Lignite price negotiation between opencast mine and power plant as a two-stage, two-person, cooperative, non-zero sum game

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ABSTRACT: Based on the simple model of the deposit the methodology of finding the optimal solution for bilateral monopoly (BM) of lignite mine and power plant is shown taking into account pit optimisation. It is proposed to treat lignite price negotiation as a kind of game. In the first stage (cooperative) both sides should select the ultimate pit maximising joint profits of BM and in the second one (competitive) the agreement should be achieved regarding profit division. This can be realised through side payments or by establishing the lignite transfer price. Lack of cooperation and opportunism can lead to the suboptimal solution – excavation of the smaller pit. Due to information asymmetry realisation of the optimal solution is more probably in vertically integrated firms. Dynamic adjustments of LOM BM plan to short-term changes of energy market using optimisation, BM model, game theory and their valuation as real options is the new direction of further research.

1 MODEL OF BILATERAL MONOPOLY

1.1 *Lignite deposit model and other assumptions*

Operation of bilateral monopoly (BM) of a power plant and a mine as well as the methodology of finding optimal solution will be shown on a simple example allowing on understanding of this new attitude (Jurdziak, 2006a).

On a two-dimensional model of the deposit (Fig.1) the idea of parameterisation connected with the modified solution of BM (Jurdziak 2004a,b) is presented. It is assumed that the cost o excavation of one block of overburden or lignite is constant and equals 10 monetary units per block (Mu, is a multiplier of small mu e.g 1000 times or more). Lignite has different quality described by the quality indicator having values in range 0.5–1.0. The value model of the deposit (Fig.1) shows the net value of each block, after subtracting the cost of excavation from value of lignite (Jurdziak, 2000).

It is assumed that the lignite price paid by a mine to a power plant is a product of the base price of lignite and the indicator of its quality. It is assumed
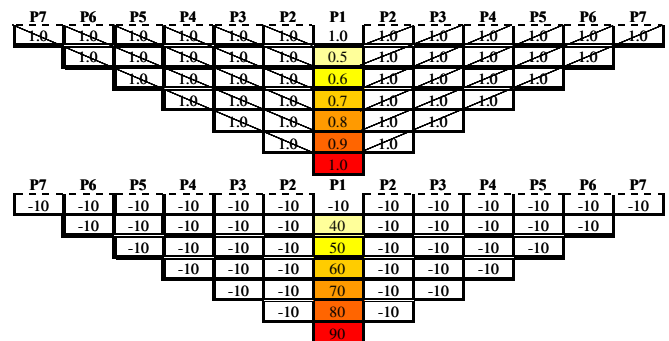

Figure 1. The lignite deposit models: quality (above) and value (below). The base price of lignite is 100 Mu/block and cost of excavation is 10 Mu/block.

that lignite with the quality indicator 1.0 has twice as much value (utility) for the power plant than those with the indicator 0.5. Lignite utility is therefore the cardinal one and can be measured as a value of electric energy generated from burned lignite lowered by all costs connected with energy production including "ecological" costs connected with removal and utilization of ballast ingredients (e.g. ashes, sulphur). A lignite utility function is an individual feature characteristic to a particular boiler in a power plant.
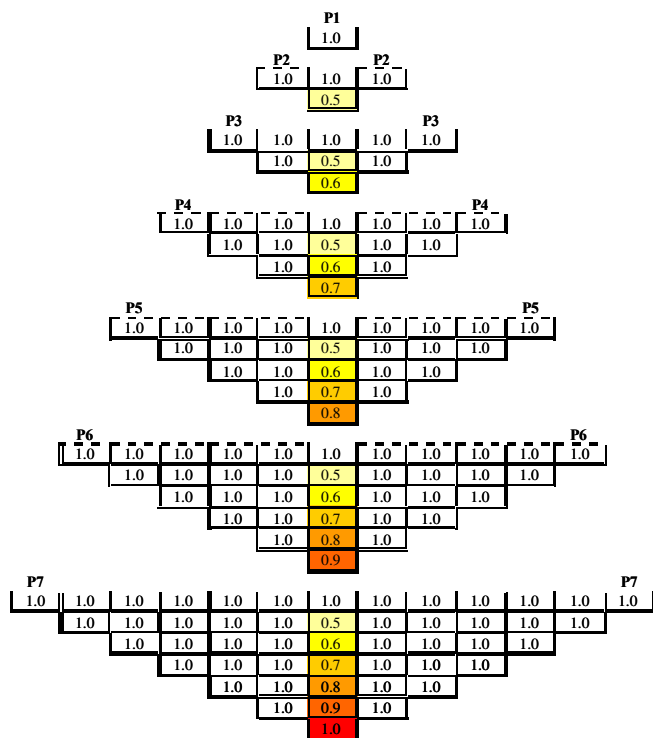
Figure 2. Nested ultimate pits P1-P7 (lignite in P2-P7).

