Basics of Building and Analyzing Adaptively Targeted Forecast Models for Supply Chain Management

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***Abstract*— Forecasting is an under estimated field of research in supply chain management. To describe the methodology for building adaptively targeted forecast models based on the recursive least squares method and to show the possibility of using these models in economic analysis. Two cases were studied, which include targeting by a single given target value and by a target trajectory described by several consecutive values. It was shown that for the autoregressive model in the case of setting several target values, the multistep procedure of the recursive least squares method is not applicable. It was also possible to clarify the necessity of introducing changes into the adaptive regression analysis scheme for the case when the adaptively targeted model is built on the basis of the autoregressive one. Procedures for building adaptively targeted models for supply chain management of setting target conditions have been proposed. The adaptive regression analysis technique has been modified for the case of an adaptively targeted autoregressive model.**

***Keywords*—** *Targeting, regression, auto regression, adaptive analysis, supply chain management, adaptive targeting analysis.*

1. Introduction

In supply-chain management, the effort of minimizing total costs in terms of reduction in chain-wide inventory has been increasingly addressed and attempted in industry. During the last two decades, however, achieving this objective has been more difficult, as customer demands become more diverse and the life cycles of products are shorter. The term "adaptively targeted forecasting model" is new and therefore requires some explanation, from which, as it seems to us, the role of adaptive modeling in building such forecast models will become clear. Undoubtedly, when building forecast trajectories using adaptively targeted models, adaptation ideas should be used, but this use is different from how it occurs when building adaptive regression models. To understand this difference, we consider the simplest situations involving various methods for making forecast calculations. Suppose, for example, that the first method uses the classic version, involving the use of a regression model. Usually, with the help of this method, the patterns of the past period are transferred to the future. If in the processes of the past stable behavior was observed and the loss of this stability is not expected, such an approach justified itself and had the right to practical use. In those cases when changes in patterns are observed over time, one should focus on an adaptive approach, with the help of which the trends of the last period are transferred to the future. Such an opportunity is provided by models in which an adaptive mechanism is foreseen. Using an adaptive mechanism, models of this type are constantly reconfigured, while maintaining their adequacy to the real process. It is this possibility that allows adaptive models to transfer the patterns of the last period to the future. Moreover, as a rule, it is recommended to use adaptive models for conducting short-term forecasts, in which the regularities of the last period are often reproduced [1-4].

2. Adaptive Targeting

In this paper, we propose adaptive inventory-control models for a supply chain consisting of one supplier and multiple retailers. It follows from the logic of the foregoing that the patterns of the past are transferred to the future to a greater or lesser extent. The targeting-based approach involves changing the patterns of the past in accordance with the target settings that determine the new nature of the processes of the future. But this does not mean that the future can be described by completely new

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patterns that have no connection with the past. The main problem is that these new patterns grow out of the patterns of the past period and, therefore, the transition process of the past to the future should be reflected in the model.

Naturally, the model with which the transition processes to be reproduced should have a mechanism by which this transition process is realized. An adaptive mechanism should be recognized as the most suitable option [2, 3, 4]. But the role of this adaptive mechanism differs from the role that it played in the adaptive model. In the adaptively targeted model, the adaptive mechanism works only once in order to - by using the target value -perform the targeting procedure, according to which there occurs a targeted change from the model which reflects the patterns of the past period to a model which considers the expectations of the future period.

In fact, the adaptively targeted model is similar in its structure to an adaptive one, so it makes sense to consider those options of adaptive models that can be used to build adaptively targeted forecast trajectories. We will mainly be interested in those approaches that are used in the practice of building adaptive models.

Note that adaptive models are used not only in economics [5]. Naturally, the requirements that are imposed on models focused on application in technology differ from those that are imposed on models used in economic forecasting. If, for example, the speed of convergence to optimal parameters, the speed of performed calculations, and the compactness of software are valued in technology, then in economics, as a rule, it is necessary to implement the possibility of obtaining results that have a meaningful interpretation. Hence, the question arises regarding the choice of a method, as well as of a model that is most suitable for economic applications. It is clear that this requirement limits the range of adaptive modeling methods that can be useful in economic forecasting. Given the basic requirement, as well as the experience of econometric studies, special attention should be paid to the capabilities of the least squares method. If we remain within the framework of multifactor linear modeling, then without a doubt, the least squares method is the main tool for building such models. It provides statistically reliable results guaranteeing the credibility of the analysis and the possibility of pro-active calculations. And yet another question arises, the positive answer to which is decisive in the choice of a method. The question concerns the possibilities of building such a model using this method that will ensure the implementation of the target impact on the forecast trajectory. The least squares method, in our opinion, provides such a possibility [6].

