UDC [338.48:622.012.2]-027.3-027.235

D. Yu. Cherevatskyi,
PhD (Technique)
O. I. Atabyekov,
Institute of Industrial Economics NAS of Ukraine, Donetsk

PRODUCTION FUNCTION OF A COAL MINE AND ECONOMIC EFFICIENCY OF ITS OPERATION

A gradual transition to economic priorities of the coal mining industry is observed in the economic policy of the state. If the main objective of the state program „Coal of Ukraine" (2005) was the increase in effectiveness of mines operation (mainly technical) as well as achieving the coal output needed for meeting the national economy's requirements [1], the current program of coal mining industry modernization [2, 3] declares the strive for ensuring the break-even functioning of coal mines.

With regards to ensuring the break-even functioning of coal mines the coal mining expert Peter McInally (International Mining Consultants Ltd, GB) thinks that the basis for the break-even functioning of coal mine as a whole is a break-even functioning of each coalface: income received as a result of longwalls development should cover not just the costs involved in functioning of separate production units but the costs of functioning of the coal mine on the whole. The following principle is postulated: longwall should not be developed unless it is capable of bringing profit: „if mining and sales of coal do not give profit this coal should remain underground" [4, p. 50]. At the same time the Ukrainian and Russian coal miners follow another principle: „Output brings economic results". That's why as it is considered by a famous coal mining specialist and scientist Y. P. Yashchenko „the minimum estimated annual coal mine output constitutes a starting point for ensuring the break-even operation of coal mine and achieving economic proportions of its self-development" [5, p. 10]. A capability to increase an output above the level of a minimum estimated parameter determines the investment attractiveness of a coal mining enterprise [6]. The same concept is described in the work [7]. The record of coal mining costs by faces which Peter McInally considers to be necessary is not being kept at all. It is done only for the coal mine as a whole.

The principles of managing the efficiency by governing the work inputs were first described by the economists of Lausanne school which is also called the mathematical school. Marginalists – followers of L. Walras, among whom were Pareto, Edgeworth and the others, described it in details on the model of Robinson Crusoe's economy [8; 9, ch. 29]. To maximize the profit, labor inputs should be correlated with the production capabilities of the company and prices actual at the markets of useful product and resources used for its production. A governing as it is, is a very delicate process allowing the fluctuations in capital assets utilization.

Neither P. McInally nor the Ukrainian economists make a clear accent on this and they do not study how coal mine characteristics change depending on various modes of its operation. That's why this work represents an attempt to study how the efficiency of coal mining depends on the characteristics of a coal mine and fluctuations of coal/ resource prices.

There is a notion of Robinson Crusoe's economy in the microeconomic theory – one producer, one consumer and two commodities (format „1x1x2"). The idea of this nominal model was evoked by the history from a famous D. Defoe's work. While residing on uninhabited island one man (Robinson) acts in the capacity of a producer and a consumer of products at the same time.

By means of labor input he produces useful product, yams, for his own consumption as is described by Daniel McFadden [8]. The second product is leisure – his spare time. Let's denote the first product as x_2, as it is described in [10], then second product (x_1) is the difference

$$x_1 = L - z \tag{1}$$

where L – time – factor which forms a constituent part of commodity cluster;

z – working time spent on production of commodity x_2.

Production function *f(z)* inherent to the company – is a numerical correlation between an output (produced commodities) q and resource input (labour time) z. The production function reflects the fact that the more time Robinson spends working the more yams he obtains. Although the amount of useful marginal product which Robinson obtains by investing a marginal labour hour is decreasing. This statement corresponds to neoclassical economics' concept of diminishing return or increasing marginal costs.

It is supposed that production activity results in a profit

$$p = pf(z) - wz \tag{2}$$

where π – company's profit;

p – price of useful product;

w – price of resource.

The main company's task is profit maximization.

The most effective volume of production depends on price ratio (*p/w*) as on a parameter.

$$p \;\; \mathbf{a} \;\; \max; z^* = \arg\max p\,(z,\, p) = z^* \qquad (3)$$

Customer's preferences (for instance Robinson's) characterize functions of utility which depend on $u(x_1$, $x_2)$ – curves of indifference.

