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FORECASTING OF SOCIO-ECONOMIC SECURITY INDICATORS BY MEANS OF EXPONENTIAL SMOOTHING

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ПРОГНОЗИРОВАНИЕ ПОКАЗАТЕЛЕЙ СОЦИАЛЬНО-ЭКОНОМИЧЕСКОЙ БЕЗОПАСНОСТИ СПОСОБОМ ЭКСПОНЕНЦИАЛЬНОГО СГЛАЖИВАНИЯ

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Abstract. The method of exponential smoothing is widely used in the forecasting of financial and economic characteristics in different sectors of the economy, departments, etc. In the construction of a forecast model by exponential smoothing time series of characteristics of socio–economic security is smoothed with the support of a weighted moving average, in which the weights obey the exponential law. In this case, the following levels of the series are given significant values in comparison with the past, because they carry more important information to determine the predicted values at the level of socio-economic security characteristics.

Аннотация. Способ экспоненциального сглаживания обширно используется при прогнозировании финансово–экономических характеристик в разных секторах экономики хозяйства, ведомствах и т. д. При построении прогнозной модели способом экспоненциального сглаживания временной ряд характеристик социально–экономической безопасности сглаживается с поддержкой взвешенной скользящей средней, в которой веса подчиняются экспоненциальному закону. В данном случае следующим уровням ряда придаются существенные значения в сравнении с прошлыми, т. к. они несут более важную информацию для определения прогнозируемых значений на уровне характеристик социально–экономической безопасности.

Keywords: socio-economic security, government, society, enterprise, employee, threat, security, interests, economics, analysis, system.

Ключевые слова: социально-экономическая защищенность, государство, общество, предприятие, работник, угроза, защищенность, интересы, экономика, анализ, система.

The method of exponential smoothing is widely used in forecasting financial and economic characteristics in different sectors of the economy, departments, etc. [1–2].

When constructing a predictive model by exponential smoothing, the time series of socio-economic security characteristics is smoothed with the support of a weighted moving average, in which the weights obey the exponential law. In this case, the following levels of the series are given significant values in comparison with the past, since they carry more important information to determine the predicted values at the level of socio–economic security characteristics [3, p. 81].

The predictive model constructed by the exponential smoothing method contains the following form:

$$Y_{t+l} = \varphi(t) + \sigma_{t+l} \quad (1)$$

where: $\varphi(t)$ — the deterministic part;
σ_{t+l} — the margin of error;
$t + l$ — forecast period.

When using the method of exponential smoothing, the deterministic segment (the most possible variant of the forecast) is specified by the predictive model, the forecast error characterizing the upper and lower limit of the predicted values is calculated by formulas.

Let there be a time series of characteristics of socio–economic security $Y_t(t = 1,2, \ldots, n)$, which is possible to represent a polynomial of p-th degree.

$$Y_t = a_0 + a_1 t + \frac{a_2}{2!} t^2 + \cdots + \frac{a_p}{p!} t^p + \delta t \quad (2)$$

Forecast levels of socio–economic security in the time period $t + 1(t = n)$ can be computed by decomposition in Taylor series:

$$Y_{t+l} = Y_t^{(0)} + lY_t^{(1)} + \frac{1}{2!}^2 Y_t^{(2)} + \cdots + \frac{1}{k!}^k Y_t^{(k)} + \frac{1}{p!}^p Y_1^{(p)} \quad (3)$$

where $Y_t^{(k)}$— k-th derivative at the time point t. Any K-th (k=0, 1, 2, ..., p) derivative is expressed by a combination of exponential means up to (p+1) order:

$$Y_{t(y)}^{[k]} = \alpha S_{t(y)}^{[k-1]} + \beta S_{t-1(y)}^{[k]} \quad (4)$$

where α — smoothing factor.

