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ANALYSIS OF THE REGRESSION MODEL OF THE ENTERPRISE'S FINANCIAL ACTIVITY BY RESEARCH ON RESIDUAL ERROR

Purpose. Improvement of regression economic-mathematical models taking into account the influence of residual error as a random variable.

Methodology. Methods of economic-mathematical modeling, regression analysis are used. The real conditional law of distribution of residual error as a complete characteristic of a random variable is applied.

Findings. A scientific and practical approach to economic and mathematical modeling based on the study on residual error, to improve the construction of regression equations.

Originality. For the first time, the application of residual error analysis as a random variable has been proposed in order to construct its conditional differential distribution function, which allows improving the quality of economic-mathematical modeling in the form of regression equations. The use of the proposed method of taking into account the residual error allows eliminating the negative impact of the violation of the conditions of the properties of the residual error in the implementation of economic and mathematical modeling using regression equations.

Practical value. The analysis of the obtained results of economic-mathematical modeling of economic activity of Inhulets Mining and Processing Plant on significant statistical material with the use of the developed algorithm of residual error research confirmed the effectiveness of the proposed approach. It is recommended to include the developed algorithm taking into account the properties of the residual error in the practice of managing the financial activities of mining enterprises.

Keywords: *mining enterprises, regression, model, residual error, scedasticity, financial activity*

Introduction. The current status of Ukraine's mining industry is causing concern. This to a significant degree results from the current economic conditions. In the situation like that it is very important to timely assess problems in mining enterprises' activities. At the same time, the vigorous flow of events causes the necessity to apply new approaches based on modern mathematical tools supported by the latest advances in digital technologies. Mathematical modeling is one of possible efficient methods. It is quite obvious that this type of modeling should provide adequate description of economic phenomena. Considering the fact that there is uncertainty in economic events under study, regression models are used in mathematical modeling. That is why when building such models, it is necessary to apply substantiated methods. In particular, it is rather important to consider conditions set when building regression models. The regression model built with non-observance of requirements to residual error properties produces distorted results. So, it is very important to consider real properties of the residual error when modeling.

Literature review. Mathematical-statistical methods based on the traditional methodology are used along with conventional statistical methods of data analysis to study real social and economic phenomena.

Complexity of application of mathematical-statistical methods involves more enhanced disclosure of the essence, regularities and trends of development of certain phenomena and processes to adequately represent properties, reserves and prospects of development and ways of enhancement.

Current research studies in the field of economics and application of their results to production mostly deal with analysis of enterprises' activities through their economic-mathematical modeling. Modeling efficiency and methods of its assessment are studied in works by academic economists Chornous G. O. [1], Sheremet A. D. [2], Savitskaya G. V [3] and others. In particular, the content of mathematical modeling of economic activities is treated in works by Vitlinskyi V. V. [4], Kyzym M. O. [5], Ponomarenko V. S [6], Trided O. M. [7], Udalykh O. O. [8], the geometric mean of the indicators that, according to the authors, determine efficiency of enterprises' production management is suggested as a criterion of efficiency. U. Mereste suggests the matrix method to measure production efficiency [9] that will enable determining changes in functioning and finding reserves for enhancing performance of an enterprise. Levchenko O. M. states that analysis of components of economic activities of the enterprise reveals significance of the economic constituent [10]. Burkova L. A. suggests singling out systems of indicators that will enable assessment of enterprise performance efficiency [11]. Issues of methods of statistical assessment of the economic strategy of enterprises that facilitates formation of their strategic development model are treated in [12]. Solution of practical tasks that can be described by a mathematical model is detailed in [13], (Aczel A., Sounderpandian J., 2008).

Unsolved aspects of the problem. Along with that, impacts of uncertainty and randomness in economic-mathematical modeling are still understudied. In particular, this applies to specificity of using regression models where the aspect of residual error properties is treated simplistically.

Purpose. The article aims to study residual error properties and consider them in economic-mathematical modeling when building a regression model.