In the model of deposit there are only 7 nested pits (P1–P7) (Fig.2) having the slope 1:1. The P7 pit is the maximum one, which contain the whole available lignite in the deposit.

In the analysis the net cash flows form nested pits are calculated and further processed. Here all and usually Lerchs-Grossmann pits generated in parameterisation process. This approach can be replaced by discounted values of excavation schedules - NPV values of optimal schedules generated (by NPVScheduler or other similar software) for different lignite prices.

1.2 Financial results of BM

For each ultimate pit we can calculate its net value – assumed mine profit from excavation of this pit (other costs are omitted) for different lignite price levels (50-170 Mu/block). Six lignite border prices have been calculated - the lowest lignite prices for which given pits have the maximum value (Tab.1). For the border price (and all prices greater up to the next border price) this pit has the maximum value. The border prices can also be calculated otherwise. It can be checked for which prices the marginal pits (MP2-MP6, Fig.3) attain positive values for the first time when price increases. It means that for the border prices it is worth to increase the pit. For example marginal pit MP3 consists of 1 block of lignite having IQ=0.6 and 4 blocks of overburden. The total cost of excavation of all blocks is 50 Mu. So it is enough to check for which base price of lignite the value of

lignite inside the marginal pit (a product of number of lignite blocks, the base price and the index of averaged quality IQ) is grater than 50 Mu. It is easy to check that for MP3 the border price is 83.(3) Mu (=50Mu/0.6).

Table 1. Description of pits and financial results of mine, power plant and bilateral monopoly.

No	Amount of lignite	Amount of overburden	Strip ratio	Border price of lignite	Averaged quality	Mine profit	Power plant profit	Point code	Joint BM profit
1	2	3	4	5	6	7	8	9	10
Lp	[block]	[block]		[Mu/block]		[Mu]	[Mu]		[Mu]
1	0	1	-	-	-	-10	-	-	-10
2	1	3	3	80	0.5	0	22.05	A	22.05
3	2	7	3.5	83.33	0.55	1.69	44.83	B	46.52
4	3	13	4.33	100	0.6	20.09	43.3	C	63.39
5	4	21	5.25	112.5	0.65	42.63	30.05	D	72.68
6	**5**	**31**	**6.2**	**122.22**	**0.7**	**67.88**	**6.5**	**E**	**74.37**
7	6	43	7.17	130	0.75	95.23	-26.75	F	68.48