In the scientific literature to select values of α were proposed various approaches [4, p. 118; 5, p. 92; 6, s. 78]. Thus, the best value of α is proposed to be found by comparing the variance of deviations of the actual values of the indicators of socio–economic security characteristics from the predicted ones formed by models constructed by the method of exponential smoothing using different smoothing characteristics. In this regard, the number of characteristics of socio-economic security are symbolically divided into a retrospective stage and a stage of pre-emption. According to the data of the pre-forecast period, models are formed and the forecast for the entire length of the 2nd part of the time series of socio–economic security characteristics is made. Following this, the differences between the actual values of socio–economic security characteristics and the forecast and variance of these deviations are revealed. The smallest variance characterizes the suitable variant at which it is obtained and is used for subsequent calculations.

The main defects of the approach are labour costs and the need for a long time series of socio-economic security statistics.

In practical calculations, as a rule, a method is used to show the length of the smoothing interval with values that are calculated by empirical formulas:

$$\alpha = \frac{2}{m+1}, \beta = 1 - \alpha \quad (5)$$

where: m — smoothing time (shown with the periodization of forecasting, specific cyclic characteristics of socio–economic security, etc.).

Based on the recurrent formula 4. you can represent an exponential mean expression of any order for expression 3.

$$S_{t(y)}^{[1]} = \alpha Y_{t(y)} + \beta S_{t-1(y)}^{[1]}, \quad (6)$$

$$S_{t(y)}^{[2]} = \alpha S_{t(y)}^{[1]} + \beta S_{t-1(y)}^{[2]} \quad (7)$$

$$S_{t(y)}^{[k]} = \alpha S_{t(y)}^{[k-1]} + \beta S_{t-1(y)}^{[k]} \quad (8)$$

$$S_{t(y)}^{[n]} = \alpha S_{t(y)}^{[n-1]} + \beta S_{t-1(y)}^{[n]} \quad (9)$$

Using exponential averages, it is possible to obtain a system of equations that provide an opportunity to qualify the characteristics of predictive models of a linear and quadratic form used in the practice of forecasting the characteristics of socio–economic security.

Let us form a predictive model of the linear form by exponential smoothing. The predictive model of the linear form by means of exponential smoothing is created according to the parameters of Table 1. for a smoothing period of 4 years (m=4).

Then:

$$\alpha = \frac{2}{4+1} = 0.4, \beta = 1 - \alpha = 0,6$$

Using the system of normal equations the trend parameters are revealed:

$$Y = 1360.0 + 124.855t \text{ и } \sigma_t = 148.641.$$

Then the initial conditions are calculated $S_{0(y)}^{[1]}$ and $S_{0(y)}^{[2]}$

Table 1.

PRIMARY DATA AND INTERMEDIATE CALCULATIONS TO CALCULATE THE PARAMETERS OF THE LINEAR MODEL BY THE METHOD OF EXPONENTIAL SMOOTHING

Year	Y	$S_{0(y)}^{[1]}$	$S_{0(y)}^{[2]}$	a_0	a_1	$\hat{Y}$
t–9	1637					
t–8	1683	1358.430	1134.634	1582.227	149.198	1731.425
t–7	1750	1488.258	1276.083	1700.433	141.449	1841.882
t–6	1796	1592.955	1402.083	1783.078	126.748	2909.826
t–5	1876	1674.173	1511.368	1836.977	108.536	1945.513
t–4	1983	1754.904	1608.782	1901.025	97.414	1998.439
t–3	2089	1846.142	1703.726	1988.558	94.943	2083.501
t–2	2225	1943.285	1799.550	2087.020	95.824	2182.844
t–1	2549	2055.971	1902.118	2209.824	102.568	2312.392
t	2879	2253.183	2042.544	2463.821	140.425	2604.246
t+1		2503.509	2226.930	2780.089	184.386	2964.475

Source: elaboration of author.

$$S_{0(y)}^{[1]} = \alpha_{0(t)} - \frac{\beta}{\alpha}\alpha_{l(t)} = 1360.000 - \frac{0.6}{0.4}124.855 = 1172.717$$
$$S_{0(y)}^{[2]} = \alpha_{0(t)} - \frac{2\beta}{\alpha}\alpha_{1(t)} = 1360.000 - \frac{2 \times 0,6}{0,4}124.855 = 985.435$$

