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INDUSTRIAL INTEGRATED STRUCTURES AS ROBINSON CRUSOE ECONOMIES

A model, formulated by the Lausanne school of economics in the 30s of the XX century and known as the economy of Robinson Crusoe, forms a compulsory course in microeconomics at various universities of the world. Though it basically corresponds to the pattern of vertically-integrated system, it was undervalued by the industrialists.

Keeping in mind that when the economy of Robinson Crusoe is in a state of equilibrium, a graph of the consumer indifference curve touches a graph of the manufacturer's production function in the point, which reflects the maximum of company profit, the analysis of operating efficiency of the system on the whole can be carried out by studying the operating mode of the producer of good only.

To adapt the classical model of Robinson Crusoe economy to the modern conditions of company operation it was offered to use a single-factor production function with an argument in the form of multi-resource equivalent (MRE), which is a hypothetic resource, combining the inputs of labour, electrical energy, fuel, materials, etc. and having the entire cost, which is equal to the entire company expenses.

Based on the analysis of profit fluctuations of coal mining enterprises (coal mines), which have various production characteristics and operate in various market conditions, a conclusion is drawn that the worse the operating conditions of the coal mine are the more intensive its production load should be to make it more cost-effective. At the same time, coal mines, working in favourable operating conditions, need to limit their production load.

It is worth to use the developed methodology to analyze and substantiate the methods of improving the operation of vertically-integrated systems in the sphere of coal washing, coke chemistry, metallurgy, power engineering and other branches of industry. At the same time, its introduction into practice requires further study of company production functions.

Keywords: Robinson Crusoe economy, integrated structures, industry, model, the Lausanne school.

JEL codes: D5.

Vertical integration is an essential factor, if not a cornerstone, in the industrial development. Ronald Coase (Ronald Harry Coase) called vertical integration the basic structural characteristic of industry [1, p. 388]. The importance and universal character of this notion was noted in his time by Bengt Karlof: 'Advanced vertical integration is a problem that troubles Mikhail Gorbachev in Kremlin as much as Directors of General Motors in Detroit' [2, p. 110]. In the planned economy the structure of industry was based on the branch principle, inter-branch enterprises were scarce. In the post-Soviet Ukraine inter-branch industrial groups started coming into being in the period of L. Kuchma presidency [3]. They remain indispensable of today's industry.

The notion about vertical integration was changing in the course of the historical

development. For Rudolf Hilferding, the 19th century economist, it was a link between industrialists and traders, who increased their trading profit at the expense of the production profit of industrial enterprises [4, p. 246]. The Japanese Power energy company J-Power is an example of vertically-integrated fuel-and-power corporation which annually delivers about 8 mln tons of coal, extracted at open-cast mines of their Australian branch company Idemitsu Australia Resource, for the use at their power stations, situated in the Japanese islands.

"Integrated corporate body", "bound and diversified system", "interglomerate", "integrated business group" are the synonymous terms, united by the feature, common to all of them. This is an interaction of enterprises in production, sales and consumption of the same final product.

Vertical integration as a theoretical discipline attracts attention of researchers, representing different scientific schools: neoclassical, institutional, dynamic comparative advantage school, corporate finance school, etc. At the same time, there are some aspects, integral character of which lacked everybody's attention. This is the Robinson Crusoe economy, developed by the marginalists of the Lausanne school (a mathematical school). Léon Walras (Marie-Ésprit-Léon Walras) and Vilfredo Pareto alongwith the English marginalists William Jevons (William Stanley Jevons) and Francis Edgeworth (Francis Ysidro Edgeworth) initiated the introduction of mathematical methods into economics. The other distinctive feature of the Lausanne school was an express mechanistic approach: they showed the economy in a state of equilibrium like a sort of a mechanism.

A Robinson Crusoe economy, also called "one manufacturer, one consumer and two commodities" (1x1x2), is a mandatory section of microeconomics course in all leading universities of the world. But neither world famous Californian scientists Hal R. Varian [5] and a Nobel Prize winner Daniel McFadden [6], nor Jeffrey Miron from Harvard and Yossi Spiegel from Tel Aviv make it clear what is the link between theoretical conclusions based on ideas of Léon Walras and modern practical knowledge.

The same is understood from the very title of the famous Russian economist A. Nekipelov's monograph – "Foundation and functioning of economic institutions: from Robinson Crusoe to market economy, based on the individual production": mathematical apparatus is getting more and more elaborated, but *per se* it remains the very same combination of coconuts and leisure [7, pp. 32-64].