However, it is not with the help of the classical least squares method scheme that this possibility is implemented, but with the help of its recurrent scheme. The recursive calculations option for the least squares method has been known for a long time, but, unfortunately, is not studied in econometrics courses [7, 8], and therefore remains less known Inter alia, it should be noted that the problem of the digital economy, associated with the need to process huge amounts of information, can very well be solved using a recurring calculation scheme. For us, it is important that with the help of the recurrence scheme, an adaptive mechanism can be built into the regression model, with the help of which the model can respond to target settings and, accordingly, perform the targeting of the forecast trajectory. Consider two options for a recursive least squares method.

First, we answer the question, why there are two schemes of the recursive least squares method needed. This is due to the method by which the target settings of the socio-economic development in the future period can be assigned. The first method in our view is that formally, for the entire anticipatory period, only one value of the target setting is assigned. In this case, the forecast model should change according to a single target value using the built-in adaptive mechanism in such a way so as to calculate the values of the targeted forecast trajectory.

The second method may include assigning the target settings in the form of a trajectory, which, as a rule, is set by several points of the expected development. In this case, two targeting options are possible. It is possible, for example, to target a forecast trajectory sequentially, for a corresponding number of times, for each point, repeatedly implementing the first option. The second option provides for the implementation of targeting at once for several points that specify the target trajectory. Theoretically, determining the preference of a variant in this case is very difficult. Much depends on the model with which forecast calculations will be carried out.

Consider the first method of targeting operation for the autoregressive model used in forecast calculations [9]

$$x_t = b_0 + b_1 x_{t-1}, \quad (1)$$

whose coefficients were estimated using the least squares method.

Implemented using the so-called one-step recursive scheme of the least squares method, the reconfiguration of the forecast model parameters is carried out using a formula that can be written as follows for the targeting operation

$$\boldsymbol{b}^T = \boldsymbol{b} + \frac{\boldsymbol{C}_t^{-1}\boldsymbol{x}_t'}{\boldsymbol{x}_t\boldsymbol{C}_t^{-1}\boldsymbol{x}_t'+1}[x_{t+1} - \boldsymbol{x}_t\boldsymbol{b}], \quad (2)$$

where

$\boldsymbol{b}$ – vector of forecast model coefficients before targeting;

$\boldsymbol{b}^T$ - vector of forecast model coefficients after targeting;

$\boldsymbol{x}_t = (1, x_t)$ – vector with the value of the last observation as a component;

x_{t+1} - target value;

$C_t^{-1} = (\boldsymbol{X}_t'\boldsymbol{X}_t)^{-1}$ - the inverse matrix of the system of normal equations of the least squares method.

The above formula provides the possibility of recursive recalculating of the regression coefficients in the case of new observations. In the function of a new observation in solving the forecast problem, we will use the values of the target settings, with the help of which an attempt is made to purposefully change the patterns reflected by the forecast model.

Practically, the formula is applicable in cases where a single value of the target setting is specified. In practice, there are situations when the target trajectory is set for the desired growth dynamics of a certain indicator in the future. Typically, the trajectory is defined by several consecutive values, each of which is considered as newly arrived. In this case, for a more accurate reflection in the model of all the features of the expected development of the forecasted process, it is convenient to use the multi-step recurrent least squares method.

Omitting the detailed conclusion, we write the formula for the multi-step recurrent least squares method of Sherman - Morrison - Woodbury [10]

$$b^T = b + C_t^{-1}X_{t+k}'\left(X_{t+k}C_t^{-1}X_{t+k}' + I_k\right)^{-1}[x_{t+k} - X_{t+k}b], \quad (3)$$

where

$\boldsymbol{x}_{t+k} = (x_{t+1}, x_{t+2}, \cdots, x_{t+k})'$ - k – dimensional vector from target values;

$\boldsymbol{X}_{t+k}$ – matrix of k rows with factor values;

$\boldsymbol{I}_k$ –. unitary matrix $k \times k$.