In that case $S_{0(y)}^{[1]}$ and $S_{0(y)}^{[2]}$ respectively are equal:

$$S_{0(y)}^{[1]} = \alpha Y_{t-1} + \beta S_{0(y)}^{[1]} = 0.4 \times 1637 + 0.6 \times 1172.717 = 1358.435$$
$$S_{0(y)}^{[2]} = \alpha S_{t(y)}^{[1]} + \beta S_{t(y)}^{[2]} = 0.4 \times 1358.430 + 0.6 \times 985.435 = 1134.633$$

On this basis

$$\alpha_0 = 2S_{t(y)}^{[1]} - S_{t(y)}^{[2]} = 2 \times 1358.430 - 1134.633 = 1582.277$$
$$\alpha_1 = \frac{\alpha}{\beta} \times (S_{t(y)}^{[1]} - S_{t(y)}^{[2]}) = \frac{0.4}{0.6} \times (1358.430 - 1134.633) = 149.198$$
$$S_{t(y)}^{[1]} = \alpha Y_{t(y)} + \beta S_{t-1(y)}^{[1]} = 0.4 \times 1683.0 + 0.6 \times 1358.430 = 1488.258$$
$$2S_{t(y)}^{[2]} = \alpha S_{t(y)}^{[1]} + \beta S_{t-1(y)}^{[2]} = 0.4 \times 1488.258 + 0.6 \times 1134.633 = 1276.082$$

Intermediate data are included in the Table 1.

The predictive model of exponential smoothing of the linear form for t+1 year will have the form:

$$Y_{t+l} = 2780.089 + 184.386t$$

where: t=1 for t+1

Forecasted value $\widehat{Y_{t+l}}$ are calculated by putting the indicator t of the year in the forecast model:

$$\widehat{Y_{t+l}} = 2780.089 + 184.386 \times 1 = 2964.475$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$\widehat{Y_{t+l}} = 2780.089 + 184.386 \times 1 = 2964.475$$

The forecast error is calculated by the formula:

$$\sigma_{y(t+l)} = \pm\sigma_{\varepsilon t}\sqrt{\frac{\alpha}{(2-\alpha)^2}[1 + 4(1-\alpha) + 5(1-\alpha)^2 + 2\alpha(4-3\alpha)e + 2\alpha^2 e^2]}$$

where: $\sigma_{\varepsilon t}$ — the mean square error calculated for deviations from the linear trend formed by the least square's method.

$$\sigma_{y(t+1)} = \pm 148.641 \times$$
$$\times \sqrt{\frac{0,4}{(2-0.4)^3}[1 + 4(1-0.4) + 5(1-0.4)^2 + 2 \times 0.4(4 - 3 \times 0.4) \times 1 + 2 \times 0.4^2 \times 1^2]}$$
$$= \pm 129.396$$
$$\sigma_{y(t+5)} = \pm 148.641 \times$$
$$\times \sqrt{\frac{0,4}{(2-0.4)^3}[1 + 4(1-0.4) + 5(1-0.4)^2 + 2 \times 0.4(4 - 3 \times 0.4) \times 1 + 2 \times 0.4^2 \times 1^2]}$$
$$= \pm 229.448$$

Forecast data of socio–economic security indicators are summarized in Table 2.

Table 2.

FORECASTED VALUE $\hat{Y}$ and $\hat{Y} \pm \sigma_y$in t+1–t+5 years

Год	Y_{t+e}	$\sigma_{y(t+1)}$	*Lower and upper boundaries*	
			$\widehat{Y_{t+e}} - \sigma_{y(t+1)}$	$\widehat{Y_{t+e}} + \sigma_{y(t+1)}$
t+1	2964.475	129.396	2835.079	3093.871
t+2	3148.861	153.778	2995.083	3302.639
t+3	3333.247	178.698	3154.549	3511.945
t+4	3517.633	203.959	3313.674	3721.592
t+5	3702.019	229.448	3472.571	3931.467

Source: elaboration of author.

