and the cash flows at risk at confidence level 95% are summarized in table 3.[26]

Table 3: Results in Mio. EUR

Scenario	Standard	Falling sales	Falling sales and increasing commodity prices
Expected cash flow	2.32	1.02	0.14
Cash flow at risk (95%)	-0.1	-1.1	-2.13

In the standard case the company expects a cash flow surplus of 2.32 Mio. EUR. With a probability of 95% the minimal cash flow will be -0.1 Mio. EUR. The standard scenario stands for the normal case and comprehends a situation, which should be handled by the company without any problems. With falling sales the company expects only 1.02 Mio. EUR and realizes minimally a cash flow deficit of -1.1 Mio. EUR with probability of 95%. That means that falling sales of 20% on average cause an expected cash flow reduction of 56%. Scenario 3 with falling sales and rising commodity prices compounds the situation. The company is now confronted with a minimal cash flow deficit of -2.13 Mio. EUR with probability of 95% and may only expect a little positive cash flow of 0.14 Mio. EUR. That implies a reduction of 94%. Cash flows must not be put on same level with the operating profit. The results demonstrate mainly liquidity-related impacts on the company's situation due to special scenarios. To survive such a stress scenario the company needs to supply liquidity of 1.1 respectively 2.13 Mio. EUR in the worst case[27] to re-balance its financial situation. Regarding all relevant income and costs in the expected cash flow model, the company is able to transfer the cash flows from a liquidity view to an operational profit view under given conditions. Thus the company gets an approximation of its future profit situation.

The figures are of particular relevance for the financial strength of the company. Simulations lead to findings for preparing companies for dedicated market scenarios. The management is aware of the consequences of future crisis and market movements. Liquidity reserves can be kept and contingency plans can be elaborated on time. A single step analysis of each quarter shows additionally further insights. The company is able to realize how long it can survive in a stress case and it can deduct appropriate countermeasures.

5. Conclusion

The article started with a short theoretical analysis of important market factors and their dependencies. Based on that research a framework for a market simulation model has been proposed. The construction contains an abstract view of complex market connectivities and regards exogenic and endogenous factors of influence. Simulations make the consequences for companies transparent. They are parameterized on empirical and theoretical researches on the one hand; on the other hand they are added by expectations. That leads to a successful model in the context of integrated risk management. The model reduces the high connectivites and complexity of markets on a transparent and representative level. It supplies important results for management as the company can react on time and protect against bad market movements.

Endnotes

[1] See (Raz & Hillson 2005).
[2] See (Smallman 2000).
[3] See (Wiedemann & Hager 2003).
[4] See (Hager 2004).
[5] For further details see (Wiedemann & Hager 2003).
[6] See (Duch 2006).
[7] See (Hager 2004).
[8] See (Lang 2005).
[9] See (Sieg 2008).
[10] See (Herz & Drescher 2010).
[11] See (Kühne 2010).
[12] See (Lang 2005).
[13] See (Baselt & Welter 2010).
[14] See (Hager 2004).
[15] System dynamics is a method used in informatics for modelling and simulating complex dynamic interdependencies.
[16] For details on Monte-Carlo-Simulation methods see (Lemieux 2009).
[17] Statistically the sum of independent, identical distributed stochastic variables with limited expected values and variances converge approximately to a normal distribution. See (Schröder 2002).
[18] Both series consist of n elements, whereas the one lasts from period t-n up to t and the other from period t-n-1 up to t-1.
[19] See (Kähler 2002).
[20] See (Kähler 2002).
[21] The estimation of trends is not part of this article and needs to be worked on elsewhere.
[22] See (Hager 2004).
[23] Time series for nickel and zinc prices are available from 1st quarter 2006. Data are available on websites www.destatis.de, www.bundesbank.de and www.finanzen.net.
[24] See (Hager 2004).
[25] Stochastic dominance is described in (Sorger 2000).
[26] The cash flow at risk is interpreted as the absolute cash flow to the confidence level 95\% at time horizon of overall four quarters. There is a different cash flow at risk interpretation, which considers the cash flow as the difference between expected cash flow and the quantile. That is also known as relative cash flow at risk. In the context of this article the absolute cash flow is used as relevant risk measure.
[27] The worst case is defined as the cash flow surplus at 95% confidence level.

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