Results. Attention is paid to issues of impacts of the residual error when building a regression model on the quality of economic-mathematical modeling. One should mention the Durbin-Watson statistic, which is a test for autocorrelation of residuals (Babak, V., 2001). Autocorrelation of residuals can be a significant problem when applying classical methods of time series analysis. In regression models describing dependencies of interrelated random values, it decreases efficiency of the LSM application. The impact of heteroscedasticity on the quality of economic-mathematical modeling is analyzed by the Goldfeld–Quandt test [14]. However, how the output variable is changing here is not still obvious. To solve this problem, let us study a simple one-factor regression model of the dependency of the output variable (y) on the input variable (x) in the linear form

$$y = a + b \cdot x + u, \tag{1}$$

where a, b are parameters; u is disturbance.

To find the parameters of (1), the system of equations should be solved using the statistical data

$$a + b \cdot x_i = y_i + u_i, \quad i = 1, ..., N,$$

where N is the statistical data quantity.

It is obvious that when the number of statistical data exceeds two, the number of equations is greater than that of unknowns and this equation system is incompatible. Along with that, using the generalized decision definition, it is quite natural to solve the system by the least squares method (LSM). For this, the sum of disturbance squares should be minimized in each of equations

$$Q(a,b) = \sum_{i=1}^{N} u_i^2 = \sum_{i=1}^{N} \left(a + b \cdot x_i - y_i\right)^2. \tag{2}$$

The simple form of function (2) enables solving the minimization task (2) equating the partial derivatives of function (2) to zero, i. e.

$$\frac{\partial Q(a,b)}{\partial a} = 0; \quad \frac{\partial Q(a,b)}{\partial b} = 0. \tag{3}$$

As function (1) is linear with respect to parameters, then (2) is a quadratic function that determines linearity of equation system (3)

$$\begin{cases} a + b \cdot \bar{x} = \bar{y} \\ a \cdot \bar{x} + b \cdot \overline{x^2} = \overline{xy} \end{cases}. \tag{4}$$

Where

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i; \quad \bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i; \quad \overline{x^2} = \frac{1}{N}\sum_{i=1}^{N} x_i^2; \quad \overline{xy} = \frac{1}{N}\sum_{i=1}^{N} x_i y_i.$$

Equation system (4) is solved with the help of Cramer formula

$$a^* = \frac{\Delta_1}{\Delta}; \quad b^* = \frac{\Delta_2}{\Delta}, \tag{5}$$

where $\Delta = \begin{vmatrix} 1 & \bar{x} \\ \bar{x} & \overline{x^2} \end{vmatrix}$; $\Delta_1 = \begin{vmatrix} \bar{y} & \bar{x} \\ \overline{xy} & \overline{x^2} \end{vmatrix}$; $\Delta_2 = \begin{vmatrix} 1 & \bar{y} \\ \bar{x} & \overline{xy} \end{vmatrix}$.

Thus, according to (5), the regression equation found by the LSM can be written as follows

$$\bar{y} = a^* + b^* \cdot \bar{x}.$$

Along with that, according to (1) and (5), the following is possible

$$y = a^* + b^* \cdot x + u, \tag{6}$$

or

$$u = y - a^* - b^* \cdot x. \tag{7}$$

Thus, residual error values can be found

$$u_i = y_i - a^* - b^* \cdot x_i, \quad i = 1, ..., N. \tag{8}$$

Further on, let residual errors be uncorrelated, i.e. there is no autocorrelation. In particular, this can be checked using the Durbin-Watson statistic. Also, let us assume that there is monoscedasticity of residual errors that can be checked by the Goldfeld–Quandt test. Availability of statistical data of residual error values found by (8) enables a histogram of values of these errors. Approximation of the histogram by a continuous function makes it possible to build a differential function of distributing the residual error as a continuous random value. Let this differential function of residual error distribution look like $f(u)$.

It should be noted that Pearson's chi-squared test can be used to confirm the assumption about the distribution law [15].