By changing the value of the smoothing period using the exponential smoothing method, it is possible to create a number of linear predictive models. Thus, linear models of exponential smoothing formed at the smoothing period of 3, 4, 5 and 6 years have the following form:

$$\widehat{Y_{(3)}} = 2822.830 + 219.1524t$$
$$\widehat{Y_{(4)}} = 2780.089 + 184.3860t$$
$$\widehat{Y_{(5)}} = 2743.712 + 163.3480t$$
$$\widehat{Y_{(6)}} = 2715.079 + 150.5091t$$

where t_1 for t+1 year is 1.

The choice of a specific forecast model can be made by comparing the deviations of the calculated levels of socio–economic security characteristics from the actual ones in the pre-forecast period. $\hat{Y}_j > Y_j$ — the minus sign, $\hat{Y}_j < Y_j$ — plus sign (Table 3).

Table 3.

COMPARATIVE DEVIATION VALUES $\hat{Y}_J$ FROM Y_J
IN THE CASE OF LINEAR EXPONENTIAL SMOOTHING MODELS, %

Year	*The smoothing period*			
	m=3	*m=4*	*m=5*	*m=6*
t–8	−4,63	−2,87	−1,67	−0,81
t–7	−5,48	−5,25	−4,81	−4,35
t–6	−5,41	−6,34	−6,72	−5,84
t–5	-2,09	−3,71	−4,77	−5,47
t–4	+0,61	−0,78	*−1,95*	−2,87
t–3	+1,00	+0,26	−0,61	−1,43
t–2	+2,15	+1,89	+1,35	+0,73
t–1	+9,05	+9,28	+9,17	+8,89
t	+7,80	+8,61	+10,57	+11,16

Source: elaboration of author.

The minimum deviations of the calculated values of the socio–economic security characteristics from the actual ones in the last year of the pre-forecast period are obtained by a linear model, a constant method of exponential smoothing at the smoothing period of 3 years (Table 3).

We construct a predictive model of the quadratic form by exponential smoothing. To form a predictive model of a quadratic form by means of exponential smoothing, we apply the data of Table 1 and smoothing period of 3 years ($\alpha = 0.5; \beta = 0.5$).

Primary conditions $S_{0(y)}^{[1]}$, $S_{0(y)}^{[2]}$ and $S_{0(y)}^{[3]}$ equal.

$$S_{0(y)}^{[1]} = a_{0(t)} - \frac{\beta}{\alpha}\alpha_{1(t)} + \frac{\beta(2-\alpha)}{\alpha}\alpha_{2(t)} = 1734.495 - \frac{0.5}{0.5} \times (-62.395) + \\ + \left(\frac{0.5(2 \times 0.5)}{0.5} 17.023\right) = 1847.959$$

$$S_{0(y)}^{[2]} = a_{0(t)} - \frac{2\beta}{\alpha}\alpha_{1(t)} + \frac{2\beta(3-2\alpha)}{\alpha}\alpha_{2(t)} = 1734.495 - 2\frac{0.5}{0.5} \times (-62.395) + \\ + \left(\frac{3 - 2 \times 0.5}{0.5} 17.023\right) = 1995.468$$

$$S_{0(y)}^{[3]} = a_{0(t)} - \frac{3\beta}{\alpha}\alpha_{1(t)} + \frac{3\beta(4-3\alpha)}{\alpha^2}\alpha_{2(t)} = 1734.495 - 3\frac{0.5}{0.5} \times (-62.395) + \\ + \left(\frac{3 \times 0.5(4 - 3 \times 0.5)}{0.5^2} 17.023\right) = 2177.023$$

where $a_{0(t)}$, $a_{1(t)}$, $a_{2(t)}$ — indicators of trends of models of the quadratic form calculated by the solution of systemthe of the normal equations — for the simulated number of levels of characteristics of social and economic safety the model will have the form:

$$\hat{Y} = 1734.495 - 62.395t + 17.023t^2 (\text{at } t_1 \text{ for } t + 1 \text{ years} = 11)$$