The written formulas make it possible to understand that recurrent estimation is an apparatus necessary for the target settings to be taken into consideration when building the forecast model. However, using the recursive approach only, in fact, allows the target of values to be recognized as observable values that have properties similar to the observations that took place in the historical period. Naturally, the inclusion of the target values in the number of observed values may well lead to a change in the model, but an insignificant one. In other words, the recurrent method does not allow reflecting the special role of the target value in the model. To reflect this special role, it is necessary, first of all, to weaken the influence of past observations on the estimated model and, due to this, to strengthen the influence of the target value. Such an opportunity is realized if, instead of the recurrence formula, the adaptive estimation formula built on its basis is used.

Adaptive estimation differs from the recursive one by introducing a special smoothing parameter, with the help of which the past values are forgotten. In adaptive procedures, this parameter is adjusted according to a control sample, the data of which are not used in model building but are intended for testing the built model in order to determine the accuracy of its forecasting capabilities. It is clear that adaptive targeting should use this parameter, but with a slightly changed purpose.

First of all, it should be noted that in adaptive targeting it does not make sense to weight each observation, as it is done when building adaptive models. However, the problem of weighting the data according to the degree of their influence on the characteristics of the forecast model remains, but it has different goals from adaptation and is solved in a different way. The main difference is that when targeting there is a need to determine the proportion of patterns of the past period that should be present in the generated forecast trajectory, that is, at the same time, the degree of influence of all past values on the future is reduced. Therefore, in the recurrence formula, in accordance with which the coefficients of the model are changed, there must be a parameter that ensures, in a sense, the regulation of the influence of the past on the future. And this means, targeting should be based on an adaptive procedure, and not the recursive one. In the general case, when using the one-step procedure, when the forecast calculations are based on the autoregressive model, the targeting operation should be carried out using the following formula

$$\boldsymbol{b}^T = \boldsymbol{b} + \frac{\boldsymbol{C}_t^{-1}\boldsymbol{x}_t^{'}}{\boldsymbol{x}_t\boldsymbol{C}_t^{-1}\boldsymbol{x}_t^{'}+\alpha}[x_{t+1} - \boldsymbol{x}_t\boldsymbol{b}]$$

(4)

in which the value of the parameter α is in the interval (0; 1).

The introduction of an adjustable parameter into the targeting procedure leads to the necessity of solving an additional problem of determining its value. Unfortunately, there is no way to determine the optimal value of this parameter. An intuitive idea of how many patterns of the past should be contained in the future is not always acceptable and, as a rule, requires additional studies to clarify the dependence of targeting results on changes of the value of this parameter. As a rule, this requires multivariate calculations.

In those cases when the target idea of the future is given by a trajectory described by several values, it is recommended to use the recursive multi-step least squares method. But this recommendation refers only to regression models. If an autoregressive model is used for forecasting, then the multistep least squares procedure is not applicable. The main problem is that the calculated value obtained in the previous step is used as a factor in evaluating the coefficients of the autoregressive model. It is not possible to build a procedure in which forecast values are calculated simultaneously with obtaining the model coefficients. Therefore, instead of a multi-step procedure, it is necessary to reuse the one-step procedure with an intermediate obtaining of calculated values. We write down the details of this procedure for targeting the autoregressive model under the assumption that m target values are given

$$x_{t+k} = b_0^{k-1} + b_1^{k-1}x_{t+k-1}, \quad k = \overline{1,m} \qquad (5)$$

$$b^k = b^{k-1} + \frac{C_{t+k-1}^{-1}x_{t+k}^{'}}{x_{t+k}C_{t+k-1}^{-1}x_{t+k}^{'}+\alpha}[x_k^T - x_{t+k}b^{k-1}] \qquad (6)$$

The notation used to record this procedure was introduced above when considering the one-step approach. The described targeting scheme provides that for $k = 1$ there is an initial model, the coefficients of which were determined on the basis of data from the past period.

