Mathematical models for predicting material damage from fires

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Аннотация. *The article examines mathematical models for analyzing and predicting material damage from fires. Using linear and non-linear dependencies, the dependence of material damage on such factors as gross domestic product, population, the cost of fixed assets and the exponential time trend was estimated. The results obtained in the study can be used for short-term forecasting of damage caused by fires.*

Ключевые слова: *Regression analysis, prediction, tools, factors, correlation dependence, modeling, fire damage.*

Introduction

In the world practice, the problem of fire protection is one of the most urgent problems that require careful analysis and forecasting of damage from them. It is possible to study the material damage caused by fires using statistical methods and nonlinear methods such as Cobb-Douglas, which allow us to identify the relationship between the material damage caused by fires in the country and macroeconomic indicators. It is necessary to anticipate the degree of damage from fires and provide protection from them proactively, that is, it is necessary to develop methods for predicting fire danger in order to ensure the least damage [1].

The relevance of scientific research consists in the development of new multi-factor nonlinear models to identify the interdependence between macroeconomic factors and the choice of those parameters that make a great contribution to the assessment of the damage caused by the number of fires. Since fires in most cases are a kind of product of society, it is better to use the following parameters for their assessment: the population, the volume of fixed assets and gross domestic product (GDP). The constructed dependencies make it possible to solve the following problems of scientific research: the ability to anticipate; predict the state of the process when changing macroeconomic parameters [2].

The scientific article is devoted to an urgent problem related to the development of new nonlinear Cobb-Douglas models in economic research based on the principles of system analysis and the influence of macroeconomic indicators on the target factor associated with economic damage from the number of fires in the Russian Federation.

Of particular importance in this work is the fact that it has developed a computer technology for decision-making based on the relationship of nonlinear models with technologies for selecting the most significant factors affecting the target indicator associated with economic damage.

The relevance of the article is not in doubt, since the developed nonlinear models and methods of effective decision-making on them make it possible to conduct economic research more quickly, reliably and at a lower cost when predicting economic damage from a fire hazard. In the course of the study, the main focus is on the relationship of various macroeconomic factors and their impact on the target factor associated with the economic damage caused by fires in the Russian Federation. The paper presents mathematical nonlinear models for predicting economic damage from fires and tools for their implementation.

1. A mathematical model

The following multi-factor models were studied $Y_t = AX_1^{\alpha} X_2^{\beta} X_3^{\gamma} e^{\lambda t}$, where Y_t -fire damage in t the year (FD), X_1 - gross domestic product (GDP), X_2 - population of the Russian Federation (CHN), X_3 - the volume of fixed assets of the Russian Federation (VF), λ - a parameter that characterizes the exponential time trend. The initial data for the analysis are presented in the following table 1.

Таблица 1

Used to analyze the characteristics

Year	FD, billion	GDP, trillion	CHN, million	VF, trillion
2003	4,175485	13,0802	145	32,173286
2004	5,893581	17,0272	144,3	34,873724
2005	6,682478	21,6098	143,8	41,493568
2006	8,475058	26,9172	143,2	47,489498
2007	8,696231	33,2475	142,8	60,391454
2008	12,228599	41,2768	142,8	74,441095
2009	11,193949	38,8072	142,7	82,302969
2010	14,565008	46,3085	142,9	93,185612
2011	18,042406	60,2825	142,9	108,001247
2012	15,6934	68,1639	143	121,268908
2013	13,2029	73,1339	143,3	133,521531

2014	18,723313	79,1997	143,7	147,429656
2015	22,870367	83,3872	146,3	160,725261
2016	14,323829	86,0102	146,5	183,403693
2017	14,217273	92,0893	146,8	194,649464
2018	15,913505	103,6266	146,9	210,940524

2. Results of the study

Figure shows a graph of the damage caused by year.

