Coal Mines Risk Modelling Using Energy Spread

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Abstract. The growing importance of the cost of electricity in coal mining, changes in the value chain in recent years and new commodity exchanges cause that mine operators independently or vertically integrated with power plants have possibility to buy and sell coal and electricity and create a specific spread. The study of risk based on the concept of a new indicator: an intrinsic spread. The intrinsic spread is calculated as a difference between the income from the sale of coal and the cost of purchasing the energy required for the coal production. This indicator shows a market risk in the coal mine in a better way, because except for income it includes a part of the cost of exploitation which can be hedged in the exchange market. Spread calculations were made on historical data and simulation modelling. Based on time series of coal and energy prices for various contracts and spot prices obtained from the EEX the impact of the type of contracts on the volatility of the intrinsic spread in subsequent periods measured by the standard deviation of returns has been analysed. It was found that hedge using futures helps to reduce the risk in the mine. Modelling of coal prices and electricity was carried out by conventional financial market econometric models. The best-fitting econometric models are multivariate models and models based on the copulas. The simulation results show that the use of futures contracts contributes little to reducing the intrinsic spread volatility. An econometric model with the technical and economic parameters of the mine typical for hard coal mine has been built. Changes in fixed and variable costs have been simulated based on triangular distributions. Parameters for simulation were estimated based on the economic data from the mines. Additionally, coal and energy prices were dependent on the market volatility. Based on the economic model and Monte Carlo simulation it has been found that the proposed method may be helpful in reducing the coal mine market risk.

1. Introduction

In general, spread can be defined as a difference between at least two cash flows. Therefore, it can be calculated for any relationship of assets between an existing specific relationship. The ability to create spreads limits only the number of combinations between the assets. The most popular places to use the spreads are currency and the bond market, where spread means a difference between bid and ask price or a difference between the percentage of financial instruments. An exact description of spread and its options has been made by Carmona [1] and Kirk [2].

For the energy market a dark spread for coal has been created and spark spread for the energy production from gas. For generators spread shows cost-effectiveness of electricity production from many fuels. The formula for the dark spread (DS) is simple:
In case of a power station spread means a difference between the price of sold energy and the cost of its generation. By analogy we introduce an adverse "energy spread" for a coal mine called an intrinsic spread (IS). In this case, the intrinsic spread is a difference between the price of coal and the cost of energy necessary for excavation and processing. This two factors have the main influence on the market risk exposure for a coal mine. IS can be simply calculated the following formula:

\[ IS_{LT} = P_{C,L,T}Q_{C,T} - P_{E,L,T}Q_{E,L} \]  

(2)
\[ P_{C,T}, P_{E,T} - \text{price of coal and energy with delivery in T,}\]
\[ Q_{C,T}, Q_{E,T} - \text{quantity of coal and energy.}\]

Trade contracts in futures form are standardized. In the formula we use numbers of contracts for coal \( n_C \) and for energy \( n_E \), delivered energy \( N_E \) and delivered coal \( N_C \) for each type of contract and intrinsic spread can be calculated as follows:

\[ IS_{LT} = n_C C_{W,T} N_C - n_E C_{E,T} N_E \]  \( (3) \)

The purchase of two contracts a date \( t \) with delivery in \( T \) guarantee the future intrinsic spread for a coal mine. In this work the market risk of coal is defined as a risk of coal and an energy price change. For the coal mine the most important is the energy price which is the prime cost quoted on the exchange. As mentioned before popular but imperfect measure of risk is variance or standard deviation of return rate from the set of contract including the intrinsic spread. Another risk measure used in this article is Value at Risk which calculates an infinite loss with specified percentage.

Hedging with futures involves on choosing from a range of available instruments that minimize the cash flow volatility. The hedge ratio \( \beta \) showing the value of the hedged portfolio [11] relative to the exposure can be derived from the formula where \( \sigma_S^2 \) is the variance of the future price change and \( \sigma_F^2 \) is the variance of the portfolio consisting of coal and energy futures:

\[ \beta = \frac{\sigma_S^2}{\sigma_F^2} \rho(S,F) \]  \( (4) \)

The number of contract \( n \) to be bought to minimize portfolio is:

\[ n = \left( \frac{\sigma_S^2}{\sigma_F^2} \right) \beta \]  \( (5) \)

where \( S \) is a portfolio value on the spot market and \( F \) is a portfolio value on futures. In a real coal mine the number of contracts to create a "safe" portfolio depends on the coal production and energy consumption. The impact of certain energy and a coal contract on the intrinsic spread hedging and consequently the market risk of a coal mine have been investigated.