This predetermined *the purpose of this paper*: to demonstrate the essence and functioning details of vertically-integrated corporations as Robinson Crusoe economies and to substantiate the possibility of using the model to estimate the optimum operation mode of integrated production systems and to evaluate the efficiency of investment projects, involved in their development process.

The Lausanne model's legend has it that one and the same person – Robinson Crusoe – acts as a producer and a consumer of the product. By labour inputs he produces a useful product – grows yams for his own consumption as described by D. McFadden or harvests coconuts as described by Hal R. Varian, which makes no difference as far as the model is concerned.

Suppose in this case coconuts act as the first commodity. The second commodity is leisure, i.e. Robinson Crusoe's spare time. If we denote the first commodity as x_2, then the second commodity (x_1) is equal to the difference

$$x_1 = L - z \qquad (1)$$

where L – is a time (factor, which is a constituent part of a commodity cluster);

z – working time, spent on production of commodity x_2.

Production function $f(z)$, inherent to the company, – is a numerical correlation

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between an output (produced commodities) q and resource input (labour time) z. The production function reflects the fact that the more time Robinson Crusoe spends working, the more coconuts he obtains. At the same time, amount of useful marginal product, which Robinson Crusoe obtains by investing a marginal labour hour, is decreasing. This statement corresponds to neoclassical economics' concept of diminishing return or increasing marginal costs.

A company is a price-taker by definition (i.e. it sells its products at prices, which are formed by forces that are not under the influence of the company): price of a commodity is denoted as p, a labour price – w.

It is supposed, that production activity results in accumulation of profit π:

$$\pi = pf(z) - wz \qquad (2)$$

where π – is a profit of a company.

The main goal of a company – obtaining a maximum profit – can be denoted in the following way:

$$\pi = pf(z) - wz \mapsto \max_{z \geq 0}, \qquad (3)$$

In this case an optimal output depends on the following parameter – a price ratio between the commodity and the resources:

$$z^* = \arg\max_{z} \pi(z, p) = z^*(p). \qquad (4)$$

Robinson Crusoe's preferences as a customer are characterized by function of utility $u(x_1, x_2)$, having the form of indifference curves.

The bigger crop Robinson Crusoe harvests, the more food he will get and less time will left, as Hal R.Varian indicated, "to improve his suntan". Due to this, the goal of a consumer is to achieve a maximum welfare standard:

$$u(x_1, x_2) \mapsto \max; px_2 \leq w(L - x_1) + \pi(p, w). \qquad (5)$$

Complete satisfaction by maximum criteria is obtained when Robinson Crusoe works and consumes in the state of equilibrium, which can be shown in the following way: the curve of operation set $f(z)$ correlates with one of the indifference curves' assemblage.

At this very point the most preferred combination of labour and consumption is achieved if this particular technology is used. And in this case the Pareto-efficiency is achieved, which means that welfare improvement of one person is impossible without detrimental effect to another person.

The process of achieving an optimum or efficiency by Pareto means finding the point at which an inclination of indifference curve is equal to the inclination of production function (as per the standard postulate on convexity of curves). If situation cannot be described as Pareto-efficiency, then curves will intercept, which means that there is another point, more preferable than this one, and one of the parties can improve its welfare without deteriorating the situation of another party. If the marginal product exceeds the marginal substitution rate then refusing from some leisure in order to get additional coconuts will bring advantage to Robinson Crusoe. If the marginal product is less than a marginal substitution rate, Robinson Crusoe will benefit more if he works less.

Thus, Robinson Crusoe economy has some patterns, defining the optimum mode of system's production functioning, which includes a consumer and a manufacturer of some good.

The fact, that optimal point by Pareto is the same for a manufacturer and for a consumer of goods, allows defining the abovementioned optimum by finding the highest profit conditions for a company. As they say: "What is good for General Motors is good for America". And it is much easier to determine the way, how to achieve the highest profit for the company than to evaluate preferences of a consumer.