The implementation of a multi-step approach to targeting is actually equivalent to using a forecast model in an adaptive mode of operation on the period of time at which changes are foreseen using the target settings of the patterns described by the model. In addition, the computational scheme (5) - (7) implements an adaptive procedure for an autoregressive rather than a regressive model. One more feature should be noted. This computational scheme is applicable both in the case of continuous targeting and in the case of targeting with some pauses without using an adaptive mechanism.

3. Analysis on the Basis of Adaptively Targeted Models for supply chain

We deal with the inventory-control problem of a two-echelon supply-chain system consisting of one supplier and multiple retailers. The adaptive targeting apparatus of the forecast model for supply chain provides the ability to conduct multivariate calculations to form a forecast image of the future. Naturally, there comes a need to compare the results of such calculations among themselves. However, for comparison, criteria are needed by which it would be possible to understand how one version of the calculation differs from another version. For these purposes, it is quite possible to use a comparative analysis of the modeled options, which, due to its specificity, will be called target analysis.

This analysis involves comparing the models obtained after targeting with the base model that describes the patterns that dominated in the past. As a result of such a comparison, it is possible to present the changes that are the result of targeting and are taken into consideration when forming the corresponding variant of the forecast trajectory, by the sum of two effects. One of these effects is called inertial. With its help, that part of the trajectory of the future is evaluated that was formed in accordance with the patterns that dominated in the past period. The second effect is the targeting effect. It allows you to evaluate the part of the trajectory of the future, which is formed due to the changes which came as a result of targeting the coefficients of the forecast model. In fact, this is the result whose dynamics we would like to see in the expected future, and which was foreseen by the targeting operation.

Thus, the target analysis allows us to compare options for computational experiments among themselves on the most important characteristics. And although this comparison does not allow us to uniquely determine the preferred option, it nevertheless gives a fairly complete picture of each option. In addition, it is possible to understand the reaction of the results of applying the targeting procedure to changes in the values of the parameter α. Based on these results, the mechanism of the interrelation between the components of the target analysis and the value of the targeting parameter, which is selected in accordance with the proportion of patterns of the past period transferred to the future, is easily defined.

Thus, from the foregoing it follows that the use of adaptive targeting in the practice of generating trajectories of a forecast image requires an integrated approach involving special studies to select the most appropriate forecast options. The application of an integrated approach, as a rule, significantly increases the time spent on obtaining the final result. But nevertheless, this additional investment of time justifies the result in which the mathematical calculations are consistent with the intentions of the target expectations.

The basis of the target analysis are the ideas of adaptive regression analysis [11, 12]. At first glance, it might seem that applying the adaptive analysis procedure can be applied to the adaptive targeting model without problems. To understand whether there is a problem with its application or not, let us turn to the consideration of the question related to the analysis of quantitative changes that are reflected in the forecast model after the targeting procedure has been carried out. It is known and mentioned above that the targeting operation is carried out using the adaptive mechanism, which is provided for in the forecast model. As a result of this operation, the coefficients of the model change and, therefore, the tendency described by the calculated values of the model changes. Of particular interest is the change in the coefficient b_1, which in the meaningful interpretation is understood as a parameter characterizing the degree of dependence of the future represented by forecast calculations on the past. The target settings with which help the targeting operation is carried out practically determine the nature of the desired changes to this parameter. In order to analyze the nature of possible changes, it is necessary to record the difference between the values of the forecasted indicator before the targeting operation and after this operation. But the first calculation after the targeting operation is different from the following calculations. Therefore, let's take a closer look at the situation that occurs after targeting. To do this, we write out the model that was before the targeting operation, and the model that turned out after the targeting operation

$$x_t = b_0 + b_1 x_{t-1} \quad (8)$$

$$x_t^T = b_0^T + b_1^T x_{t-1} \quad (9)$$

Let us consider due to what the change in the value of the forecasted indicator occurred. To do this, we write the difference

$$x_t^T - x_t = b_0^T - b_0 + (b_1^T - b_1)x_{t-1} \quad (10)$$

or

$$\Delta x_t = \Delta b_0 + \Delta b_1 x_{t-1}. \quad (11)$$

From the expression obtained, it follows that the calculated value after targeting changes by a value, which, in accordance with the above defined terminology, is determined on the basis of the intensive component. It is natural. The purpose of the targeting procedure is, by design, to change the intensive component of the model. Only with a change in the intensive component does it become possible to form a forecast image from trajectories that describe patterns that differ from patterns of the past period. Thus, using targeting, the intensive component of the forecast model changes.