Considering the fact that function (7) in relation to y is monotonically increasing and differentiated, inverse function (6) exists and is monotonically increasing and differentiated too. If the interval $(u, u + \Delta u)$ is set, then the interval $(y, y + \Delta y)$ can be obtained with the help of function (6). Events $(u < U < u + \Delta u)$ and $(y < Y < y + \Delta y)$ are identical, so the corresponding probabilities are equal

$$P(u < U < u + \Delta u) = P(y < Y < y + \Delta y).$$

Then, according to the definition of the differential function of distribution of the continuous random value Y, we have

$$g(y) = \lim_{\Delta y \to 0} \frac{P(y < Y < y + \Delta y)}{\Delta y} = \lim_{\Delta y \to 0} \frac{P(u < U < u + \Delta u)}{\Delta y} =$$
$$= \lim_{\substack{\Delta y \to 0 \\ \Delta u \to 0}} \frac{P(u < U < u + \Delta u)}{\Delta u} \cdot \frac{\Delta u}{\Delta y} = f(u(y)) \cdot u'(y).$$

Thus, the function

$$g(y) = f(u(y)) \cdot u'(y),$$

determines the differential distribution function of equation (1) and is the total characteristic Y as a random value.

Considering (7), formula (13) looks like the following and is the conditional law of distribution with respect to the variable x

$$g(y/x) = f(y - a^* - b^* \cdot x). \tag{9}$$

According to (14), the mathematical expectation of Y can be found as follows

$$M[Y/x] = \int_{\underline{y}}^{\bar{y}} y \cdot f(y - a^* - b^* \cdot x)\,dy, \tag{10}$$

where $\underline{y}$, $\bar{y}$ are upper and lower bounds of variation of y.

In its turn, the mean-square deviation is found by the formula

$$\sigma_{y/x} = \sqrt{\int_{\underline{y}}^{\bar{y}} \left(y - M[Y/x]\right)^2 f(y - a^* - b^* \cdot x)\,dy}. \tag{11}$$

It should be noted that the determined characters (10) and (11) are conditional as they depend on the variable x. Moreover, formula (10) determines theoretical regression of Y against X, and formula (11) determines scedasticity of Y against X.

Formula (9) enables calculating the probability of the preset deviation from regression line (10). For this, the following formula is used

$$P\left(\left|Y - M[Y/x]\right| < \Delta\right) = \int_{M[Y/x]-\Delta}^{M[Y/x]+\Delta} f(y - a^* - b^* x)\,dy,$$

where Δ is the preset deviation from the regression line.

It is deemed reasonable to consider the regression model analysis in order to study residual error impacts using the example of assessing the financial performance of Inhulets Mining and Concentration Works (InGZK) in the city of Kryvyi Rih [16, 17]. The calculations were Mathcad-based [18]. It should be noted that statistical substantiation of the obtained results was not performed to the full extent due insufficient material provision. However, in terms of quality, these results are true.

Table 1 presents the relevant statistics of InGZK. Based on the data, dependency of income on current assets values is considered over a certain time interval [16, 17].

The regression model of dependency of income (Y) on the current assets value (X) is found as follows

$$y = a + b \cdot x + u, \tag{12}$$

where a, b are parameters, u is disturbance.

Table 1

Statistics of InGZK production

Years	Income (y_i) (UAH)	Current assets (x_i) (UAH)	x_i^2	x_iy_i	Regression (LSM)	u_i
2001	796 086	378 681	1.43399E+11	3.0146E+11	2 576 085	–1779999
2002	886 660	348 862	1.21705E+11	3.0932E+11	2 563 969	–1677309
2003	1 136 460	525 939	2.76612E+11	5.9771E+11	2 635 920	–1499460
2004	1 446 530	406 689	1.65396E+11	5.8829E+11	2 587 465	–1140935
2005	2 053 653	835 021	6.9726E+11	1.7148E+12	2 761 508	–707855
2006	2 084 934	852 886	7.27415E+11	1.7782E+12	2 768 767	–683833
2007	2 998 135	1 617 929	2.61769E+12	4.8508E+12	3 079 624	–81489
2008	6 441 396	6 726 606	4.52472E+13	4.3329E+13	5 155 414	1285982
2009	4 384 200	5 632 716	3.17275E+13	2.4695E+13	4 710 938	–326738
2010	8 897 838	7 225 286	5.22048E+13	6.4289E+13	5 358 041	3539797
2011	9 875 431	11 822 216	1.39765E+14	1.1675E+14	7 225 895	2649536
2012	9 986 708	12 263 759	1.504E+14	1.2247E+14	7 405 305	–326738
2013	10 352 257	17 185 530	2.95342E+14	1.7791E+14	9 405 150	947107
2014	11 341 151	17 032 936	2.90121E+14	1.9317E+14	9 343 147	1998004
2015	9 489 519	25 161 471	6.331E+14	2.3877E+14	12 645 985	–3156466
2016	11 306 531	23 501 747	5.52332E+14	2.6572E+14	11 971 596	–665065
2017	15 711 286	35 096 304	1.23175E+15	5.5141E+14	16 682 770	–971484
2018	18 706 815	40 843 517	1.66819E+15	7.6405E+14	19 018 014	–311199
Average	7 105 310.6	11 525 450	2.83052E+14	1.4293E+14		