3. Data preparing and model building

For the purpose of the analysis the data has been downloaded from Energy Exchange Market in Germany. Data range has been characterized by periods of low and high price volatility. Moreover it was the time of bull market on raw material exchange until 2009 and the fall in the market after that period (Fig. 1). Determining the profitability of the intrinsic spread-based hedging consisted of the following calculations:

A. The matrix with price for futures on coal and energy was created. The trading of individual instruments was not carried every trading day. To standardize the amount of data from different contracts the days in which there was no trade of at least one of the instruments have been removed. Mostly it happened at the end of the contract expiry date when the year contract was changed for quarter and quarter where change into month contracts. Finally, the month, quarter and year future price matrix has the size of 1302x33.

B. The rate of return matrix of the individual instruments has been calculated. Relatively often in the situation where there was a change of delivery period between consecutive trading days in the given type of contract there were price jumps. It was assumed that the analysis of hedging of mine cash flows would be carried out based on constant conditions of transition between contracts.

C. The hedged portfolio has been built. The combination of shares of individual contracts in the portfolio should meet the conditions on the minimum rate of the return variance. The economic model of the mine assumes yearly production on 2.4 Tg of coal and use 160 GWh of energy. These are
average values for hard coal mining in Poland. An entire portfolio hedging means purchase (sign "-") or sale (positive value) in number of contracts as presented in Tab. 1.

**Table 1.** Coal and energy contract quantity for whole mine coal production and energy consumption

| Commodity | Type of contract |
|-----------|------------------|
| Energy    | month | quarter | year   |
| Coal      | 200   | 600     | 2400   |
|           | -20   | -60     | -240   |

D. Portfolio can be secured with the combinations of different contract types. In some periods it may occur that operator has more futures than actual sales of coal or energy consumption. Therefore, we assume that the base portfolio will be created in such a way that for some delivery periods would be used contracts with the smallest amount secured. For instance, one quarter futures contract will be replaced by the corresponding monthly contract. An annual contract will be replaced by 6 monthly contracts and 2 quarterly. At the end the coal mine sale and energy cost was hedged by the available contracts to minimize the risk. Based on this, we estimate the volatility of the new hedged portfolio and 10-day VaR as a risk measure.

4. Intrinsic spread hedging using single futures
Presented in Figure 1 future value of the coal mine cash flow for the next delivery period can be hedged by the contract with the present price. The average volatility value of the future cash flow for the next 3 years for coal mine in the analysed period is € 59.03 million and the 10-day VaR-1% is € 34.55 million. The future intrinsic spread can be effectively hedged even by purchase only one type of contracts. For the analysed data the effective hedging to minimize variance can be made by the purchase (or sale) one type of contract of 15 energy futures (from F1BM-1M to F1BY-3Y) and 15 coal futures (from FT2M-1M to FT2Y-3Y) In Table 2 we calculate correlation $\rho_{CF,Fut}$ between the cash flow in the next three years and the futures contracts price. As risk measure the cash flow volatility (CF Vol.) and the 1% Var-10 days have been estimated. The number of contracts minimizing the market risk was estimated based on formula (5). The greatest risk reduce is for FT2Q with coal delivery in three quarters. This naive method reduced the VaR from € 34.55 million to € 10.20 million when operator hedge intrinsic spread only by one future. In this case operator should only buy or sell most correlated contracts. Other coal contracts with the exception of the FT2Y with delivery in 3 years also contribute to the decrease in VaR value. The revenue for coal sale is dominant for the mine cash flow so most correlated contracts can effectively reduce the portfolio risk.

![Figure 1. Portfolio value for hedged mine](image-url)
5. Intrinsic spread hedging profitability

Spread hedging with a single contract is simple but may not be optimal, because the combination of many instruments is usually less risky. According to Markovitz’s portfolio theory [12] an effective portfolio minimizes variance at the assumed risk level. Based on the method presented in [13] it has been verified whether the random selection of instruments reduce the variance of portfolio. We assume that in the future it would be impossible to determine which instruments would be better for hedging mine spread.

On the EEX for analysed period were quoted 15 contracts with the same delivery date for energy and coal. Therefore, 15 sets of intrinsic spread contracts can be created. The delivery date was from a

