ATLANTIS PRESS
Advances in Intelligent Systems Research, volume 167
International Scientific and Practical Conference "Digitization of Agriculture - Development Strategy" (ISPC 2019)

Digital models of naive, adaptive and rational expectations of regional agriculture forecasting

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***Abstract*—The development of agriculture in Russia is a high-priority task. Implementation of "Digitalization of Agriculture" program by 2021 will allow solving a number of problems existing in this industry (food security of the country, export potential increase, etc.) and creating a high-tech branch. One of the directions of "Digitalization of Agriculture" program at the regional level is "smart sectoral planning" which will allow optimizing farmer's activities when making a decision under the conditions of limited time. Currently, digitalization of agriculture in our country is at a low level. There is a lack of scientific and practical knowledge on technologies and methods in this field, a low level of forecast prices for agricultural products, etc. Let us consider the issue of adaptive forecasting in agricultural sector. The real processes in this industry take place in changing conditions, so the economic system has to adapt to them. The model describing economic system behavior will constantly adapt to the economic process. Adaptive forecasting methods allow building a class of self-adjusting models of economic systems that are able to reflect dynamic, changing over time processes in regional agricultural sector, to highlight the most significant parameters and to give fairly accurate forecasts of processes in future. The goal of this paper is to study using of adaptive methods for forecasting in the agricultural sector of the region. Using the data on the agricultural sector efficiency in certain region (Lipetsk Region), we show the mechanism of action of naive, adaptive and rational expectations models. As economical time series, statistical data were used on agricultural sector efficiency in the Lipetsk region – profitability level, parameters for output technological efficiency. As a result of studying the mechanism of action of naive, adaptive and rational models, conclusions were drawn about the feasibility of the wide acceptance of adaptive method for forecasting in the agricultural sector of the region as one of the factors for digital agriculture development.**

Keywords*—adaptive model, naive expectations model, rational model, profitability level of agricultural products, parameters of technological efficiency of agricultural production.

I. INTRODUCTION

Over recent years, adaptive methods have been widely used by domestic and foreign scientists for verifying models describing economic systems. Adaptation principles were used in economic forecasting for the first time at the beginning of the 50s of the XX century. First adaptation models were based on the exponential smoothing method proposed by R.G. Brown. Later, this field of expertise was developed by P.R. Winters, A. Leach, R. Wade, G. Tail, D. Math, S. Wageb, J. Box (Box, Jenkins, Reinsel, 2000), I.A. Muller, R. Reed, I.I. Perelman, A. Shapiro, P. Harrison, C. Holt (Holt, 1957), Jenkins (Jenkins, 2000), D. Ward, G.R. Markland, R.F. Mayer, D. Trigg, M.L. Shawn (Shaw, 1984), W. Chow, S. Roberts, A. Rao, et al., and also Russian scientists Yu.P. Lukashin, (Lukashin, Rahlina, 2012) E.M. Levitsky, A.G. Ivakhnenko, A.A. Frenkel, E.M. Chetyrkin, V.V. Vensel, V.P. Borodyuk, V.V. Davnis (Davnis, Tinyakova, 2006), P.A. Ivaschenko, A.S. Korkhin, et al. (Armstrong, 1989; Hansen, Sargent, 1991; Newey, West, 1994; Chow G.C., 1989; Pesaran, Shin Smith, R. J., 2001; Dickey, Fuller, 1979; Cesarno, 1983; Boshoff, 2012; Pesaran, Shin Y. & Smith, 2001; Katsoulacos, 2014) [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11].

Studying of adaptive methods took place in three directions: the first one was focused on the complexity of adaptive forecast models; the second one – on improving adaptive forecasting mechanism; the third direction involves the combination of adaptive principles with other forecasting methods. The works of E.M. Levitsky, V.V. Davnis [1] deal with the development of models for the combined use of adaptive forecasting with other forecasting methods. However, these forecasting models do not to the full extent take into account the properties of economic systems, in particular, in agricultural industry. Therefore, there is a need to adapt these models to real-life conditions of Russian agricultural sector.