According to the data of the last row of Table 1, system (4) is written as follows

$$\begin{cases} a + 11\,525\,450b = 7\,105\,310.6 \\ 11\,525\,450a + 2.83052\cdot 10^{14} b = 1.4293\cdot 10^{14} \end{cases}.$$

According to (6), solution of system (19) looks like

$$a^* = 2\ 422\ 217; \quad b^* = 0.406. \qquad (13)$$

Thus, according to (19), the regression equation looks like

$$y = 2\ 422\ 217 + 0.406x. \qquad (14)$$

The residual errors calculated by (5) are given in the last column of Table 1 as the difference between values of the second and the next to last columns of Table 1.

Fig. 1 presents the histogram of residual error values according to Table 1.

Approximation of the histogram in Fig.1 is represented by the cuspidal function

$$f(u) = \begin{cases} 0, & u < -3.2\cdot 10^6 \\ 2.113\cdot 10^{-7} - 1.65\cdot 10^{-20}u^2, & 3.2\cdot 10^6 \le u \le 3.6\cdot 10^6 \\ 0, & u > 3.6\cdot 10^6 \end{cases}. \qquad (15)$$

At that, the determination coefficient is $R^2 = 0.819$.

It should be noted that for finite function (15) the properties that should occur for differential functions of distribution are fulfilled on the whole. In particular, the function is normalized to 1, i. e.

$$\int_{-\infty}^{\infty} f(u)\,du = 1.$$

Fig. 2 presents the graph of function (14).

According to (9), the differential function of the output variable distribution is written as

$$g(y/x) = f(y - 2\ 422\ 217 - 0.406x). \qquad (16)$$

Fig. 3 presents the graph of the conditional distribution law (16) at the fixed value of the variable x

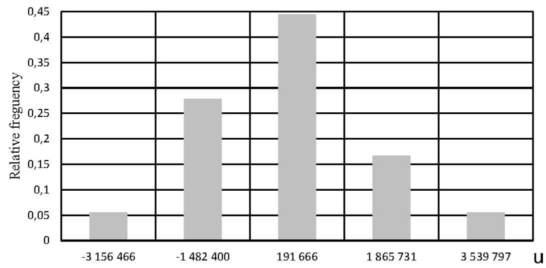

Fig. 1. Relative frequency of the residual error

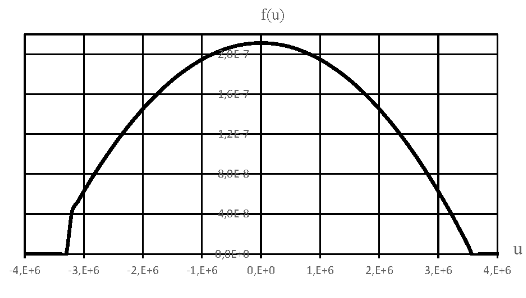

Fig. 2. The differential function of residual error distribution

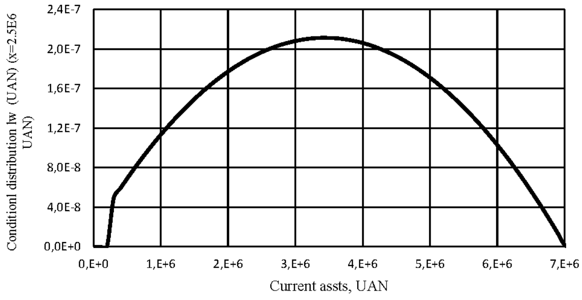

Fig. 3. Conditional law of current assets value distribution

$$g(y/x = 2.5 \cdot 10^6) = f(y - 1\,407\,217). \quad (17)$$

According to (10 and 17), the conditional mathematical expectation makes

$$M\left[\frac{Y}{X} = 2.5 \cdot 10^6\right] = \int_0^{3 \cdot 10^7} y \cdot f\left(y - 1\,407\,217\right) dy = 3.464 \cdot 10^6.$$