1 – following numbers of nested pits P1-P7,
5 – the lowest lignite price for which the given pit has the maximum value,
7 – The net value of the pit, sum of non-discounting cash flows from the mine

$$\Pi_k = p_w q_w IQ_w - k_b(q_w + q_n) \qquad (1)$$

where: Π_k = mine profit, [Mu], p_w = base price of lignite which is optimal for the given power plant, [Mu/block], q_w = amount of lignite, [block], IQ_w = quality indicator of averaged lignite, $q_w IQ_w$ = equivalent amount of base lignite, k_b = cost of excavation of one block of overburden or lignite, [Mu/block], q_n = amount of overburden, [block].
8 – power plant profit from selling electricity generated from burning lignite contained inside the pit:

$$\Pi_e = (p_e c_1 - p_w - c_2)q_w IQ_w \qquad (2)$$

where Π_e = power plant profit, [Mu], p_e = price of electricity unit (eu), [Mu/eu], q_w = amount of lignite, [block], c_1=const amount of energy generated from one block of base lignite [eu/block], c_2=const cost of transformation of one block of base lignite into electric energy [Mu/block].
9 – description of points having two coordinates: mine profit and power plant profit for a given border lignite price (Fig.6),
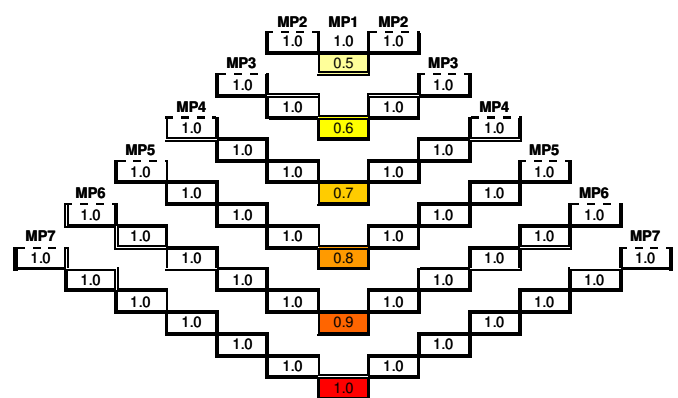10 – sum of mine and power plant profits.

Figure 3. Marginal ultimate pits MP2- MP7.

Besides value of pits (1) in Table 1 are shown also profits of power plant from processing lignite contained inside nested pits (2).

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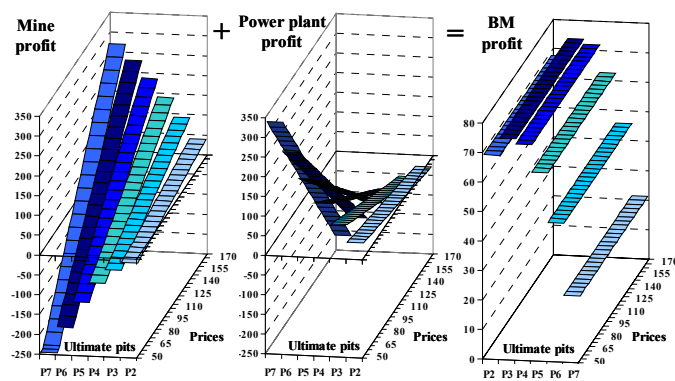
Figure 4. Profits of mine, power plant and BM.

It has been assumed that:
- the electricity price is stable and equals 0.13 mu/eu,
- effectiveness of lignite transformation into electricity is proportional to index of its quality,
- power plant costs are similar to costs in mine in order to keep approximate 50% share in costs of electricity production.

The optimal base price of lignite maximising joint profits of BM is 122.(2) Mu/block and the P6 pit is the best for the mine – it has the highest value. Joint BM profits for all prices between 122.(2) and 130 Mu/block are constant. Excavation of the P7 pit is not profitable for BM. In spite of greater mine profits (95.23 Mu) joint BM profits are smaller than for the P6 pit (Fig.4). It can be seen that joint BM profits are not lignite price varying. Improvements in financial results of BM should be therefore found in the optimal adjustment of shape and size of the ultimate pit into electricity demand (its prices) than in the prolonged negotiation of lignite prices. The lignite price decides only about profit division between both sides and do not improve joint results.