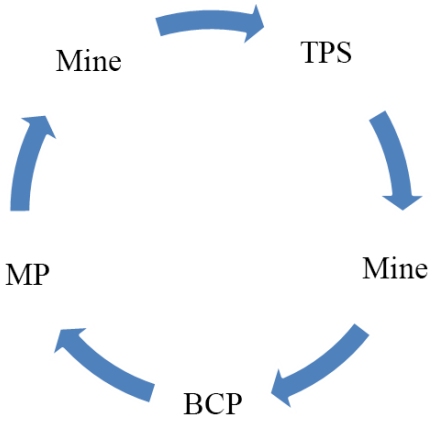
Thus, the task of system's optimization may be limited to constructing a production function of a company and determining its highest profit in the conditions when prices of a final product and the resource inputs, used for its production, are not stable.

A book under the title of "Robinson Crusoe's Economic Man: A Construction and deconstruction" interprets the Lausanne school Robinson Crusoe adventures as a sort of schizophrenia as the criticists considered him a person with a split mind, who urged to improve his personal welfare to the maximum in both categories of a consumer and a manufacturer [8].

But the degree of schizophrenia may increase, if we try to bring the model nearer to the modern industry. Lack of attention to the Robinson Crusoe economy from the part of modern industrialists is caused not just by its basically demo character, its deliberately chosen title and a presence of two specific commodities, such as coconuts and leisure. The model itself is very complex and hard for proper identification.

Suppose Robinson Crusoe discovered coal deposits on his island and started excavating fuel for the use at his farm instead of harvesting coconuts. This is another format of Lausanne model: he himself produces a fuel resource as a good and he himself consumes it. At the same time, he has some leisure in the form of his free time, i.e. the period when he is not excavating coal.

But the modern technology of excavating the fossils is far more progressive than mining of coal with a pick. A modern coal mine uses electric and thermal energy, generated from coal, it requires metal to hold the roof of mine headings and make tools. In the meantime, metal is also an embodiment of coal in the form of coke and electric power. The complexity of this interaction is shown on the diagram on Figure 1 as an interaction "Electric power station – Thermal power station (TPS), by-product coke plant (BCP) – metallurgical plant (MP)".



Source: compiled by the authors.

Fig. 1. Integrated system of coal mining and coal processing

Using electric power as a resource, Robinson Crusoe as a miner excavates coal and delivers it to the consumer, Robinson Crusoe as a power engineer. The abovementioned is not just an economy of "1x1x2" but a clearly defined vertical integration scheme. Even if a holding is not formalized institutionally the communication between the enterprises is rather strong. According to our assessments, the efficiency of energy enterprise affects greatly the efficiency of a coal mining enterprise: even a narrow-range fluctuation in specific consumption of solid fuel at the thermal power station can result in increase of EROI index[1] in national industry from 8 to 10:1.

[1] EROI – energy return on investment. EROI is a ratio of generated energy to consumed one, energy profitability.

For comparison: this index in the US coal mining industry constitutes 80:1 (data as of 1990), an average worldwide index is 46:1 [9].

On the other hand, Robinson Crusoe as an energy engineer generates electrical power using coal as a fuel source and then delivers it to the consumer, Robinson Crusoe as a coal miner. This scheme also corresponds to the Lausanne model and forms an embodiment of vertical integration.

Examples, indicated above, can be extended to a metallurgical branch as well.

The Ukrainian business group System Capital Management (SCM) in addition to coal-energy division (DTEK) and coal metallurgical division Metinvest owns a coal machine building division (Corum Group) as well. The latter supplies machines and equipment for mechanization of coal mining processes and consumes electricity and metal on a large scale.

A number of schemes and the complexity of classification increases since the other group of enterprises, called horizontally-integrated, should also be referred to Robinson Crusoe's economy. An example of such enterprises is the Pavlogradugol – company, which is a part of DTEK group. Production units (coal mines), forming this company, are not directly involved in the sales of their products. They have no market entry and delegate these functions to the parent company.

Such isolation of economic space is an inherent feature of not only a majority of the national companies, but the corporations of the countries with advanced market economies. The same operating pattern is used by the private company DTEK Pavlogradugol, state-owned enterprise Krasnoarmeyskugol (both are from Ukraine) and the American coal mining company Walter Energy, etc. There is Robinson Crusoe, who produces and the one who accepts the products – this is a pattern of vertical integration of industrialists and traders by Hilferding.

Fragment of vertically-integrated company DTEK is represented by a horizontally-integrated Pavlogradugol (10 mines) on the lower level of technological chain and a horizontally-integrated power-generating company Vostokenergo (3 thermal power plants) on the upper level of technological chain. Neither coal mines (power plants), nor coal mining (electricity generation) companies conduct business on their own and supply their products to the parent company (business group). And what makes them close to Robinson Crusoe economy is managing a company output (operating modes) according to the product and resource prices.