Now consider the second step in the calculation of the forecast trajectory, which is carried out after targeting. To do this, we write out the original model and the model transformed using the targeting operation. We will assume that the calculations are simultaneously performed using the original and targeted models

$$x_{t+1} = b_0 + b_1 x_t$$

(12)

$$x_{t+1}^T = b_0^T + b_1^T x_t^T$$

(13)

Consider the difference of these expressions

and carry out a series of transformations with the resulting expression. To do this, we first subtract and add to this expression the value $b_1^T x_t$, as a result we get

$$x_{t+1}^T - x_{t+1} = b_0^T - b_0 + (b_1^T x_t^T - b_1^T x_t) + (b_1^T x_t - b_1 x_t)$$

. (15)

We will carry out an operation similar to the one we just performed one more time. To do this, subtract and add to the same expression $b_1 x_t^T$.

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As a result, we get a representation of the difference between the value obtained after targeting the model and the value that was present before targeting

$$x_{t+1}^T - x_{t+1} = b_0^T - b_0 + (b_1^T x_t^T - b_1 x_t^T) + (b_1 x_t^T - b_1 x_t)$$

. (16)

To obtain an expression that allows a meaningful interpretation of the targeting operation, we will add these two expressions (15) and (16). Then, making simple transformations, we reduce similar elements and divide them after the reduction by 2. As a result of these operations, we obtain an expression of the following form, convenient for a meaningful interpretation

$$x_{t+1}^T - x_{t+1} = b_0^T - b_0 + \frac{b_1^T + b_1}{2}(x_t^T - x_t) + \frac{x_t^T + x_t}{2}(b_1^T - b_1)$$

. (17)

The resulting expression highlights the extensive and intensive components, with the help of which it is possible to structure the effect of targeting and to evaluate on the quantitative level the substantial meaning of the results of the targeting operation. For a more compact record, the resulting expression, and the convenience of a meaningful interpretation, we introduce the notation

$$\Delta x_{t+1} = x_{t+1}^T - x_{t+1};$$

$$\Delta x_t = (x_t^T - x_t);$$

$$\Delta b_0 = b_0^T - b_0;$$

$$\Delta b_1 = (b_1^T - b_1),$$

then, using the notation introduced, expression (17) can be rewritten in the form

$$\Delta x_{t+1} = \Delta b_0 + \frac{b_1^T + b_1}{2} \Delta x_t + \frac{x_t^T + x_t}{2} \Delta b_1$$

. (18)

Thus, the expression obtained allows us to present at a formal level in a structured form the changes that should be reflected in accordance with targeting in the forecasted process in the form of three components.

The first component, as a rule, is not meaningfully interpreted, identifying it with a value that has concentrated the influence of all factors unaccounted for in the model. The composition of unaccounted factors is not controlled, although, of course, its changes occur over time, which, of course, should be reflected in the forecast model. Despite the generalizing and insufficiently accurate characteristic of this component, its influence on the level and orientation of the forecast trend is quite noticeable and, therefore, should be taken into consideration.

The second and third components have a clearly understood interpretation, with the help of which the sources of changes in the forecasted indicator are determined. So, the second component shows the changes that should occur in the future due to changes in the volume dimensions of the forecasted indicator. The third component shows the changes that can occur in the dynamics of the forecast trajectory as a result of changes in the degree of influence of the past on the future. Moreover, and it should be noted, the magnitude of changes due to volume is calculated using the average coefficient of the forecast model, and the value obtained due to changes of the degree of influence of the past on the future, is determined with the current value of the average volume of the forecasted indicator.