Calculated $S_{t(y)}^{[1]}$, $S_{t(y)}^{[2]}$ and $S_{t(y)}^{[3]}$

$$S_{t(y)}^{[1]} = \alpha Y_{t-1} + \beta S_{t-1(y)}^{[1]} = 0.5 \times 1637 + 0.4 \times 1847.959 = 1742.479$$
$$S_{t(y)}^{[2]} = \alpha S_{t(y)}^{[1]} + \beta S_{t-1(y)}^{[2]} = 0.5 \times 1742.479 + 0.5 \times 1995.461868.973$$
$$S_{t(y)}^{[3]} = \alpha S_{t(y)}^{[2]} + \beta S_{t-1(y)}^{[3]} = 0.5 \times 1868.973 + 0.5 \times 2177.023 = 2022.998$$

Model parameter a_0, a_1, a_2 equal:

$$a_0 = 3\left(S_{t(y)}^{[1]} - S_{t(y)}^{[2]}\right) + S_{t(y)}^{[3]} = 3(1742.479 - 1868.973) + 2022.998 = 1643.516$$

$$a_1 = \frac{\alpha}{2(1-\alpha)^2} \\ \times [(6 - 5 \times 0.5) \times 1742.479 - 2(5 - 4 \times 0.5) \times 1868.973 + (4 \\ - 3 \times 0.5) \times 2022.988] = 57659$$

$$a_2 = \frac{\alpha^2}{(1-\alpha)^2} \times S_{t(y)}^{[1]} - 2S_{t(y)}^{[2]} + S_{t(y)}^{[3]} \\ = \frac{0.52}{2(1-0.5)^2} \times (1742.479 - 2 \times 1868.973 + 2022.998) = 27.530$$

In that case $\hat{Y}_{t-8}$ equal 1599.611; $Y_j - \hat{Y}_j$ for t–8 years equal 83.389 ($\hat{Y}_j$ — calculated for t–8/t years).

Then, the integration calculation is repeated for $S_{t(y)}^{[1]}$, $S_{t(y)}^{[2]}$ and $S_{t(y)}^{[3]}$; a_0, a_1, a_2; $\hat{Y}_j$, $Y_j - \hat{Y}_j$.

Intermediate calculations are formed in Table 4.

Forecasted value $\widehat{Y_{t-e}}$ are calculated by the formula:

$$\hat{Y}_{t-1} = a_0 + a_{1t} + \frac{a_2}{2}t^2 \quad (10)$$

where: t_1 for t+1 years equal 1,

$$\hat{Y}_{t+1} = 2870.749 + 342.341 \times 1 + \frac{1}{2} \times 50.579 \times 1^2 = 3238.379$$

$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$$

$$\hat{Y}_{t+5} = 2870.749 + 342.341 \times 5 + \frac{1}{2} \times 50.579 \times 5^2 = 3238.379$$

The forecast error is found by the formula:

$$\sigma_{y(t+1)} = \pm\sigma_{\varepsilon t}\sqrt{2\alpha + 3\alpha^2 + 3\alpha^2 t^2}$$

where $\sigma_{\varepsilon t}$ — the standard deviation of the actual equations of characteristics of social and economic security from the calculated, calculated by the trend model of the quadratic form, and equal ± 58.2526.

Then:

$$\sigma_{t+1} = \pm 5.2556\sqrt{2 \times 0{,}5 + 3 \times 0{,}5^2 + 3 \times 0.5^3 \times 1} = \pm 84.917$$

$$\dots \qquad \dots \qquad \dots$$

$$\sigma_{t+5} = \pm 5.2556\sqrt{2 \times 0.5 + 3 \times 0.5^2 + 3 \times 0.5^3 \times 5^2} = \pm 194.297$$

Indicators $\hat{Y}_{t+1}$, $\hat{Y}_{t+1}\sigma_{y(t+1)}$, $\sigma_{y(t+1)}$ are summarized in Table 4. The models of the quadratic form formed by the method of exponential smoothing at the period of smoothing in 3, 4, 5 and 6 years will have the form:

$$\hat{Y}_{(3)} = 2870.749 + 342.341t + 1/2 \times 50.579t^2$$
$$\hat{Y}_{(4)} = 2857.399 + 316.279t + 1/2 \times 41.703t^2$$
$$\hat{Y}_{(5)} = 2845.564 + 300.589t + 1/2 \times 57.714t^2$$
$$\hat{Y}_{(6)} = 2836.365 + 219.699t + 1/2 \times 35.906t^2$$

Table 4.