II. METHODS

A. *Naive, adaptive and rational expectations models*

One of the main decision-making criteria is expectation. Agricultural production development depends on expected sales, investments, inflation rates, etc.

Expectations models are represented by the following types:

- Naive.
- Adaptive.
- Rational.

B. *Naive expectations models*

Investors' expectations regarding their future income in the following time period will be described using the equation.

$$y_t = \beta_0 + \beta_1 \cdot x^*_{t+1} + u \qquad (1)$$

where yt – investments in period t, - expected income in period t+1.

When making investment decisions, economic operators use income forecast for the period t+1 as reference. The parameters of equation (1) are estimated based on current and previous data.

C. Formation mechanism of adaptive expectations model

Adaptive expectations hypothesis is based on the study of past values of a variable. This means that economic operators, taking into account past values, receive a forecast for the future but it lags behind real data, since adaptation to a new situation occurs gradually. Several economic processes (for example, the dependence of wage level on inflation level) have lags, and adaptive expectations models describe precisely these economic processes.

Let us consider a model of the following type

$$y_t = a + b \cdot x^*_{t+1} + \varepsilon_t \qquad (2)$$

where y_t — actual value of resulting component;

x^*_{t+1} — value of expected factor component.

Expectations are formed as follows:

$$x^*_{t+1} - x^*_t = \alpha \cdot (x_t - x^*_t)$$

or

$$x^*_{t+1} = \alpha \cdot x_t + (1-\alpha) \cdot x^*_t$$

where $0 < \alpha < 1$.

Expected value of x_t^* variable during t period is an arithmetic average of weighted expected and actual values during the previous period. Expectations are adjusted during $t + 1$ time period for certain α fraction. Parameter α is defined as the difference between the actual and expected value of the factor component during the previous period. If α tends to 1, then probability of an event is higher, if α tends to zero, this shows the stability of existing trends. [4].

Let us insert the following formula in model (2) instead x^*_{t+1} (3):

$$y_t = a + b \cdot (\alpha \cdot x_t + (1-\alpha) \cdot x^*_t) + \varepsilon_t = a + \alpha \cdot b \cdot x_t + (1-\alpha) \cdot b \cdot x_t + \varepsilon_t \qquad (3)$$

Model (1) for period $(t\text{-}1)$ will look like this:

$$y_{t-1} = a + b \cdot x^*_t + \varepsilon_{t-1} \qquad (4)$$

Multiple (4) by $(1 - \alpha)$:

$$(1-\alpha)y_{t-1} = (1-\alpha) \cdot a + (1-\alpha) \cdot b \cdot x^*_t + (1-\alpha) \cdot \varepsilon_{t-1} \qquad (5)$$

Subtract term-by-term (5) from (3):

$$(1-\alpha)y_{t-1} = a - (1-\alpha) \cdot a + a \cdot b \cdot x_t + (1-\alpha) \cdot \varepsilon_{t-1} \qquad (6)$$

or

$$y_t = \alpha \cdot a + a \cdot b \cdot x_t + (1-\alpha) \cdot y_{t-1} + u_t \qquad (7)$$

where $u_t = \varepsilon_t - (1-\alpha) \cdot \varepsilon_{t-1}$.

Model (2) allows identifying the expected values of variable, it is a long-term function of adaptive expectations. Model (7) defines the actual values of variables, it is a short-term function of adaptive expectations.

D. Formation mechanism of rational expectations model

The theory of rational expectations is based on the concepts of John Muth [8], Thomas Sargent [9] and Robert Lucas [7]. Rational expectations of economic operators are based not only on past experience, but on the knowledge of individual experts.

Consider the model of the following type: $y_t = a + bx_{t-1} + c\, z_{t-1} + \varepsilon_t$ (8), where x_t is influenced by z_{t-1} – exogenous variable and random error ε_t.

(2)

In equation (8) lag values of x and z are used, since at the time t nothing is known about the current values x_t and z_t,. Experts form their expectations regarding x_t at the moment (t-*1*) as following: $F(x_t, l_{t-1}) = a + b\, x_{t-1} + c\, z_{t-1}$, (9), where l_{t-1} – available information at the moment t-*1*.