The more Robinson gets the yield, the more he has the food, but the less time is left "to improve his suntan". This is the reason why the customer's task consists in welfare maximization

$$u(x_1, x_2) \;\; \mathbf{a} \;\; \max; px_2 \le w(L - x_1) + p\,(p, w) \quad (4)$$

Entire satisfaction in maximum criteria is reached when Robinson works and consumes in the state of balance and the curve of operation set *f(z)* correlates with the assemblage of indifference curves (fig. 1).

In this very case the most preferred combination of labor and consumption is achieved if this particular technology is used.

Thus the ratio between the commodity price and the price of resources used for its' production determines the most effective output.

If we denote the mined coal as a variable x_2, then the second commodity which is an analog of leisure time can be denoted as „saving" which is a provisional commodity produced by the coal mine during the idle operation. It is not occasional that we used the term „idle operation" instead of „an interval in production activity" since coal mine is in operation even in the periods when it does not mine coal – coal mining production requires continuous ventilation and extraction of ground waters.

If the notion of „leisure" in the economy of Robinson is a time which is not spent for production (fixed duration of the day minus *z*), then in case of a coal mine the quantity x_1, the „savings" is a difference between the inputs of resources when a mine operates at its maximum production capacity and costs corresponding to the actual quantity of mined coal. When the capital assets of a coal mine are fully utilized the volume of the „savings" is equal to zero and vise versa – coal mine which does not produce a mineral produces just „savings".

Unlike the Robinson's economy, the inputs of resources at the coal mine are not limited to labor input only. These are combined inputs of labor, energy resources, materials, etc. It is impossible to make a graphic embodiment of all this diversity.

To have an idea of a production function of a coal mine it is acceptable to use the technique similar to the method of indirect assessment of a cost of an enterprise by the profit it makes. The company has the level of capitalization equal to the banking capital bringing the same profit at a fixed loan interest. In the similar way we can determine the operating costs – it can be considered that they are determined by some multi resource equivalent (MRE). We'll continue to denote it as z. It contains labor inputs, cost of electricity, thermal energy, material costs, etc. In such case the price of MRE will be denoted as *w*.

The individual input of MRE (*z*=1) corresponds to the specific coal output (equal to production capacity of a coal mine *s*=1)

$$s = \frac{q}{P} \qquad (5)$$

$$r = \frac{z}{z_P} \qquad (6)$$

where *s* – extent of a mine production capacity utilization, fractions of one;

q – annual coal output, thousand tons;

P – production capacity of a mine, thousand tons;

r – specific consumption of multi resource equivalent MRE (relative to the volume of MRE when coal mine production capacity is utilized in full), fractions of one;

z_P – consumption of MRE when production capacity of mine is used in full, conventional units.

The ratio (7) reflects the specific character of coal mine production function.

$$z \le z_0; q = 0 \qquad (7)$$

Where z_0 – MRE input which does not depend on the volume of production (its invariable part).

In principle the production function of a mine could be determined empirically. The production activity of many enterprises is notable for the periods of rise and decline which differ by their economic characteristics. Thus a long-term observation can in principle give an idea of the ratio between the coal mine volume of production and a prime cost of coal. But the real picture is more complicated. The graph shown as an example on fig. 2 reflects the dynamics of industrial and economic performance of coal mine „Trudovskaya" during 2000 – 2006.

Overlaying of two processes: of the price rise and changes in coal output gives paradoxical results: coal production of 881 thousand tons in 2004 costs less than the coal production of 517 tons in 2006 – 115 and 128 million hryvnas respectively.

If we admit that the production function of a coal mine is represented by logarithmic dependence:

$$s = K \cdot Ln(r) + 1, \qquad (8)$$

where *K* – a regression coefficient,

then any value *s* is corresponded to some value *r*

$$r = e^{(s-1)/K} \qquad (9)$$

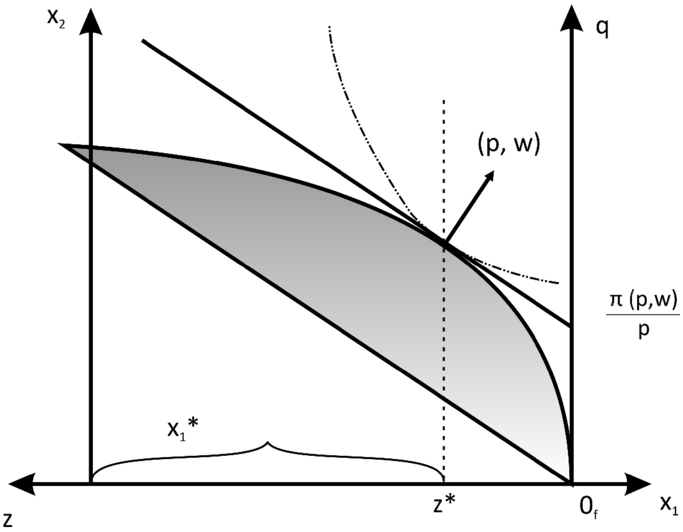

Fig. 1. The equilibrium in Robinson Crusoe's economy

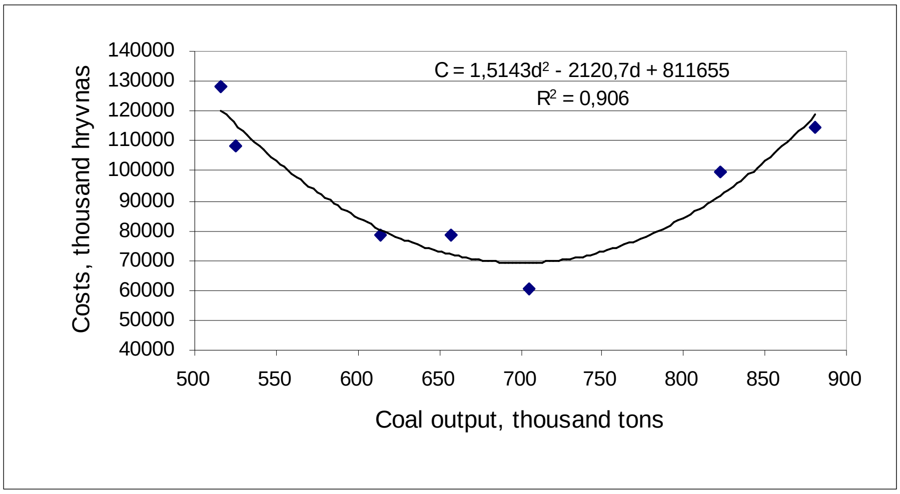

Fig. 2. Costs and coal output ratio at the coal mine „Trudovskaya".

where *e* – is a natural logarithm base (approximately 2,71).

Thus coal production costs depend on production capacity utilization, the value of alternative *w*, which changes in the course of time and a coefficient *K* which reflects the specific characteristics of the coal mine. In the other words coal production costs depend on the constant MRE input.

Since in this work we do the relative estimation of MRE input, a corresponding value z_p reflects the price of MRE unit in the year *t*.

$$w_t = \frac{C_t}{r_t} \quad (10)$$

where w_t – is the total cost of MRE during the year *t*, thousand hryvnas;

C_t – the annual coal mine costs year *t*, thousand hryvnas;

r_t – total MRE input during the year *t*, fractions of one.

On the other hand the variable C_t depends also on the degree of production capacity utilization

$$C_t = K_1 \cdot Ln(s) + C_{1t} \quad (11)$$

where K_1 – regression coefficient;

C_{1t} – fixed term of regression dependency.

When the enterprise operates at full swing (when *s*=1), the absolute term of regression model becomes the index of specific output costs for the particular coal mine. So in order to „calibrate" the model (8), we need data on the extent of coal mine estimated capacity utilization and net cost of production during two years *t* and *t+1* having not much difference in resource prices. These two years should at the same time have a positive dynamics of coal production.

It is suitable to calculate value $C_{1(t+1)}$ by the diagram made with the help of MS Excel program shell – we should make a graph and seek logarithmic function trend line. The target value r_{t+1} is calculated from the following ratio:

$$r_{t+1} = \frac{C_{t+1}}{C_{1(t+1)}} \qquad (12)$$

The value *K* of the equation (8) is made more exact with the help of „Solution search" module of Ms Excel program shell. If *K* value is calculated correctly then specific value of MRE consumption for the year *t+1* will be equal to r_{t+1}.