According to (11) and (17), the mean-square deviation makes

$$\sigma\left[Y/X = 2.5 \cdot 10^6\right] =$$

$$= \sqrt{\int_0^{3 \cdot 10^7} \left(y - M\left[Y/X = 2.5 \cdot 10^6\right]\right)^2 f\left(y - 1\,407\,217\right) dy} = 1.578 \cdot 10^6.$$

In the general case, conditional characters are functions. According to (10), the theoretical regression of Y against X is found

$$M\left[Y/x\right] = \int_0^{3 \cdot 10^7} y \cdot f\left(y - 2\,422\,217 - 0.406x\right) dy. \quad (18)$$

Fig. 4 presents graphs of dependency of income on current assets values. Analysis of the graphs (Fig. 4) shows that the graph of formula (13), i. e. built applying the LSM, is identical to that of formula (17), which is theoretical regression. This coincidence proves the right choice of the approach to the study.

Use of (11) in the form

$$\sigma_{\frac{y}{x}} = \sqrt{\int_0^{3 \cdot 10^7} \left(y - M\left[\frac{Y}{x}\right]\right)^2 f\left(y - 2\,422\,217 - 0.406x\right) dy},$$

enables determining scedasticity of Y against X, whose line is presented in Fig. 5.

According to (10), probability of the preset deviation of the output variable from the regression line can be determined. Using (16 and 18), the following is written

$$P\left(\left|Y - \int_0^{6 \cdot 10^7} y \cdot f\left(y - 2\,422\,217 - 0.406x\right) dy\right| < \Delta\right) dy =$$

$$= \int_{\int_0^{6 \cdot 10^7} y \cdot f\left(y - 2422217 - 0{,}406x\right) dy - \Delta}^{\int_0^{6 \cdot 10^7} y \cdot f\left(y - 2422217 - 0{,}406x\right) dy + \Delta} f\left(y - 2\,422\,217 - 0.406x\right) dy. \quad (19)$$

Fig. 6 presents graphs of (19) that demonstrate dependency of probability of the preset deviation of the output variable on the regression line. Deviation is preset in fractions of the mathematical expectation, i.e.

$$\Delta\left(x\right) = \delta \cdot \int_0^{6 \cdot 10^7} y \cdot f\left(y - 2\,422\,217 - 0.406x\right) dy,$$

where δ is a fraction of the mathematical expectation (19).

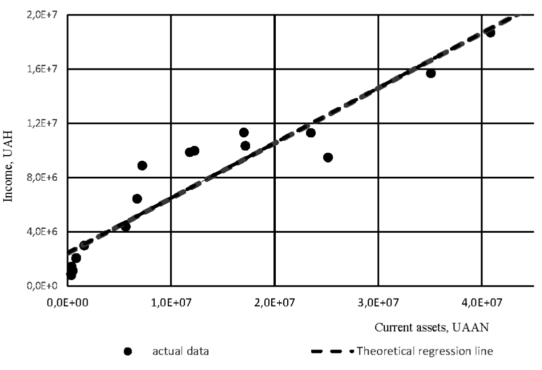

Fig. 4. Dependency of income on the current assets value

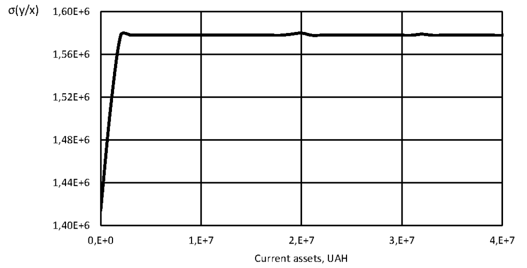

Fig. 5. The line of income scedasticity against the current assets value

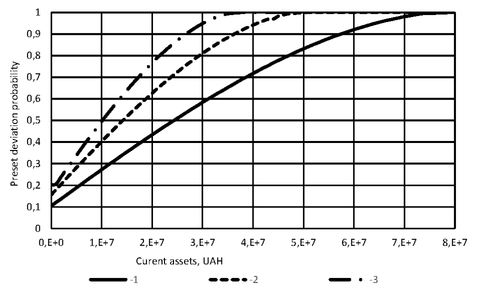

Fig. 6. Dependency of preset deviation probability on the current assets value:
1 – $\delta = 0.1$; *2* – $\delta = 0.15$; *3* – $\delta = 0.2$

It can be observed that when the value of current assets increases, probability of the output variable to fall in the interval limited by the preset deviation rises. Moreover, if the interval increases, i. e. when δ rises, probability of the output variable to fall in the interval at the constant value of current assets also rises.

