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Forecasting and Managing the Development of Regional Manufacturing Based on Econometric Modeling and Digital Interface

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Abstract. The article focuses on modeling, forecasting, and scenario-based management of manufacturing output, using the Nizhny Novgorod Region as a case study. The relevance of the work stems from the need of government authorities and businesses for a reliable tool when making strategic decisions under conditions of economic uncertainty. The main objective is to construct econometric models that provide medium-term forecasts of industrial output shipments and to develop a digital calculator with a web interface for analyzing various scenarios of industrial sector development. The scientific novelty of the study is fourfold: (1) an extended Cobb – Douglas production function incorporating macro-level conditions is refined; (2) an approach to separately modeling the real and inflationary components of industrial output shipments is proposed and implemented; (3) a novel methodological technique for forecasting one price index (the producer price index, PPI) based on another (the consumer price index, CPI) is proposed and implemented; and (4) new approaches to scenario modeling of the regional economy that incorporate macro-forecasts are proposed and implemented. The study employs a wide range of time-series econometric methods, including ARIMAX and ARDL models, stationarity tests, residual diagnostics, and automated specification selection. The principal findings consist of two predictive ARDL models, which were integrated into the newly developed digital calculator with a user-friendly web interface. It is shown that real manufacturing output in the Nizhny Novgorod Region is influenced by the value of fixed assets in the "Manufacturing" type of economic activity, the permanent resident population, retail trade turnover, the monthly average consumer price index, and the price of Urals crude oil. Based on the constructed models, a digital calculator was developed – a flexible tool that enables users to promptly assess the consequences of changes in key macroeconomic parameters, compare alternative development scenarios, and produce analytically grounded forecasts of the region's manufacturing development. This tool appears highly useful for government authorities and other users in planning and optimizing production processes.

Key words: manufacturing, volume of industrial output shipments, Nizhny Novgorod Region, ARDL model, ARIMAX model, digital calculator.

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Introduction

Industrial production in most regions of the Russian Federation is the most important component of their economic life, determining competitiveness and prospects for further economic development. One of the basic indicators demonstrating the activity of the industrial sector of the economy is the volume of shipped products of its own production. The shipment reflects the degree of demand for manufactured products within and outside the region and allows assessing the effectiveness of its manufacturing sector. In modern conditions, this indicator is of particular importance, since Russian industrial enterprises face many challenges, both from the geopolitical situation and the availability of global markets, as well as internal conditions related to the problems of import substitution and technological development, the growing tax burden and the high cost of credit resources.

It is worth noting that forecasting the volume of shipments in the medium term is not an easy task. Modern economic processes are characterized by a high degree of uncertainty and unpredictability. Economic sanctions, the COVID-19 pandemic, technological innovations and other factors create additional difficulties in the strategic management of the region's industrial sector. Therefore, the introduction of innovative forecasting methods is becoming relevant, which will allow for more accurate consideration of external and internal circumstances affecting the activities of enterprises.

This study considers forecasting industrial production using the example of the Nizhny Novgorod Region, which is one of the top 5 Russian regions in terms of scientific and technological development[1], which suggests the potential for further industrial growth. The region has large production facilities in the field of mechanical engineering, chemical industry, instrument engineering and many other industries. The industrial complex in the Nizhny Novgorod Region produces a third of the gross regional product, makes a third of payments to the budget and creates a quarter of all jobs in the region[2]. We will limit ourselves to considering the manufacturing industry in our study since the extractive industry of the Nizhny Novgorod Region, due to limited natural resource potential of the region, does not represent a significant share of industrial production. However, an objective assessment of the current state and development prospects of the industrial sector is possible only if reliable forecasting tools are available. That is why there is a need to develop a scientifically sound methodology that makes it possible to most accurately predict the volume of shipments of manufacturing products in the region and determine its sensitivity to both internal and external factors.

The aim of the study is to build an econometric model for medium-term forecasting of the shipment of own-made products by the economic activity "Manufacturing" in the Nizhny Novgorod Region and to develop a digital calculator with a web-based user interface.