Profits for all elements of BM have been calculated for the established electricity price. It is worth therefore to check how the changes of this price influence the level of BM profits. They are presented as a consequence of pit selection and the electricity price (Fig.5). It can be seen that for different prices different pits maximise joint profits. Such analysis is important in order to realize that mine tying up to one particular design and one schedule of its development can sometimes lower joint profits. After changes of economic conditions or cost structure the optimisation process should be carried once again in order to find out if the best solution is still realised. If not the mine should adjust the ultimate pit and schedule to new situation. Such adjustment can be treated as a real option to change the scale of operation.

Such analysis can be helpful in improvement of joint results of integrating vertically firms such as BOT „Gornictwo i energetyka” S.A. - the holding of 3 power plants and 2 mines. In case of separate entities with different owners the own gains of one or both sides can be more important than joint results (Jurdziak, 2005a,b). Analysis of power game in such situations is the subject of further analysis.
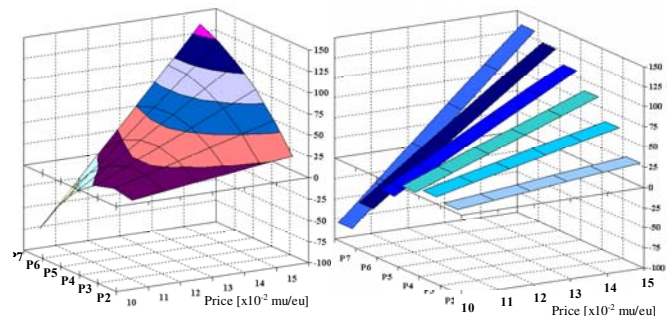

Figure 5. Financial results as a 2D function of electricity prices (0.1-0.15 mu/eu) and ultimate pits (P2-P7). Continuous approximation (left side) and discrete solution (right).

2 LIGNITE PRICE NEGOTIATION AND GAME THEORY

2.1 *Solution of BM as a positive-sum game*

Bilateral monopoly (BM) of a mine and a power plant and their mutual relation (especially negotiation of lignite supply and its prices) can be treated as a game. Both sides consider different strategies (selection the ultimate pit and lignite price) and want to maximise their utility which can be identified with financial their results.

Interests of both sides in this game are not completely opposed, due to cooperation can bring maximisation of joint profits through selection of the optimal pit based on outcomes of L-G pit optimisation, the BM model and the forecasts of demand for electricity (their prices) in long run (Jurdziak 2004a, b). The negotiation between mine and power plant can not be therefore treated as a zero-sum game. If cooperation can improve results the game has positive but variable sum.

2.2 *The polygon of acceptable payoffs*

The payoffs polygon for the mine can be constructed using data from Table 1. The method of border prices determination shows that it is profitable for the mine to excavate the given pit if the lignite price is placed between the border price calculated for this pit and the border price for the next one (bigger). The mine can excavate particular pit getting other prices for lignite – between the prices determining break even points for mine and for power plant (e.g.102.9-124.1 Mu/block for the P6 pit) still having profits. However if the lignite price

Proceedings of the 8th International Symposium Continuous Surface Mining, September 24-27th, 2006. Aachen, s. 469-476.

3

is outside the border prices interval it is better for the mine to excavate the different pit due to this brings the mine higher profits.
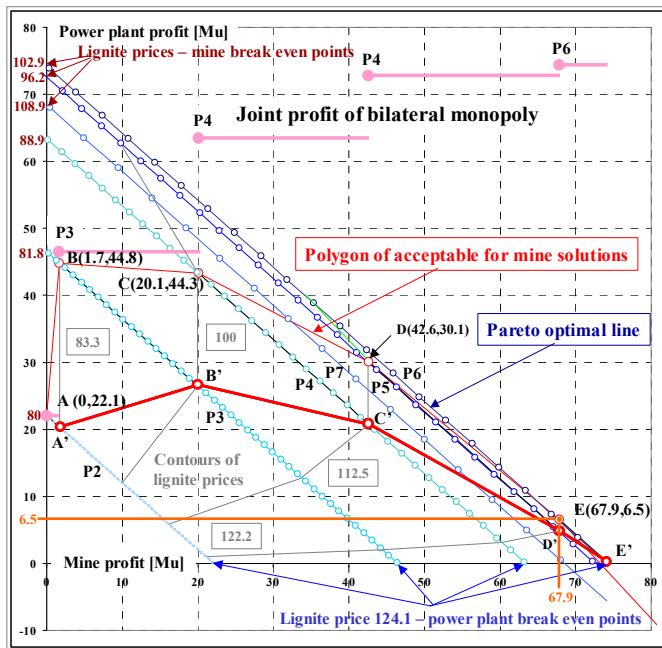