The expression (18) allows us to determine the changes occurring after targeting in the forecast trajectory only in the absolute values of the actually observed process. As a rule, comparisons based on absolute values may not always provide sufficient correctness. Therefore, we transform this expression in such a way that it allows for a comparative analysis in relative values. To do this, we divide the left and right parts of this expression by the value of the forecast indicator that it had before targeting, and we get the following expression

$$\frac{\Delta x_t}{x_t} = \frac{\Delta b_0}{x_t} + \frac{b_1^T + b_1}{2}\frac{\Delta x_{t-1}}{x_t} + \frac{x_{t-1}^T + x_{t-1}}{2}\frac{\Delta b_1}{x_t} \quad (19)$$

The resulting expression is a weighted sum of relative values. The first component of this expression should be understood as the share of those changes that can be introduced into the processes of the future by those factors that are not taken into consideration by the model. If it turns out that this proportion is excessively large, then one needs to revise the model with which the image of the future is formed.

The second component of this expression shows the share of changes in the dynamics of the forecasted indicator, which is formed by changing the value of the indicator itself. In essence, this is an extensive component of expected growth in the future. If it prevails in the forecast trajectory, then this implies that ensuring the growth of this indicator will require additional resources. From this we can conclude that the target setting focuses on such an approach to the development of the future, in which there will be an appropriate share of costly solutions.

According to the third component of expression (19), one can determine the share of the expected growth of the forecasted indicator, which is formed on the basis of changes in the degree of influence of the past on the future. This should be understood as a situation where in the past growth opportunities in the future were established and these opportunities were taken into consideration in the target setting, on the basis of which the adaptive targeting procedure was carried out. The third component is essentially the intensive component of the target analysis.

4. Computational Experiment

To illustrate the logic and results of the target analysis, consider a numerical example. Let the data on the number of small and medium-sized enterprises be given by the following numerical series:

x_1=425.7; x_2=437.8; x_3=434.8; x_4=413.2; x_5=444.4; x_6=499.0; x_7=554.5.

The autoregressive model built using the least squares method is as follows

$$x_t = -209.353 + 1.522x_{t-1},$$

R^2=0.735.

The process is clearly not stable ($b_1 >$ 1), therefore, it is impractical to use the model for forecasting.

We will set the target value with the possible growth rates of the achieved level in the expected future: δ_1=1.111. Then the value of the target variable is: x_{t+1}^{T1}=554.5·1.111=616.173.

As a result, after the first step of targeting, we get

$$x_{t+1}^{T1} - x_{t+1} = b_0^{T1} - b_1 + (b_1^{T1} - b_1)x_t =$$

=-148.433 - (-209.353) + (1.3819-1.5216) × 554.5 = -16.573

The results of the analysis allow us to conclude that the growth of small and medium-sized enterprises was excessively high. Due to this, even a rather high value of the set target variable ensured the correction of the model to reduce growth.

Now consider the details of the target analysis after the second step of autoregressive calculations. For a given target variable, we obtain

$$x_{t+2}^{T1} - x_{t+2} = b_0^{T1} - b_0 + \frac{b_1^{T1} + b_1}{2}(x_{t+1}^{T1} - x_{t+1}) + \frac{x_{t+1}^{T1} + x_{t+1}}{2}(b_1^{T1} - b_1) =$$

=-148.433 - (-209.353) + (1.382+1.522) / 2 × (617.826-634.399) +

+ (617.8264+634.3997) / 2 × (1.3819-1.5216) =

= 60.919 – 24.061 – 87.501= -50.642

The results of the analysis show that due to unaccounted factors, the calculated value should have increased by 60.9198. At the same time, targeting the model to reduce the growth of the forecasted indicator in the future led to a situation where the extensive component of growth turned out to be negative (-24.061). At the same time, due to the same reasons after targeting, the value of the auto regression coefficient was reduced, which led to a negative value of the intensive growth component (-87.501). Calculations showed that as a result of adaptively targeted transformation of the model, the forecast would decrease by 50.642.

5. Conclusion

The purpose of this work is to explore how advanced forecasting methods for supply chain management could be applied in global supply chain management and their requirements. The methodology for building adaptively targeted models for supply chain management and their application in the formation and analysis of forecast options is not only original, but also very useful for substantiating the forecast image of the future. However, to say that using this analysis you can choose the best forecast option is absolutely wrong. At the same time, according to the results of the analysis, it is possible to understand the nature of the interrelation of target settings with the dynamic properties of the forecast options. This focuses on the possibility of implementing computational experiments using this model, according to the results of which future ideas are considered and the effectiveness of the options specified by the target settings is investigated.

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