To adapt a classical Lausanne model to modern production conditions the authors of this paper offered a single-factor production function with multi-resource equivalent (MRE) – a sort of hypothetical resource, which includes not just a direct labour as in the case of Robinson Crusoe, but electricity, materials, fuel, etc. costing as much as the production costs at actually operating business [10].

Production function of the enterprise is written as:

$$s = k \cdot Ln(r) + 1, \qquad (6)$$

where s – an annual output of the enterprise, standardized by its production capacity, unit fractions;

r – a standardized MRE input (relative to the total costs at full production capacity), unit fractions;

k – a regression coefficient, which reflects the internal parameters of the enterprise, based on mining and geological conditions of coal deposit, technological state of production, etc.

$$s = \frac{q}{P} \qquad (7)$$

$$r = \frac{z}{z_P}, \qquad (8)$$

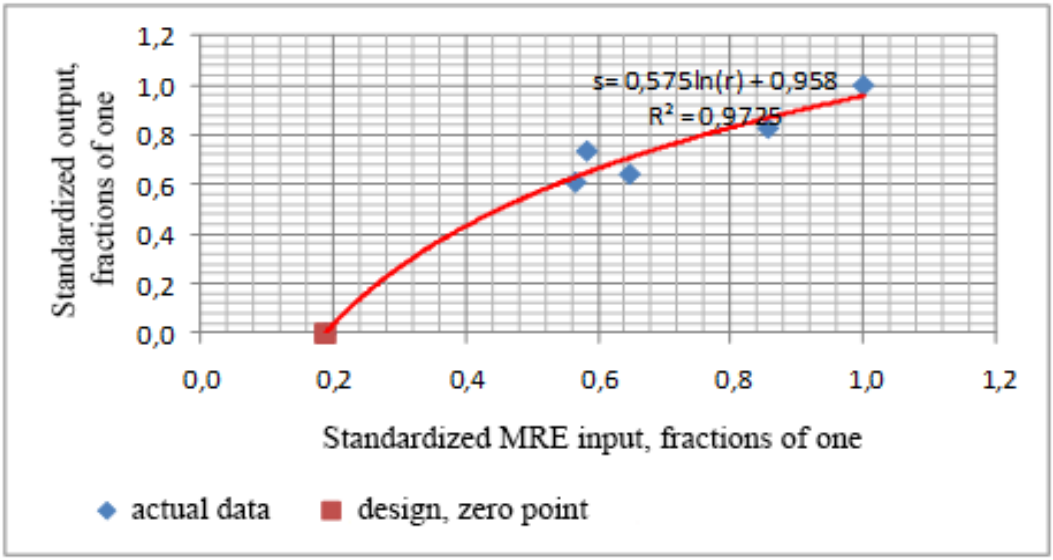
where q – annual output, in physical terms;

P – production capacity of an enterprise;

z – current annual inputs of MRE;

z_p – annual MRE input, when the enterprise operates at full capacity.

The production function of the Pokrovskoye Colliery Group, owned by PJSC "Donetsksteel", is given here as an example (Figure 2).



Source: compiled by the authors.

Fig. 2. Standardized production function of the Pokrovskoye Colliery Group

According to the classical model, the good x_2 is a coal in quantity s; when p and w are respectively: the cost of the extracted coal and the cost of inputs, when coal mine operates at a full capacity (s=1); the good x_1, by analogy with the Robinson Crusoe's leisure L-z, is a value z_p-z, i.e. production resource savings (1-r).

The formula of profit standardized by coal value takes the form:

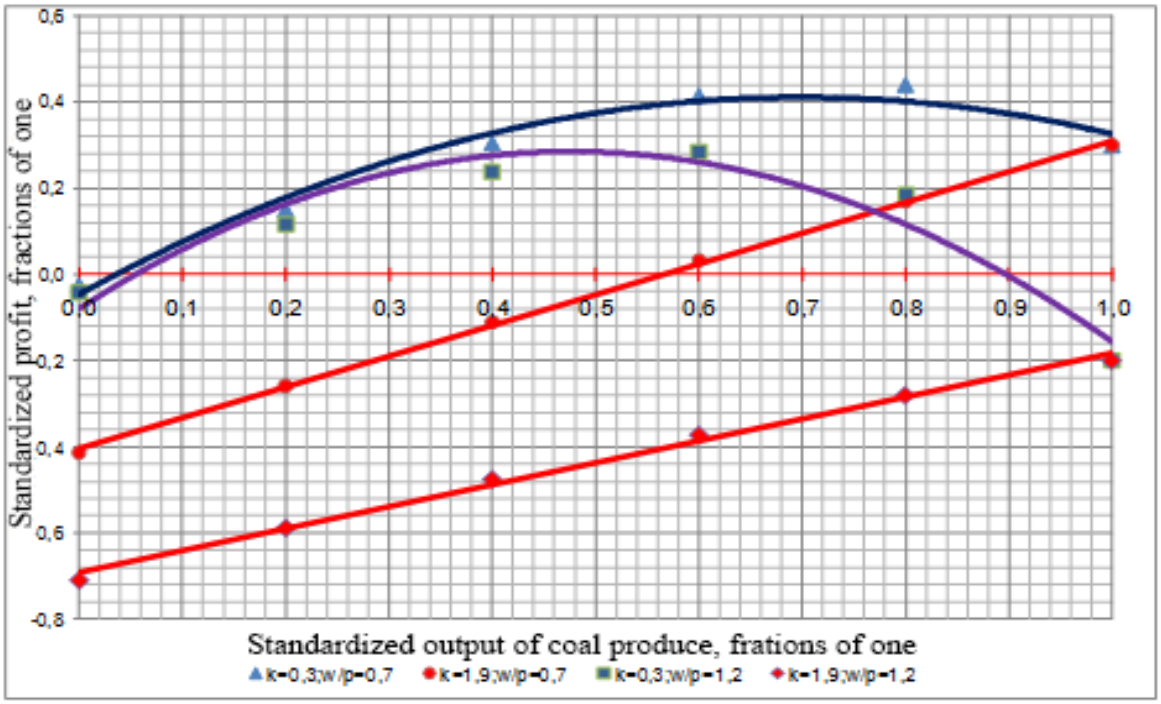
$$\frac{\pi}{p} = s - \frac{w}{p} r. \qquad (9)$$

Fig. 3 shows the calculated profit fluctuations at the enterprises having different operational characteristics, characterized by value k, in various market conditions, which can be described by the ratio w/p.

The higher the k value, the more complicated the operational characteristics of the enterprise are (very deep horizons, high gas content), and the higher (due to economic considerations) a coal production at the collieries should be in order to compensate for high dead expenses (resource input for mine drainage, ventilation, degasification). At shallow mines with a low level of output coal production needs to be adjusted since clean-up costs are decisive in the overall resource inputs. Fig. 4 demonstrates the difference in the elasticity of the production functions.

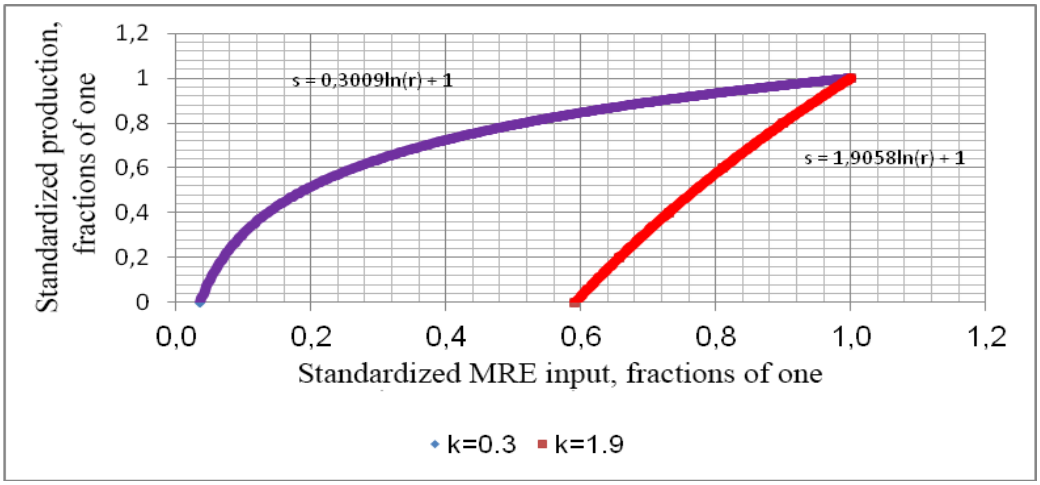
The less the value of w/p ratio, the better a market situation is for a colliery.