(8)

$$y_t - F(x_t, l_{t-1}) = \varepsilon_t. \qquad (10),$$

where variable $F(x_t, l_{t-1})$ – rational expectations as regard to variable x_t, ε_t – error in forecasting of variable y_t. Suppose that hypothesis $F(\varepsilon_t) = 0$, where ε_t is unpredictable, is true (if ε_t is predictable, experts will recompose the equation (10), so that the error will become unpredictable).

Variable y_t can be found using equation $y_t = \omega_0 + \omega_1 x_t^* + u_t$, (11), where variable $x_t^* = F(x^*_t, l_{t-1})$. (12)

Estimation procedure for rational expectations model is as follows:

1. Estimating equation (8) parameters, getting the models

$$x_t = \hat{a} + \hat{b} x_{t-1} + \hat{c} z_{t-1} + u_t \qquad (13)$$

$$\hat{x}_t = \hat{a} + \hat{b} x_{t-1} + \hat{c} z_{t-1}. \qquad (14)$$

2. $\hat{x}_t$ values are inserted in equation (11) instead of x_t^*, and estimation parameters ω_0 and ω_1 are found using LS method.

III. Results

Let us show the implementation of adaptive expectations model using the data on profitability of agricultural products in the Lipetsk region [12], [13].

Table 1 contains the data on profitability level of agricultural products sold in the Lipetsk region, %

Table 1 Profitability level for agricultural products sold in the Lipetsk region, %.

TABLE I. THE DATA ON PROFITABILITY LEVEL OF AGRICULTURAL PRODUCTS SOLD IN THE LIPETSK REGION, %

Period, X_t	**Profitability level (Y_t)**	**Period, X_t**	**Profitability level (Y_t)**
1	28.1	27	15.86
2	16.49	28	9.3
3	14.43	29	11.5
4	9.11	30	9.52
5	12.37	31	8.94
6	11.08	32	12.96
7	10.55	33	10.08
8	6.64	34	11.43
9	12.78	35	13.86
10	8.66	36	11.19
11	10.87	37	6.43
12	7.47	38	2.76
13	9.08	39	7.06
14	11.27	40	8.72
15	16.59	41	20.82
16	14.04	42	26.13
17	14.93	43	26.8
18	14.72	44	27.41
19	13.22	45	33.05
20	12.22	46	33.39
21	23.33	47	33.5
22	18.91	48	28.4
23	16.42	49	30.5
24	14.01	50	22
25	18.08	51	23.67
26	15.43	52	26.21

Let us construct the simplest adaptive model (1) which describes the dependence of the result on the actual values of the factor (Table 2, Fig. 1).