As an example let's look into the characteristics dynamics of the Donetsk based academician A.A. Skochinsky coal mine which has an estimated capacity of 1800 thousand tons per year (table 1).

The above data prove how much the price fluctuations affect the efficiency of coal mine functioning. Though the production output was less in 2005 than in 2000, the coal mine received profit of 36 mln. hryvnas in 2005 whereas it was loss-making (losses of 13 mln. hryvnas) in 2000.

The estimated indexes are given in the table 2.

As a result of regression model calibration (selection of regression model terms in such a way that the condition r_{2001}=0.269 is met), the value of regression coefficient *K* is admitted to be equal to 0,500 for A.A. Skochinsky coal mine, which corresponds to zero specific consumption of MRE which in its turn is equal to 0,136 (fig. 3).

Data obtained with the help of "Solution search" module show that the 69% coal mine production capacity utilization is optimal for the price situation of 2006 (ratio between the costs and coal output value at full capacity operation of coal mine equal to 0,925). In these conditions the profit reaches its maximum and constitutes 19% relative to product value at the rated mine capacity.

Dependence of mine profit from the degree of production capacity utilization at various price ratios is given in fig. 4.

At product price to resource price ratio which existed in 2000, the coal mine is loss making and cannot bring profit under any conditions. As to the year 2006 there are operation „risk zones" determined by low capital assets utilization. The coal mine can operate profitably at s>0.181.

But „A. A. Skochinsky" coal mine though having hard operating conditions is not the worst example of coal mining enterprise.

Fig. 5 shows operating characteristics of 3 coal mines developing high dip coal seams. These are coal mines „Olkhovatskaya", „Bulavinskaya" and „Uglegorskaya". They have estimated capacity of 450, 490 and 750 thousand tons per year respectively. All of them are parts of a state-owned enterprise „Ordzhonikidzeugol" (Yenakiyevo).

Their inherent regression coefficients (*K*) are arranged in an ascending order from 0,915 („Olkhovatskaya" mine) up to 1,549 („Uglegorskaya" mine). In the other words, at „Uglegorskaya" mine more than 50% of MRE input is not used for coal production but for keeping coal mine in operating state, i.e. ventilation of mine workings, air compression, water pumping, mine surface complex maintenance, etc.

When describing the characteristics of function graphs, the economists use the term „flexibility": the less inclined the line is the less flexible it is. The horizontal line (nonelastic at all) shows the complete indifference of function to changes of the argument. And vice versa the vertical characteristic is completely elastic. Of the three coal mines under scrutiny, „Olhovatskaya" coal mine has the most inflexible characteristic *s*(*r*), and „Uglegorskaya" mine has the most flexible one.

Let's assume that the *w/p* ratio for all three mines is 0,8 and any changes in the conditions of optimum depend solely on the changes of K values (Table 3).

The more flexible the production function of a coal mine is, the more it should be „loaded" to maximize the profit. It is evident that as far as the stated criteria is concerned, optimal production load for „Olhovskaya" mine exceeds its' production capacity parameters. As to „Bulavinskaya" and „Uglegorskaya" mines it can not be achieved at all. To achieve at least a break-even operation at „Olhovatskaya" mine, the degree of estimated capacity utilization should not be less than 0,43 (140 thousand tons per year). At „Uglegorskaya" mine this parameter should be higher than 0,63 (470 thousand tons).

None of the above mines achieved such parameters in the 21st century. The highest coal output (0,39) was registered at „Bulavinskaya" coal mine in 2002. But even then it was far behind the required level of breakeven parameter (even though the price ratio (0,8) was quite favorable during that period). Production capacity utilization was around 0,2 at „Olhovskaya" and „Uglegorskaya" coal mines in the most favorable years of the analyzed period. It is clear that all analyzed coal mining enterprises are irreversibly loss-making.

It is worth mentioning that in the 1970th coal mines of the Central Donbass were economically stable enterprises which utilized their capital assets almost completely.