If a coal price is low compared to price of multi-resource equivalent (w/p>1), then collieries with difficult operating conditions have no chance to make profit: a Graph line on fig. 3 goes completely below the x-axis. In this situation it makes sense to increase output, which will help to minimize the losses. On the whole, the abovementioned tactics is in the interests of vertically-integrated power and energy groups as well as metallurgical corporations.



Source: compiled by the authors.

Fig. 3 Graph of standardized profit fluctuation at collieries having various operating conditions and at various market situations.



Source: compiled by the authors.

Fig. 4. A production function of collieries operating in various geological conditions.

If market conditions are favourable for coal production ($w/p<1$), even collieries having difficult operating conditions can achieve a break-even point (BEP). This happens when a standardized profit graph crosses an x-axis (at around $s=0.6$). Thus, a calculated future development of production promotes an increase of a profit.

On the contrary, the situation at the collieries, operating in good geological condition, is absolutely different. Even if the market situation is unfavourable ($w/p=1,2$), a cost-

effective operation of colliery can be ensured when its fixed assets are used to achieve 0,1 to 0,9 of its rated capacity. The higher production loads may bring about losses.

If market situation is favourable, i.e. coal prices are high and resource costs are low, colliery of this type will quickly exceed the level, at which BEP is achieved, and will remain profitable, when the colliery's basic production assets are used at full capacity.

Condition (10) forms the Robinson Crusoe's economics efficiency criterion: production loads at the colliery should not exceed its optimum value:

$$s \leq s_{opt}, \qquad (10)$$

where s_{opt} – is an optimum production load for the existing production technology.

A previous experience proves the appropriateness of the above stated academic points. The period of rather low coal prices was prevailing in Australia till the middle of 2016. One half of the local collieries, which covered one third of a thermal coal production, worked at a loss. "In the last 2 years we lost 21,000 working positions" – Mr. Michael Roche, a director-general of Queensland Resources Council (QRC) announced [11].

At the same time, as referred to in the report of Wood MacKenzie agency [11]: 'While demand remains for thermal coal, so that all product continues to sell, the price has remained soft... The market remains oversupplied and a focus on efficiency has seen some producers increase their production rates in a bid to lower their unit costs by spreading their fixed capital costs over a larger volume of production'.

But this is an example of how exactly the Robinson Crusoe economy should work when the operating conditions are difficult. And for the Japanese power company J-Power the best approach to managing its Australian branch coal company is to ensure the stable production, when resource input costs are dropping and the cost of their basic product – electric power – remains stable.

There are examples of another kind. In view of unfavourable market conditions in 2012, coal production at the Maple colliery was reduced by its owner – Walter Energy Inc. – by one third [12]. The same approach was chosen by the majority of the US mining companies, including all the major ones, though vertical integration pattern was usually not used in the US mining industry.

And this is an example of how exactly a corresponding Robinson Crusoe economy should act, when the resource input prices remain stable and a price of the final product is decreasing.

Still, the possibilities of using the Robinson Crusoe economy as an economic pattern are not confined to the abovementioned examples.

The explained approach was used by the authors of the paper to evaluate the investment project, aimed at introduction of vent wells massive boring technology at the Pokrovskoye Colliery Group. Though the innovative degassing method involves significant additional expenses, it is recommended for implementation in order to achieve a high production rate and to improve mine safety [13].

In this case vertical integration means the "colliery – drilling module" combination. The elements of the mentioned combination represent different branches of industry, but both of them are the property of the PJSC "Donetsksteel".

The use of Robinson Crusoe economy concept is substantiated by the necessity to study the effect of boring operation costs, carried out by a specialized body on the fluctuations of production function of a colliery. In this case the calculated costs of boring operations exceeded the actual expenditure of the colliery group since the calculations included the expenses of the parent company for procurement of a costly technological complex.

The research, carried out by the authors of the paper, showed the following: if the degassing technology by boreholes drilled from the surface is not implemented,

the condition (10) will not be fulfilled, i.e. the achieved output will surpass the optimum level at the given conditions of coal mine functioning.

Implementation of the innovative degassing technology will create necessary conditions for the economically attractive development of coal production and the group as a whole even though boreholes' drilling involves high additional costs. Practice confirmed these conclusions.