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**Table 2.** Future cash flow hedging with hedge ratio for different contracts

|        | F1BM-1M | F1BM-2M | F1BM-3M | F1BM-4M | F1BM-5M | F1BM-6M |
|--------|---------|---------|---------|---------|---------|---------|
| \(\rho_{CF,Fut.}\) | 0.11    | 0.25    | 0.23    | 0.25    | 0.25    | 0.26    |
| CF Vol. | 58.7    | 57.2    | 57.4    | 57.2    | 57.2    | 57.1    |
| 1% VaR | 33.9    | 32.6    | 33.1    | 33.0    | 31.8    | 32.9    |

|        | F1BQ-1Q | F1BQ-2Q | F1BQ-3Q | F1BQ-4Q | F1BQ-5Q | F1BQ-6Q |
|--------|---------|---------|---------|---------|---------|---------|
| \(\rho_{CF,Fut.}\) | 0.28    | 0.25    | 0.21    | 0.34    | 0.32    | 0.26    |
| CF Vol. | 56.6    | 57.2    | 57.7    | 55.6    | 56.0    | 57.0    |
| 1% VaR | 34.6    | 31.8    | 32.5    | 31.3    | 31.7    | 32.8    |

|        | F1BY-1Y | F1BY-2Y | F1BY-3Y | F1BY-4Y | F1BY-5Y | F1BY-6Y |
|--------|---------|---------|---------|---------|---------|---------|
| \(\rho_{CF,Fut.}\) | 0.53    | 0.53    | 0.49    | 0.43    | 0.40    | 0.37    |
| CF Vol. | 50.1    | 50.2    | 51.4    | 53.3    | 54.1    | 54.9    |
| 1% VaR | 30.6    | 28.6    | 29.3    | 30.6    | 31.0    | 32.2    |

|        | FT2M-1M | FT2M-2M | FT2M-3M | FT2M-4M | FT2M-5M | FT2M-6M |
|--------|---------|---------|---------|---------|---------|---------|
| \(\rho_{CF,Fut.}\) | 0.89    | 0.92    | 0.93    | 0.93    | 0.93    | 0.92    |
| CF Vol. | 26.9    | 23.5    | 21.9    | 22.1    | 22.2    | 22.9    |
| 1% VaR | 13.4    | 11.7    | 10.9    | 11.4    | 11.1    | 10.2    |

|        | FT2Q-1Q | FT2Q-2Q | FT2Q-3Q | FT2Q-4Q | FT2Q-5Q | FT2Q-6Q |
|--------|---------|---------|---------|---------|---------|---------|
| \(\rho_{CF,Fut.}\) | 0.94    | 0.94    | 0.93    | 0.92    | 0.90    | 0.89    |
| CF Vol. | 20.9    | 20.7    | 21.7    | 22.7    | 26.2    | 27.3    |
| 1% VaR | 11.4    | 10.6    | 10.2    | 11.0    | 13.7    | 14.0    |

|        | FT2Y-1Y | FT2Y-2Y | FT2Y-3Y |
|--------|---------|---------|---------|
| \(\rho_{CF,Fut.}\) | 0.93    | 0.89    | 0.70    |
| CF Vol. | 21.3    | 27.5    | 42.2    |
| 1% VaR | 11.7    | 14.9    | 23.1    |
month to a year, so years and quarter futures values was divided accordingly by 12 and 3. An average value and standard deviation of the future cash flow after hedging and the correlation matrix between the volatility of random created portfolios have been calculated. The lowest volatility of intrinsic spread represents the set with the longest delivery date. The hedging with long time to delivery contract results that in the analysed period the volatility of set of three years contract for coal and energy was € 3.96 million. The creation intrinsic spread one month before delivery was characterized by the highest volatility € 4.87 million. The average value of all strategy was € 4.48 million.

The next step was to assign a random share of strategy in portfolio to check the blind strategy in setting the intrinsic spread. For this example, the volatility of the strategy was calculated using formula:

$$\sigma_P = \sqrt{\sum^n_{i=1} w_i^2 \sigma_i^2 + \sum^n_{i=1} \sum^n_{j=1} w_i w_j \sigma_i \sigma_j \rho_{i,j}}$$  (6)

where $\sigma_{i,j}$ is an intrinsic spread standard deviation for coal and energy prices, $w_{i,j}$ wage of a selected strategy and $\rho_{i,j}$ is a Pearson correlation coefficient. In ModelRisk 10 000 scenarios have been simulated. Random weight was assigned to each set of contracts and for portfolio in each scenario future cash flow volatility was calculated. Thus, without favouring any strategy it was verified, whether the hedging with the set of intrinsic spread using futures was advantageous for the coal mine. The total sum of weight equalled 1 but the random strategy selection may cause that the delivery in some period is not hedged and vice versa: the commodity contract on future exchange may exceed the coal production and energy consumption. For the constructed portfolio the results of simulation show that even random selection of contracts set causes reduction in the spread volatility to € 3.50 million. For 78% of simulation result the random selection of strategy has less volatility than the hedging based on fixed contracting for each delivery period.