Finally, it should be mentioned that the conducted study on the residual error enables analyzing the regression model at economic-mathematical modeling through application of the real conditional differential function of residual error distribution as its total characteristic.

Conclusions. Market relations in Ukraine require application of modern management methods based on economic-mathematical modeling. Special attention should be paid to adequacy of mathematical models as they are synthesized considering uncertainties. As regression analysis is used when building models, accuracy of conclusions is impacted by the residual error. Studying the residual error enables analyzing a regression model at economic mathematical modeling through application of the real conditional law of residual error distribution as its total characteristic as a random value. Analysis of economic performance of Inhulets Mining and Concentration Works confirms efficiency of the suggested algorithm.

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Аналіз регресійної моделі фінансової діяльності підприємства шляхом дослідження залишкової похибки

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Мета. Удосконалення регресійних економіко-математичних моделей з урахуванням впливу залишкової похибки як випадкової величини.

Методика. Використані методи економіко-математичного моделювання, регресійного аналізу. Застосовано реальний умовний закон розподілу залишкової похибки як повної характеристики випадкової величини.

Результати. Сформовано науково-практичний підхід до економіко-математичного моделювання на основі дослідження залишкової похибки задля удосконалення побудови регресійних рівнянь.

Наукова новизна. Уперше запропоновано застосування аналізу залишкової похибки як випадкової величини з метою побудови її умовної диференціальної функції розподілу, що дозволяє підвищити якість економіко-математичного моделювання у вигляді регресійних рівнянь. Використання запропонованого методу врахування залишкової похибки дозволяє усунути негативний вплив порушення виконання умов властивостей залишкової похибки при реалізації економіко-математичного моделювання за допомогою регресійних рівнянь.

Практична значимість. Аналіз отриманих результатів економіко-математичного моделювання економічної діяльності Інгулецького гірничо-збагачувального комбінату на значному статистичному матеріалі із застосуванням розробленого алгоритму дослідження залишкової похибки підтвердив дієвість запропонованого підходу. Рекомендується включити розроблений алгоритм із врахуванням властивостей залишкової похибки до практики управління фінансовою діяльністю гірничорудних підприємств.

Ключові слова: *гірничорудні підприємства, регресія, модель, залишкова похибка, скедастичність, фінансова діяльність*

Анализ регрессионной модели финансовой деятельности предприятия путем исследования остаточной погрешности

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Цель. Усовершенствование регрессионных экономико-математических моделей с учетом влияния остаточной погрешности как случайной величины.

Методика. Использованы методы экономико-математического моделирования, регрессионного анализа.

Применялся реальный условный закон распределения остаточной погрешности как полной характеристики случайной величины.

Результаты. Сформирован научно-практический подход к экономико-математическому моделированию на основе исследования остаточной погрешности, чтобы усовершенствовать построение регрессионных уравнений.

Научная новизна. Впервые предложено применение анализа остаточной погрешности как случайной величины с целью построения ее условной дифференциальной функции распределения, что позволяет повысить качество экономико-математического моделирования в виде регрессионных уравнений. Использование предложенного метода учета остаточной погрешности позволяет устранить негативное влияние нарушения выполнения условий свойств остаточной погрешности при реализации экономико-математического моделирования с помощью регрессионных уравнений.

Практическая значимость. Анализ полученных результатов экономико-математического моделирования экономической деятельности Ингулецкого горно-обогатительного комбината на значительном статистическом материале с применением разработанного алгоритма исследования остаточной погрешности подтвердил действенность предложенного подхода. Рекомендуется включить разработанный алгоритм по учету свойств остаточной погрешности в практику управления финансовой деятельностью горнорудных предприятий.

Ключевые слова: *горнорудные предприятия, регрессия, модель, остаточная погрешность, скедастичность*, *финансовая деятельность*

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