Figure 6.The polygon of acceptable by BM payoffs and lines of the stable BM profits (x+y=const) for all pits together with lignite price contours and prices of lignite determined by break even points for the mine (Y) and the power plant (X).

The sum of mine and power plant profits is constant due to joint profits of BM depends on electricity prices and selection of the pit (Fig.5) and are independent of lignite prices (Fig.4). All points corresponding to strategies of excavation of the particular pit with different lignite prices are placed on the one line x+y=const, going through the point determined by the border price for this pit.

For each lignite price the mine has the predominant strategy – the excavation of the L-G optimal pit for this price. It gives mine the highest profit. Other pits for this price gives smaller profits, so as dominated strategies should be excluded (Fig.7). On the basis of the predominant strategy the polygon of acceptable solutions for the mine can be constructed. It is an area of polygon determined by points representing payoffs in optimal strategies (points A, B, C , D, E in Tab.1) and their projections on lines lying below (points A', B', C', D', E' on Fig.6). The sum of intervals: AA', BB', CC', DD' and EE' represents predominant pure strategies.

The line lying furthest to the right (going through the point E) represents the ultimate pit which brings the highest profit to BM for the given electricity price. From the point of view of joint profit maximisation the optimal pit is P6. It gives the joint profit 74.37 Mu. The lowest lignite price, which brings the mine the biggest profit from excavation P6 pit, is 122.2 Mu/block. With lower

price, between 112.5 and 122.2 Mu/block, the mine can attain higher profits excavating the P5 pit.

Unfortunately in a two-person, positive-sum games the conflict of group rationality (maximisation of joint profit) with the individual one (maximisation of own profit) can appear. It takes place in analysed situation. Division of profit in excavation of the P6 pit is unequal. In the best case (under the lowest price 122.(2) Mu/block) the power plant attains profit 6.50 Mu and the mine 67.9 Mu (10 times greater) (Fig.6). Such unequal division can enhance on side to choose the solution, which is not optimal in Pareto sense. Individual rationality and opportunism sometimes can win. Such solution can not be acknowledge as a proper one due to only the outcome which is Pareto optimal can be accepted as the game solution (Straffin 2004).

In the analysed example only the excavation of the pit P6 is the Pareto optimal strategy (line x+y=74.37, Fig.6). This pit can be profitable excavated when lignite prices are between 102.9 Mu/block (break even point for the mine, x=0) and 124.1 Mu/block (break even point for the power plant, y=0). Due to only in a small area (122.2-124.1 Mu/block) line of the maximum BM profit covers the polygon of acceptable for mine payoffs it would be better for attaining compromise to separate the lignite price negotiation from the selection of the optimal pit and conduct negotiations in two stages.

2.3 Negotiation as cooperative, two-stages, two-person, non zero-sum game

In the first stage (strictly cooperative) based on the disclosed cost data, outcomes of parameterisation process of lignite deposit (using L-G optimisation), and forecasts of future demand for electricity (level of its future prices) both sides should select the optimal ultimate pit which maximises joint BM profits. The pit can be selected using methods described in (Jurdziak, 2004a, b) or graphically by creating the mine and power plant payoffs polygon (Fig.6). The first stage would be the two-person, non-zero sum game, which target is the selection of the optimal ultimate pit.