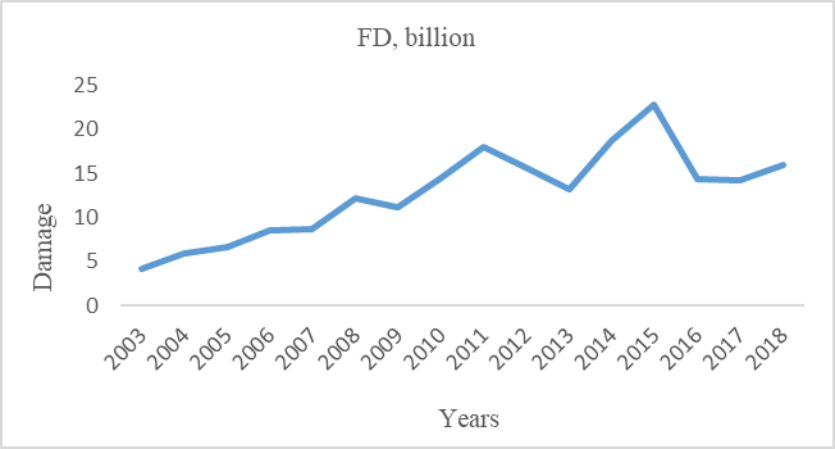

Рисунок. Schedule of material damage

The correlation matrix of the economic damage target with the above four factors is presented in table 2.

Таблица 2

The correlation between the factors

	FD	GDP	CHN	VF	Year
FD	1	0,82	0,24	0,76	0,81
GDP	0,82	1	0,57	0,99	0,99
CHN	0,24	0,57	1	0,65	0,57
VF	0,76	0,99	0,65	1	0,99
Year	0,81	0,99	0,57	0,99	1

A correlation was found between GDP and VF with a correlation coefficient of 0,99, as well as between GDP and the time parameter with a

correlation coefficient of 0,99. It can be seen that there is a close relationship between them and models should use one of these factors in order to exclude multicollinearity.

Next, multivariate nonlinear Cobb-Douglas dependencies were constructed using an exponential trend. Significant models and their main indicators are presented in table 3.

Таблица 3

The statistical characteristics of the models

Model	R^2	F	SD
$FD = 0,1348\, GDP^{1,38}\, e^{-0,0991t}$	0,91	65,912	0,149
$FD = GDP^{1,174}\, CHN^{-0,54} VF^{0,363}\, e^{-0,1185t}$	0,997	1048,438	0,154
$FD = GDP^{1,35711}\, CHN^{-0,3913}\, e^{-0,09553t}$	0,997	1491.413	0,149
$FD = 0,05833\, GDP^{1,1888}\, VF^{0,3988}\, e^{-0,1258t}$	0,912	41,37	0,154

Other models obtained with other combinations of macroeconomic parameters showed worse results and are not given in the article.

For the above models, the following important indicators were calculated, presented in table 4.

Таблица 4

The predictive characteristics of the models

MAPE	MAE	MSE	RMSE	Average approxima-tion error	WAPE	Prediction accuracy
10,474	1,542	4,742	2,178	1,542	12,04	87,96
10,366	1,155	4,758	2,182	1,515	11,83	88,17
10,439	1,539	4,774	2,185	1,539	12,02	87,98
10,409	1,517	4,711	2,171	1,517	11,85	88,15

An important metric WAPE (Weighted Absolute Percentage Error) is measured as a percentage. Through this indicator, the forecasting accuracy is calculated as a percentage, as 100-WAPE.

In terms of statistical parameters, the above models are very effective. Computational experiments on the models were calculated using MS Excel

and the SPSS statistical package, as well as using the developed software package [3-5].

Conclusion

The nonlinear models presented in the article, taking into account the identification of significant macroeconomic parameters that make the greatest contribution to the indicator of material damage from the number of fires, have shown efficiency sufficient for their practical application. Multivariate linear dependences of the Cobb-Douglas type are proposed and investigated, which demonstrate a high dependence of the presented factors on the assessment of material damage on the number of fires in the Russian Federation. A set of software tools for predicting economic damage from the number of fires by significant macroeconomic parameters is presented [3-5].

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