Untimely and insufficient capital investments, manpower shortages (at mines with steep dip seams coal is mined mostly manually) led to degradation of coal production at them. Crisis of coal mining enterprises could be avoided if the correlation between a production function and a profitability was taken into consideration and a competent investment policy was pursued: the more flexible the production function of the coal mine is the more attention and financial support such coal mine deserves. On the contrary the coal mines having inflexible

Table 1

Industrial and economic indexes of A. A. Skochinsky coal mine.

Year	Coal output, thousand tons	Commercial output, thousand tons	Commercial output value, thousand hryvnas	Commercial output costs, thousand hryvnas	Profit, thousand hryvnas
2000	554	523	44091	56654	-12563
2001	616	531	59683	76835	-17152
2002	349	313	33157	55068	--21911
2003	714	674	69058	97024	-27966
2004	962	831	129073	146021	-16948
2005	531	529	155950	119884	36066
2006	564	554	157740	141445	16295

Table 2

The estimated indexes of the coal mine functioning

Year	Extent of coal mine estimated capacity utilization, fractions of one	Multi resource equivalent input, fractions of one	Commercial output value at full capacity operation of the coal mine, thousand hryvnas	Production costs at full capacity operation of the coal mine, thousand hryvnas	Production costs and commercial output value ratio at full capacity operation of coal mine, fractions of one	Profit and commercial output value ratio at full capacity operation of coal mine, fractions of one
2000	0,308	0,251	143334	225318	1,572	-0,088
2001	0,342	0,269	174370	285172	1,653	-0,098
2002	0,194	0,200	170863	274661	1,607	-0,128
2003	0,396	0,300	174218	323273	1,856	-0,161
2004	0,534	0,395	241509	369452	1,530	-0,070
2005	0,295	0,245	528901	489071	0,925	0,068
2006	0,313	0,254	503426	556159	1,105	0,032