![Figure 3](image.png)

**Figure 3.** Risk for hedged mine measured with intrinsic spread volatility with random selection of coal and energy futures
6. Stochastic modelling of intrinsic spread hedging strategy for coal mine
Based on historical time series we simulate energy and coal price and estimate new intrinsic spread for future delivery period. This spread has been hedged with futures. The time series simulation has been made in ModelRisk. Using copulas we simulate dependence between time series not linear only joint distribution of coal and energy price which can be described as marginal distribution of those commodities. The dependence structure describes type of copula and its parameters. It was assumed that the mine operator in some economic and technical conditions could be interested in spread hedging. The coal mine cash flow model based on the costs of the average coal mine and is representative for hard coal mine industry in Poland. In the economic model all prime costs (except for the depreciation) are divided into fixed and variable.

| Cost               | Value | Cost change, % | Fixed cost | Variable cost |
|--------------------|-------|----------------|------------|---------------|
| -                  | €M    |                | %          | %             |
| materials          | 23.05 | -11.3          | 15.3       | 2.0           | 75            | 25            |
| energy             | 11.71 | -5.7           | 29.3       | 11.8          | 70            | 30            |
| salaries           | 82.10 | -2.2           | 13.7       | 5.8           | 100           | 0             |
| external services  | 29.08 | -2.6           | 19.3       | 8.4           | 38            | 62            |
| taxes,             | 82.10 | 1.1            | 14.0       | 7.6           | 70            | 30            |
| other cost         | 4.78  | 8.1            | 35.8       | 21.9          | 73            | 27            |
| coal production,   | 10.23 | -5.4           | 0.2        | -2.6          | -             | -             |
| 10⁶ Mg             |       |                |            |               |               |               |

Verification of the profitability of the mine hedging was conducted for 20 month. The changes in operating costs of mine were simulated in two ways. The fixed cost in subsequent iterations resulted from the value in the previous period and the value indicated by random number generator based on a triangular distribution. The parameters of distribution have been estimated based on real data from a coal mine (tab. 3). The exception in the mine cost modelling was the energy cost because its value also depends on the energy price estimated using one of the methods creating time series. Variable costs in an economic model are dependent on changes in a variable unit cost and a production volume. Changes in a variable unit cost depend on the same random variable generator as in the case of fixed cost.

The coal mine revenue was simulated on the basis of time series ARA Index and the variable output (coal production). In this simulation we assume that the last known price for Polish coal market equals 65.0 €/Mg. In the next month coal price change was indexed based on a simulated value for the ARA Index. The coal price and the energy price were simulated using a copula function. Based on information criterion best fit to data has Clayton copula (Fig. 4). Variable 1 is represented by spot energy price and Variable 2 by spot coal price. Taking on the financial market long position contrary to the natural position i.e. for a coal mine buying coal contract and selling an energy contract when market tendency is adverse the coal mine operator can sell contract and losses on real transaction will be compensated by the profit from the futures. The results of the simulation show that there is no financial compensation in each month. In Fig. 5 an example of simulated cash flow for the next 20 month has been presented.

For 13 out of 20 months a positive or a negative profit change from the coal mine operational was reduced by the opposite profit change from the intrinsic spread hedging. In 1st, 13th, 16th, 19th and 20th month the same direction in profit or loss change has been observed.
Figure 4. Best fitted Clayton copula to coal and energy spot prices

Figure 5. Profit change vs value of contract for the mine hedged intrinsic spread

The cash flow change for 10 000 of iteration was presented in 6. As the result of the application of the internal spread hedging the average value of the cash flow volatility for a coal mine is significantly
less (dashed yellow histogram) and fell from the initial value of € 4,95 million (without hedging) to € 4,29 million. The difference in the value of cash flows is relatively small but due to finance hedging the mine operator is more certain and can plan their production effectively.

![Cash flow volatility](image)

**Figure 6.** Result of cash flow simulation for hedged and unhedged coal mine

7. **Summary**

The determined economic parameter have been calculated solely for the purpose of the coal mine hedging cost-effectiveness. Based on example on hard coal mine, the results show that the application of the hedging intrinsic spread strategy reduces the risk of cash flow volatility. It has been determined the volatility parameters for the hedged and unhedged mine. Monte Carlo simulation shows that in most cases intrinsic spread hedging was a good solution for the coal mine operator. The key issue in hedging modelling is selection of the input parameters and time series processes. Further studies may include:

- more accurate calculation of production cost and their correlation, which was not included in this research due to a small number of the analysed mine,
- impact of an exchange rate on contract prices expresses in the national currency,
- better fitting of statistical distributions taking into account the wider range of inputs historical data.

The analysis of the hedging profitability can be expanded with the production planning in the next periods, because sales volume and coal price volatility have the greatest influence on decision how to implement hedging in the mine.

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