TABLE II. SOURCE DATA FOR THE SIMPLEST ADAPTIVE MODEL

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
X_t	28.1	16.5	14.4	9.1	12.4	11.1	10.6	6.6	12.8	8.7
$\alpha=0.1$	17.3	17.2	16.9	16.2	15.8	15.3	14.8	14.0	13.9	13.4
$\alpha=0.5$	22.1	19.3	16.9	13.0	12.7	11.9	11.2	8.9	10.9	9.8
$\alpha=0.9$	26.9	17.5	14.7	9.7	12.1	11.2	10.6	7.0	12.2	9.0
$\alpha_{эксп.}=0.1$	28.0	26.9	25.6	24.0	22.8	21.6	20.5	19.1	18.5	17.5
$\alpha_{эксп.}=0.5$	28.1	22.3	18.4	13.7	13.1	12.1	11.3	9.0	10.9	9.8
$\alpha_{эксп.}=0.9$	28.1	17.7	14.8	9.7	12.1	11.2	10.6	7.0	12.2	9.0
	11	12	13	14	15	16	17	18	19	20
X_t	10.9	7.5	9.1	11.3	16.6	14.0	14.9	14.7	13.2	12.2
$\alpha=0.1$	13.1	12.6	12.2	12.1	12.6	12.7	12.9	13.1	13.1	13.0
$\alpha=0.5$	10.3	8.9	9.0	10.1	13.4	13.7	14.3	14.5	13.9	13.0
$\alpha=0.9$	10.7	7.8	9.0	11.0	16.0	14.2	14.9	14.7	13.4	12.3
$\alpha_{эксп.}=0.1$	16.9	15.9	15.2	14.8	15.0	14.9	14.9	14.9	14.7	14.5
$\alpha_{эксп.}=0.5$	10.3	8.9	9.0	10.1	13.4	13.7	14.3	14.5	13.9	13.0
$\alpha_{эксп.}=0.9$	10.7	7.8	9.0	11.0	16.0	14.2	14.9	14.7	13.4	12.3
	21	22	23	24	25	26	27	28	29	30
X_t	23.3	18.9	16.4	14.0	18.1	15.4	15.9	9.3	11.5	9.5
$\alpha=0.1$	14.1	14.5	14.7	14.7	15.0	15.0	15.1	14.5	14.2	13.8
$\alpha=0.5$	18.2	18.5	17.5	15.7	16.9	16.2	16.0	12.7	12.1	10.8
$\alpha=0.9$	22.2	19.2	16.7	14.3	17.7	15.7	15.8	10.0	11.3	9.7
$\alpha_{эксп.}=0.1$	15.4	15.7	15.8	15.6	15.9	15.8	15.8	15.2	14.8	14.3
$\alpha_{эксп.}=0.5$	18.2	18.5	17.5	15.7	16.9	16.2	16.0	12.7	12.1	10.8
$\alpha_{эксп.}=0.9$	22.2	19.2	16.7	14.3	17.7	15.7	15.8	10.0	11.3	9.7
	31	32	33	34	35	36	37	38	39	40
X_t	8.9	13.0	10.1	11.4	13.9	11.2	6.4	2.8	7.1	8.7
$\alpha=0.1$	13.3	13.3	12.9	12.8	12.9	12.7	12.1	11.2	10.7	10.5
$\alpha=0.5$	9.9	11.4	10.7	11.1	12.5	11.8	9.1	5.9	6.5	7.6
$\alpha=0.9$	9.0	12.6	10.3	11.3	13.6	11.4	6.9	3.2	6.7	8.5
$\alpha_{эксп.}=0.1$	13.7	13.7	13.3	13.1	13.2	13.0	12.3	11.4	10.9	10.7
$\alpha_{эксп.}=0.5$	9.9	11.4	10.7	11.1	12.5	11.8	9.1	5.9	6.5	7.6
$\alpha_{эксп.}=0.9$	9.0	12.6	10.3	11.3	13.6	11.4	6.9	3.2	6.7	8.5
	41	42	43	44	45	46	47	48	49	50
X_t	20.8	26.1	26.8	27.4	33.1	33.4	33.5	28.4	30.5	22.0
$\alpha=0.1$	11.6	13.0	14.4	15.7	17.4	19.0	20.5	21.3	22.2	22.2
$\alpha=0.5$	14.2	20.2	23.5	25.4	29.2	31.3	32.4	30.4	30.5	26.2
$\alpha=0.9$	19.6	25.5	26.7	27.3	32.5	33.3	33.5	28.9	30.3	22.8
$\alpha_{эксп.}=0.1$	11.7	13.2	14.5	15.8	17.5	19.1	20.6	21.3	22.3	22.2
$\alpha_{эксп.}=0.5$	14.2	20.2	23.5	25.4	29.2	31.3	32.4	30.4	30.5	26.2
$\alpha_{эксп.}=0.9$	19.6	25.5	26.7	27.3	32.5	33.3	33.5	28.9	30.3	22.8

	51	52	53	54	55	56				
X_t	23.7	26.2	20.7	19.6	20.0	17.0				
α=0.1	22.3	22.7	22.5	22.2	22.0	21.5				
α=0.5	24.9	25.6	23.1	21.4	20.7	18.8				
α=0.9	23.6	25.9	21.2	19.8	20.0	17.3				
$α_{эксп.}$=0.1	22.4	22.8	22.6	22.3	22.0	21.5				
$α_{эксп.}$=0.5	24.9	25.6	23.1	21.4	20.7	18.8				
$α_{эксп.}$=0.9	23.6	25.9	21.2	19.8	20.0	17.3				

After assessment of parameters α = 0.27, b = 0.44, a =3.74, we will get the long-term model function of the simplest adaptive model (Fig. 1).