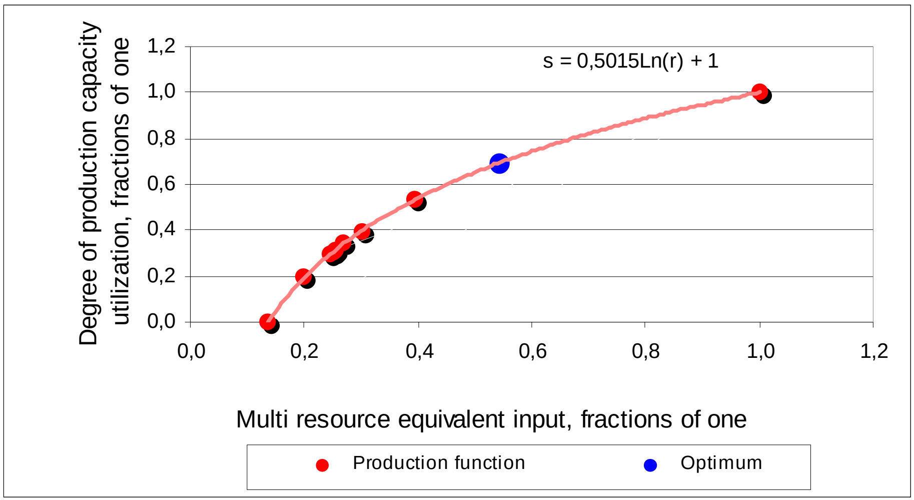

Fig. 3. Production function of A. A. Skochinsky mine

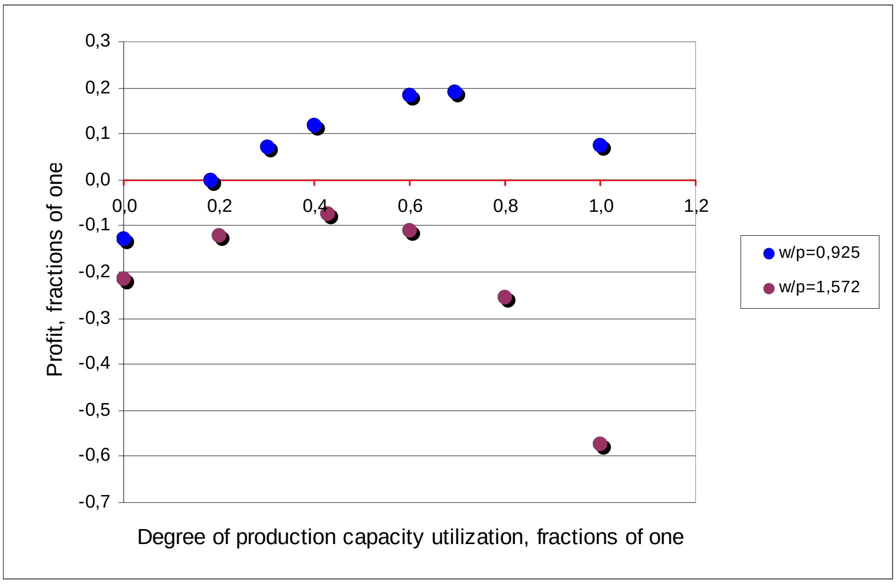

Fig. 4. Dependence of profit from coal output at price ratios of 2000 and 2006 at „A. A. Skochinsky" coal mine

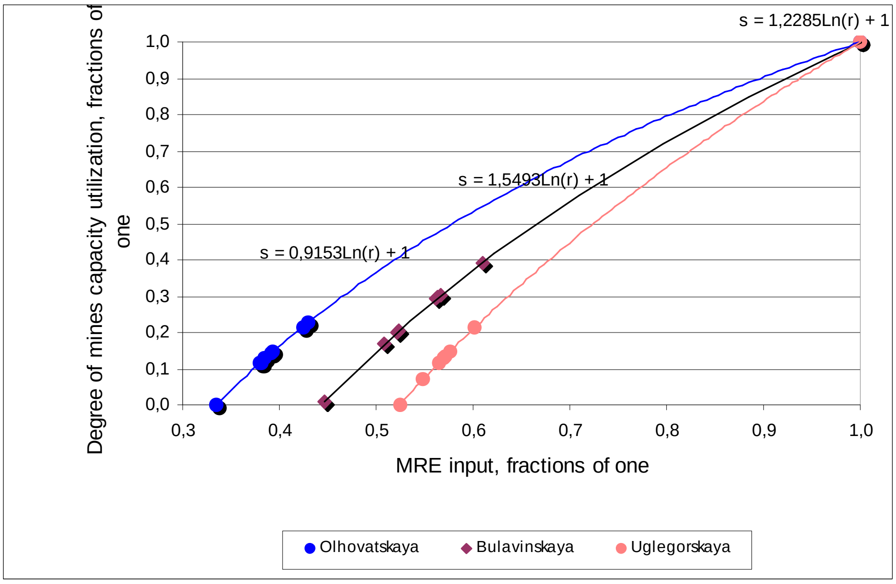

Fig. 5. Operating characteristics of SE „Ordzhonikidzeugol" coal mines

Table 3

Characteristics of production load of coal mines

Coal mine	*K value*	Optimum production load value ((s_{opt}))	Production load at break even operation (zero profit)
"Olhovatskaya"	0,915	1,126	0,430
"Bulavinskaya"	1,229	1,533	0,560
"Uglegorskaya"	1,543	2,021	0,630

characteristics may require imposing production load limit to maximize profit.

To prove the made conclusions it is reasonable to give the following actual data. Due to the state of the market the US based coal mining company „Walter Energy" took a decision to reduce the coal production at its less profitable coal mine „Maple" at Western Virginia by 35% (the prices of coking coal constituted 220 USD per ton in the I quarter of 2012 which was the decrease of 10% compared to the prices of the IV quarter of 2011. Prices of dust coal constituted 180 USD per ton in the I quarter of 2012 which was the decrease of 15% compared to the prices of the IV quarter of 2011). The coal mine „Maple" produces about 60 thousand tons of coal per month and has around 230 workers on its' payroll. At this coal mine the reduction in production is planned to be effected at the expense of working hours reduction by 10 days per month [1]. This is the procedure to be followed if we act as per Lausanne school model.

Thus the interrelations between the production function of a coal mine and its economic characteristics were studied in this article. The notion of production function elasticity is used. It is shown that the more flexible the characteristic of the coal mine is the higher extent of production capacity utilization it requires.