Only during the second stage, if the division of profit implicated by the optimal solution (here 6.5 Mu for the power plant and 67.9 Mu for the mine) is not accepted by one of BM sides, both of them can take the decision to split the profit differently. This new profit division can be realised by:

- side payments in order to eliminate too big differences in profit shares or attain other accepted division of profit or
- establishing the different lignite price (transfer price) for mutual clearing off their accounts. In such a case both the ultimate pit selection and other decisions regarding

4

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changes of pit size and shape should be done using optimal lignite price calculated for the modified BM model in order to keep economic effectiveness and rationality of decisions. The profit division using lignite transfer price requires deep cooperation and is more probably in firms vertically integrated or in holdings.

2.4 *Threat of non cooperative behaviour and opportunism*

In order to avoid negative behaviours connected with non-cooperative attitude and opportunism in this stage of the game (implicated by completely opposed interests) it is worth to build negotiation on the rational foundation and in advance decide about the fair profit division. Such division should be built in formula price contracts (Blair & Kasermann, 1987) in order to avoid frequent renegotiations after any changes of key factors having influence on the optimal solution. Frequent and repetitive negotiations increase transactional costs and the forced adoption of unfair profit division can lead to changes on other ground. One way is the cost increase of other services offered by mine to power plant (e.g. ash dumping in the pit). What can be treated as the side payments extortion in the retaliation for lowering lignite prices. Much more dangerous however is resignation by the mine from excavation of the optimal pit maximising joint BM profits in aid of excavation of the pit which maximises only own profits of the mine. The mine will definitely select the smaller pit with lower amount of lignite what shorten life of the mine and the power plant and lower the electric energy supply in long run. Not mention about lowering power plant profits what should be obvious.

The full control of the mine activity can be secured only by the full vertical integration (Jurdziak, 2005a, b).

2.5 *The predominant strategy of the mine and the asymmetry of information*

On Figure 7 the profits of the mine and the power plant are presented in slightly different form – as a function of lignite price. The predominant strategy of the mine creates the broken line from intervals of linear mine profits for particular ultimate pits. It is the continuous, monotonically increasing function in area of all accepted lignite prices from the lowest allowing on profitable excavation of the deposit (here 80 Mu/block), up to the highest price accepted by power plant – determining its break even point (here 124.1 Mu/block). The power plant profits are not continuous and are only monotonically decreasing within intervals with jumps in border prices depicted changes of the pit in the predominant strategy of the mine.

This means that the power plant can not draw its long run profit function without knowledge, which pits are profitable for the mine to be excavated for given lignite prices. The selection of the ultimate pit (its size and shape) by the optimisation program determines the amount and quality of available lignite and revenues and costs of power plant .

The mine has an information advantage over power plant – it knows the deposit and can conduct its optimisation generating a series of nested ultimate pits and price intervals for their profitable excavation. Such knowledge is not available in the power plant what worsens its position during negotiation. This asymmetry of information in condition of free market (domination criteria and individual rationality) can threaten power plant interests. The mine always increases own gains by increasing the lignite price. The power plant lowering the lignite price never knows if this increases or decreases its long run profits. For example by the decreasing of lignite price below 100 Mu/block power plant profits decreases about 15 Mu, what is the contradiction with expectations. Tendency to vertical integration of mine and power plant is therefore profoundly natural and even desired. It liquidates risk and uncertainty and gives the integrated energy producer full control over mining activity.
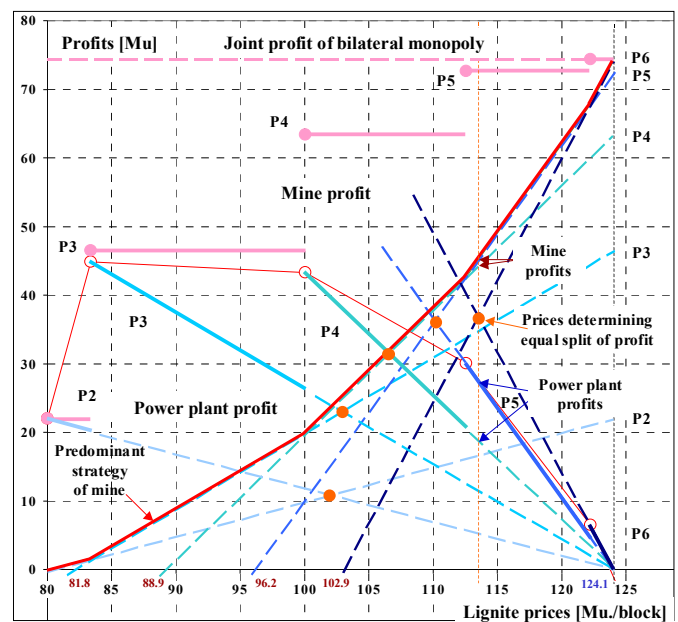