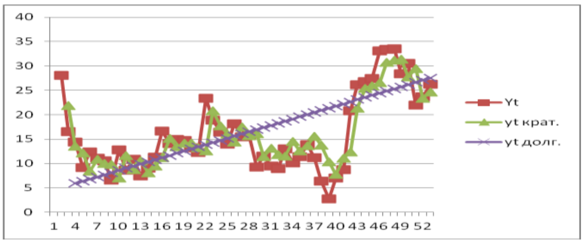

Fig. 1. Forecast of profitability level of agricultural products in the Lipetsk region using the simplest adaptive model.

According to the adaptive expectations model (6), let us construct a short-term function that describes the dependence of the result on the actual values of the factor (Table 3, Fig. 2).

According to the rational expectations model (8), the equation has the form $y_t = -3 + 1{,}2x_t^* + u_t$ (Table 4, Figure 3).

TABLE III. SOURCE DATA FOR ADAPTIVE EXPECTATIONS MODEL

X_t	2	3	4	5	6	7	8	9	10
Y_t	16.49	14.43	9.11	12.37	11.08	10.55	6.64	12.78	8.66
Y_{t-1}	28.1	16.49	14.43	9.11	12.37	11.08	10.55	6.64	12.78
X_t	11	12	13	14	15	16	17	18	19
Y_t	10.87	7.47	9.08	11.27	16.59	14.04	14.93	14.72	13.22
Y_{t-1}	8.66	10.87	7.47	9.08	11.27	16.59	14.04	14.93	14.72
X_t	20	21	22	23	24	25	26	27	28
Y_t	12.22	23.33	18.91	16.42	14.01	18.08	15.43	15.86	9.3
Y_{t-1}	13.22	12.22	23.33	18.91	16.42	14.01	18.08	15.43	15.86
X_t	29	30	31	32	33	34	35	36	37
Y_t	11.5	9.52	8.94	12.96	10.08	11.43	13.86	11.19	6.43
Y_{t-1}	9.3	11.5	9.52	8.94	12.96	10.08	11.43	13.86	11.19
X_t	38	39	40	41	42	43	44	45	46
Y_t	2.76	7.06	8.72	20.82	26.13	26.8	27.41	33.05	33.39
Y_{t-1}	6.43	2.76	7.06	8.72	20.82	26.13	26.8	27.41	33.05
X_t	47	48	49	50	51	52			
Y_t	33.5	28.4	30.5	22	23.67	26.21			
Y_{t-1}	33.39	33.5	28.4	30.5	22	23.67			

The short-term function of adaptive expectations model is $y_t = 1{,}01 + 0{,}12 \cdot x_t + 0{,}73 \cdot y_{t-1} + u_t$ (Fig. 1).

After assessment of parameters *α* = 0.27, *b* = 0.44, *a* =3.74, we will get the long-term function of adaptive expectations model $y_t = 3{,}74 + 0{,}44 \cdot x^*_{t+1} + \varepsilon_t$ (Fig. 2).

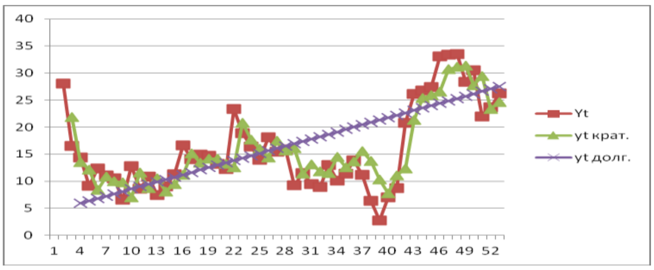

Fig. 2. Short-term and long-term forecast of profitability level of agricultural products in the Lipetsk region using adaptive expectations model.