Since the Donetsksteel owns some other vertically integrated structures, such as "colliery and coal preparation plant", "coal preparation plant and by-product coking factory", "by-product coking factory and metallurgical plant", it is worth doing further researches to determine an optimum operating mode of such enterprises in cases of considerable fluctuation of input costs and final product prices.

Based on the national and international experience, a conclusion can be drawn that the current situation does not facilitate the intensification of business.

Low prices for metal and coal triggered a wide-scale restructuring in the most of vertically-integrated structures [14].

Robinson Crusoe economy in the form of "metallurgical corporation having coal assets" as in the case of other related entities can be analyzed by the same pattern: by developing a production function of the enterprise in the form of dependence of its output from MRE inputs and by evaluating the optimum operating conditions.

Conclusions

A model, formulated by the Lausanne school of economics in the 1930s of the XX century and known as the economy of Robinson Crusoe, forms a compulsory course in microeconomics at various universities of the world. Though it basically corresponds to the pattern of vertically-integrated system, it was undervalued by the industrialists.

Methodology, used for describing the economies of "1x1x2" pattern, which means "one producer, one consumer and two commodities" can be used for defining the optimum operating modes of vertically-integrated systems as well as for evaluating the efficiency of investment projects, aimed at their development.

Keeping in mind that when the economy of Robinson Crusoe is in a state of equilibrium, a graph of the consumer indifference curve touches a graph of the manufacturer's production function in the point which reflects the maximum of company profit and the analysis of operating efficiency of the system on the whole can be carried out by studying the operating mode of the producer of good only.

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Based on the analysis of profit fluctuations of coal mining enterprises (coal mines), which have various production characteristics and operate in various market conditions, a conclusion is made, that the worse the operating conditions of the coal mine are the more intensive its production load should be to make it more cost-effective. At the same time, coal mines, working in favourable operating conditions, need to limit their production load.

As the Australian and US experience proves, hypothetic constructs satisfy the coal mining practice in different countries, which allows asserting that it is possible to use the principles of Robinson Crusoe economy in respect of real enterprises.

In order to test this concept in Ukraine, we used a production data of the Pokrovskoye Colliery Group, which is a vertically-integrated structure with a drilling company, providing services for making degassing boreholes.

Conclusions, drawn on the basis of enterprise production function analysis, show the efficiency of innovative degassing technology and a possibility of using it in the development of an enterprise. The practical results of massive boring technology introduction at coal mining production of the Pokrovskoye Colliery Group proved the validity of theoretical analysis.

It is worth using the developed methodology to analyze and substantiate the methods of improving the operation of vertically-integrated systems in the sphere of coal washing, coke chemistry, metallurgy, power engineering and other branches of industry. At the same time its introduction into practice requires further research of company production functions.

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ІНТЕГРОВАНІ СТРУКТУРИ У ПРОМИСЛОВОСТІ ЯК ЕКОНОМІКИ РОБІНЗОНА КРУЗО

Модель, розроблена у 30-х роках XX ст. економістами лозаннської школи, відома як економіка Робінзона Крузо, є обов'язковим елементом університетських курсів з мікроекономіки, але виявилася недооціненою промисловцями, хоча за своєю природою відповідає схемі вертикально інтегрованих систем.

Методологія опису економіки формату «1×1×2», що означає «один виробник, один споживач і два товари», може бути використана для розрахунку оптимальних режимів роботи інтегрованих виробничих систем та оцінки ефективності інвестиційних проектів, пов'язаних з їх розвитком.

Ключові слова: економіка Робінзона Крузо, інтегровані структури, промисловість, модель, лозаннська школа.

JEL codes: D5.

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ИНТЕГРИРОВАННЫЕ СТРУКТУРЫ В ПРОМЫШЛЕННОСТИ КАК ЭКОНОМИКИ РОБИНЗОНА КРУЗО

Разработанная в 30-х годах XX в. экономистами лозаннской школы модель, известная как экономика Робинзона Крузо, является обязательным элементом университетских курсов по микроэкономике, но оказалась недооценена промышленниками, хотя по своей природе соответствует схеме вертикально интегрированных систем.

Методология описания экономик формата «1×1×2», что означает «один производитель, один потребитель и два товара», может быть использована для расчета оптимальных режимов работы интегрированных производственных систем и оценки эффективности инвестиционных проектов, связанных с их развитием.

Ключевые слова: экономика Робинзона Крузо, интегрированные структуры, промышленность, модель, лозаннская школа.

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