PRIMARY DATA AND INTERMEDIATE CALCULATIONS FOR CALCULATING THE PARAMETERS OF THE PREDICTIVE MODEL OF EXPONENTIAL SMOOTHING OF THE QUADRATIC FORM

Year	*Y*	$S^{[1]}_{t(y)}$	$S^{[2]}_{t(y)}$	$S^{[3]}_{t(y)}$	a_0	a_1	a_2
t−9	1637						
t−8	1750	1742.479	1868.973	2022.998	1643.515	−57.659	27.530
t−7	1750	1712.739	1790.856	1906.927	1672.576	16.767	37.954
t−6	1796	1731.369	1761.113	1834.020	1744.790	78.165	43.164
t−5	1876	1763.684	1762.399	1798.209	1802.067	94.027	37.096
t−4	1983	1819.842	1791.120	1794.665	1880.830	109.387	32.266
t−3	2089	1901.421	1846.271	1820.468	1985.918	128.518	29.347
t−2	2225	1995.210	1920.740	1870.604	2094.013	135.303	24.333
t−1	2549	2110.105	2015.423	1943.013	2227.060	150.365	22.273
t	2879	2329.552	2172.487	2057.750	2528.945	262.884	42.328
t +1		2604.276	2388.382	2223.066	2870.749	342.341	50.579

Source: elaboration of author.

Table 5.

FORECAST DATA $\hat{Y}_{t+l}$, $\sigma_{y(t+l)}$ and $\hat{Y}_{t+l} \pm \sigma_{y(t+l)}$

Year	$\hat{Y}_{t+e}$	$\sigma_{y(t+e)}$	*Lower and upper boundaries*	
			$\hat{Y}_{t+e} - \sigma_{y(t+e)}$	$\hat{Y}_{t+e} + \sigma_{y(t-e)}$
t+1	3238.379	84.917	3153.462	3323.296
t+2	3635.589	105.016	3551.573	3761.605
t+3	4125.377	131.875	3993.502	4257.252
t+4	4644.745	162.168	4482.577	4806.913
t+5	5214.688	194.297	5020.391	5408.985

Source: elaboration of author.

Deviations of the actual levels of socio–economic security characteristics from the calculated ones calculated by quadratic models of exponential smoothing are given in Table 6 ($\hat{Y}_j > Y_j$ — the minus sign, $\hat{Y}_j < Y_j$ — plus sign).

Table 6.

COMPARATIVE INDICATORS OF DEVIATIONS $\hat{Y}_J$ FROM Y_J WHEN USING LINEAR MODELS OF EXPONENTIAL SMOOTHING, %

Year	*The smoothing period*			
	m=3	*m=4*	*m=5*	*m=6*
t−8	+4.95	+4.03	+3.41	+2.96
t−7	+2.38	+3.18	+3.52	+3.67
t−6	−2.70	−1.45	−0.59	+0.01
t−5	−2.05	−2.00	−1.67	−1.31
t−4	−1.18	−1.73	−1.88	−1.85
t−3	−1.92	−2.63	−3.06	−3.30
t−2	−0.74	−1.75	−2.54	+3.12
t−1	+6.28	+5.49	+4.68	+3.97
t	+2.29	+3.45	+3.92	+4.04

Source: elaboration of author.

Thus, the minimum deviation of the actual values of the socio–economic security characteristics from the calculated ones in the pre-forecast period was obtained by applying the quadratic model of exponential smoothing built at the smoothing period of 3 years. The revealed results make sense to apply in the analysis of socio–economic security at the level of the country, region and economic entity to develop certain measures to counter the detected threats.

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