According to the rational expectations model (8), the equation has the form $y_t = -3 + 1{,}2x_t^* + u_t$ (Table 4, Fig. 3).

TABLE IV. SOURCE DATA FOR RATIONAL EXPECTATIONS MODEL

№	1	2	3	4	5	6	7	8	9
X_t	28.1	16.5	14.4	9.1	12.4	11.1	10.6	6.6	12.8
X_{t-1}		28.1	16.5	14.4	9.1	12.4	11.1	10.6	6.6
Z_{t-1}		3.6	2.5	1.7	3.3	5.1	2.5	0.4	2.1
№	10	11	12	13	14	15	16	17	18
X_t	8.7	10.9	7.5	9.1	11.3	16.6	14.0	14.9	14.7
X_{t-1}	12.8	8.7	10.9	7.5	9.1	11.3	16.6	14.0	14.9
Z_{t-1}	6.2	0.8	-0.2	1.9	2.5	3.5	1.8	6.8	5.6
№	19	20	21	22	23	24	25	26	27
X_t	13.2	12.2	23.3	18.9	16.4	14.0	18.1	15.4	15.9
X_{t-1}	14.7	13.2	12.2	23.3	18.9	16.4	14.0	18.1	15.4
Z_{t-1}	5.4	0.6	3.9	5.0	1.9	-1.1	0.3	3.7	1.5
№	28	29	30	31	32	33	34	35	36
X_t	9.3	11.5	9.5	8.9	13.0	10.1	11.4	13.9	11.2
X_{t-1}	15.9	9.3	11.5	9.5	8.9	13.0	10.1	11.4	13.9
Z_{t-1}	2.8	4.2	4.7	0.2	-2.7	1.7	2.3	2.4	0.7
№	37	38	39	40	41	42	43	44	45
X_t	6.4	2.8	7.1	8.7	20.8	26.1	26.8	27.4	33.1
X_{t-1}	11.2	6.4	2.8	7.1	8.7	20.8	26.1	26.8	27.4
Z_{t-1}	1.9	1.9	1.6	1.1	1.7	4.0	3.5	0.6	6.5
№	46	47	48	49	50	51	52		
X_t	33.4	33.5	28.4	30.5	22.0	23.7	26.2		
X_{t-1}	33.1	33.4	33.5	28.4	30.5	22.0	23.7		
Z_{t-1}	10.6	0.0	-0.6	3.4	2.3	0.9	-0.7		

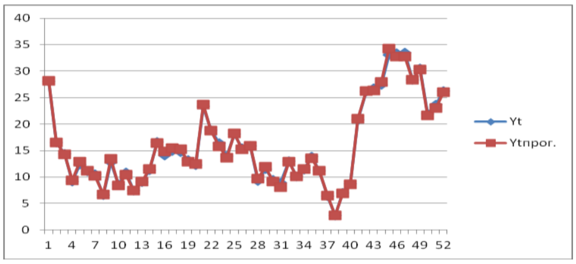

Fig. 3. Forecast of profitability level of agricultural products in the Lipetsk region using rational expectations model

IV. DISCUSSION

Using of the simplest adaptive model is reasonable for predicting the parameters of agro-industrial complex of certain region; this model should be adapted to real-life economic processes. In this regard, it is necessary to implement a rational component (expert task of initial level). In this case, the mechanism of the simplest adaptation model gives good results in predicting the parameters of the agro-industrial complex of certain region.

Adaptation expectations model gives good results for long-term forecasting. In the short-term forecasting, it is necessary to constantly adapt the parameter α. For such adaptation, for example, the function may be used where α means dependence on any variable reflecting hikes and declines of the economic system, or on difference between calculated and real data.

Using of rational expectations model is reasonable for time series analyzing provided that economic operators are experts in their field and have mathematical tools for analysis

V. CONCLUSION

Using of adaptive technique allows accurate assessments of the activities of the agro-industrial complex of certain region and predicting its further development. Therefore, it is reasonable, within the framework of "Digitalization in Agriculture" program, to use adaptive forecasting approach and automated assessment procedures based on the abovementioned mechanism.

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