References

1. **Програма** „Українське вугілля": Затверджено постановою Кабінету міністрів від 19 вересня 2001 р. №1205.– Київ, 2001.– 66 с. 2. **Програма** економічних реформ України на 2010 – 2014 рр. [Електронний ресурс].– Режим доступу : http://www.dt.ua/2000/2020/69596 3. **План-графік** реформ. Напрямок „Реформа вугільної галузі": Схвалено наказом Мінвуглепрому від 22.07.2010 р. №270 [Електронний ресурс]. – Режим доступу : http://www.mvp.gov.ua/mvp/control/uk/publish/category?cat_id=83903. 4. **Макиналли П.** Как сделать российские шахты рентабельными / П. Макиналли // Уголь.– 1999.– № 9.– С. 46 – 50. 5. **Ященко Ю. П.** Достижение экономических пропорций расширенного воспроизводства на действующих шахтах Донбасса / Ю. П. Ященко // Уголь Украины.– 2011.– № 9.– С. 6 – 11. 6. **Ященко Ю. П.** Критерии инвестиционной привлекательности и оценка инвестиционной емкости развития угольных шахт / Ю. П. Ященко // Уголь Украины.– 2011.– № 11.– С. 11 – 18. 7. **Кравченко А. А.** Анализ себестоимости готовой продукции шахт Донбасса / А. А. Кравченко, Л. Н. Вертельная, Е. А. Думанская // Уголь Украины. – 2011.– № 6.– С. 8 – 12. 8. **McFadden D.** Robinson Crusoe meets Walras and Keynes / Daniel McFadden.– Berkley : Department of Economics, University of California, 1975. – 21 с. 9. **Вэриан Х. Р.** Микроэкономика. Промежуточный уровень: Соврем. подход : [Учеб. для вузов по экон. специальностям] / Хэл Р. – Вариан.– М. : Изд. об-ние „ЮНИТИ", 1997. – 767 с. 10. **Сонин К.** Микроэкономика: Теория общего равновесия [Электронный ресурс].– Режим доступа : http://pages.nes.ru/ksonin/Lecture%20Micro%20GE%201.pdf 11. **„Walter Energy Inc."** ожидает неутешительных результатов I кв. 2012 г., несмотря на увеличение производства угля // Уголь.– 2012.– № 6.– С. 92.

Череватський Д. Ю., Атабєков О. І. Виробнича функція й рентабельність роботи шахти

Роботу присвячено пошуку залежності рентабельності видобування вугілля від властивостей шахти і кон'юнктури цін на вугільну продукцію й ресурси. Дослідження виконано із залученням теорії економіки Робінзона Крузо – один виробник, один споживач і два товари (формат „$1\times1\times2$") – і ретроспективних даних реально існуючих шахт. Установлено, що економічна ефективність функціонування підприємств залежить від еластичності виробничих функцій, що їм властиві.

Ключові слова: шахта, рентабельність, виробнича функція, економіка Робінзона Крузо.

Череватский Д. Ю., Атабеков О. И. Производственная функция и рентабельность работы шахты

Работа посвящена поиску зависимости рентабельности добычи угля от свойств шахты и конъюнктуры цен на угольную продукцию и ресурсы. Исследования выполнены с привлечением теории экономики Робинзона Крузо – один производитель, один потребитель и два товара (формат „$1\times1\times2$") и ретроспективных данных реально существующих шахт. Установлено, что экономическая эффективность функционирования предприятий зависит от эластичности производственных функций, которые им свойственны.

Ключевые слова: шахта, рентабельность, производственная функция, экономика Робинзона Крузо.

Cherevatskyi D. Yu., Atabyekov O. I. Production Function of a Coal Mine and Economic Efficiency of Its Operation

This work represents an attempt to study how the efficiency of coal mining depends on the characteristics of a coal mine and fluctuations of coal/ resource prices. A theory of Robinson Crusoe's economy – one producer, one consumer and two commodities (format „$1\times1\times2$") as well as a history record of currently functioning coal mines were used when doing this research. It was determined that the economic efficiency of mining enterprises operation depends on the flexibility of their inherent production functions.

Key words: mine, economic efficiency, production function, Robinson Crusoe's economy.

Received by the editors: 10.09.2012
and final form 20.11.2012