Figure 7. Profits of mine, power plant and BM as a function of lignite prices. The continuous line represents power plant profits for the predominant strategy of the mine.

3 CONCLUSIONS

Utilization of the BM model and methods of pit optimisation allows on treatment of lignite price negotiation between mine and power plant in long term contracts as the cooperative, two-stage, two person, non zero-sum game. Due to improvement

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in economic results should be found in the optimal adjustment of shape and size of the ultimate pit to electric energy demand and not in the prolonged negotiations of lignite price the game should be carried in two stages. In the first one (cooperative) both sides should select the ultimate pit maximising joint profits of the whole system. Only in the second stage (a competitive one), after a settlement is obtained regarding acceptable profit division, it can be realised through selection of a proper transfer price of lignite. So the problem of choosing appropriate transfer price would be only a technical one. It should be stressed that the agreed and accepted split of profit would determine the transfer price and not the other way round. This stage would be the positive-sum game (if the sum is constant it is identical with zero-sum game) in which the sum is equal to maximal profit Π_{Vmax}.

Analysis of this game leads to conclusion that only full vertical integration of both firms can secure realisation of optimal solution maximising joint BM profits. Existence of information asymmetry – mine predominance implicated by deposit knowledge, can in competitive attitude of both sides and concentration only on the lignite price negotiation lead to suboptimal solutions – not effective in Pareto sense. The mine for each lignite price level can choose the predominant strategy (maximising their own payoffs) relying upon selection of the optimal ultimate pit. Usually it will be a smaller pit than the pit optimal for the whole BM. This lowers the joint profits; shorten the time of lignite excavation and lower the deposit utilization rate.

Presented procedure of the optimal ultimate pit selection maximising joint BM profits can be used for the optimal mineable lignite reserves determination based on economic criteria connected both with the mine and the power plant as well as with the electric energy market.

The open matter, requiring further research, is fair profit division that is finding the solution for the second stage of the game. It seems that application of Nash bargaining solution should be helpful (Jurdziak, 2006b in press).

Another problem is the transition from long run and strategic decisions connected with selection of optimal pit into day-to-day relations of both sides operating as separate entities or within the vertically integrated energy producer (Jurdziak, 2005a, b).

It seems that the short-term solutions should be placed within LOM Plan of the BM development but simultaneously it should be adjustable to short-term electricity demand changes in order to allow on taking advantage of electricity price increases. It can be done through optimisation of short-term schedules – appropriate selection of BWE capaci-

ties on different levels and proper sequencing of excavation from different faces for optimal blending (Kawalec, 2004). Liberalization of energy markets requires more dynamic management of energy supply so more dynamic should be also management of lignite supply from mines to power plants. Now there are available software solutions which link long and short term scheduling (e.g. Mine2-4D) what should be helpful in the dynamic and optimal management of excavation. Integration of such methods with the economic model of BM operation on the basis of game theory and their valuation using real options is the new proposal for lignite mines and power plants.

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