We set and solved the following tasks to achieve this aim: analysis and selection of variables (factors) that affect the shipment of manufacturing products in the Nizhny Novgorod Region; construction of econometric models for the shipment of manufacturing products in the Nizhny Novgorod Region of two types: an autoregressive moving average model with additional regressors (ARIMAX) and an autoregressive and distributed lag model (ARDL); selection of the most adequate and suitable specification among the obtained models for making forecasts; construction of forecast models for various scenarios of the development of the macro-economic situation in the Russian Federation; design and implementation in the JavaScript programming language (ECMAScript 2015 – ES6 standard) using HTML5 and CSS3 technologies of a digital forecast calculator for the shipment of manufacturing products in the Nizhny Novgorod Region.

The relevance of the research is due to the need to develop effective forecasting tools in the regions in order to design various scenarios for the region's development, taking into account the impact of certain external shocks and control influences. The need for such developments is also explained by the fact that the current mechanisms for building plans and forecasts in regional government structures often do not provide for the use of advanced data analysis and forecasting methods based on the involvement of a large pool of regional indicators, but are guided by federal forecasts. In addition, the level of use of modern digital technologies in

[1] The development strategy of the Nizhny Novgorod Region. 2023. Available at: https://strategy.nobl.ru/stati/nauka-i-innovaczii/chem-proslavilas-nizhegorodskaya-nauka-etoj-osenyu/

[2] Ministry of Industry, Trade and Entrepreneurship of the Nizhny Novgorod Region. Available at: https://minprom.nobl.ru/activity/1746/

forecasts of the socio-economic development of the region remains low, which determined the direction of research development. The results of the work can be used by executive authorities and business entities to improve the quality of forecasts and the effectiveness of decisions made in managing the regional industrial sector.

The literature review will show a lot of current Russian studies on forecasting industrial production, but they either relate to the Russian Federation economy as a whole without taking into account regional specifics, or are limited to building econometric models without conducting interactive scenario analysis. Incorporating macroeconomic environment parameters (oil prices, exchange rates, inflation, etc.) into models, along with supply and demand factors, will allow interested economic agents not only to make forecasts based on econometric models, but also to conduct scenario experiments for more correct management of industrial production in the region.

Literature review

A number of works by Russian and foreign researchers are devoted to the problems, factors and methods of managing the development of the industrial production sector at the federal and regional levels.

For example, the work of N.M. Sergeeva and E.V. Skripkina emphasizes that manufacturing, mining, wholesale and retail trade remain the leading industries in the structure of gross value added (GVA) of the Russian economy despite the crisis and sanctions pressure (Sergeeva, Skripkina, 2024).

The indicator of the volume of shipments of own-made products, completed works and services by industrial enterprises is recognized as one of the key indicators of the state and dynamics of the industrial sector (Pirogova, Maiorova, 2025; Shvaika, Khripin, 2025; Sokolova, Sidorov, 2022). Forecasting it at the regional level is important for shaping development strategies, making operational management decisions, and evaluating the effectiveness of import substitution policies. The studies highlight the heterogeneity of industrial development in Russian regions and, as a result, the need for regional specification of predictive models. For instance, it was revealed a significant differentiation in the industrial development of the regions of the Central Federal District (CFD): an increase in the share of manufacturing industry in the Moscow and Tula regions was accompanied by a decrease in this share in Moscow (Pirogova, Maiorova, 2025). This highlights the need to develop different forecast scenarios even within the same federal district. In this regard, research on forecasting industrial production indicators in certain regions of the Russian Federation is particularly relevant (for example, Gladkikh, Malugina, 2023; Sokolova, Sidorov, 2022).

An important task is to identify factors that have a significant impact on the resulting industry indicators at both the national and regional levels when building a forecast model. For example, in L.G. Rudenko's work, regression analysis revealed the following significant determinants of the growth of manufacturing production in Russia: the volume of mining, the net financial result of organizations, the number of workers and the number of organizations involved in research and development (Rudenko, 2024). Regression analysis has shown that the factors determining the GVA of the industry of the Central Federal District, excluding Moscow and the Moscow Region, are fixed assets and employment of the region's population (Krupko et al., 2018). In the work (Gubarev et al., 2020), fixed assets and labor resources of individual industries are also considered as determinants of the GVA of industry.

The research of M.Yu. Malkina for the regions of the Nizhny Novgorod Region cluster revealed a positive impact on GRP growth of both supply factors (accumulated fixed assets, current investments, number of employees) and demand factors (per capita income in the previous period), as well as monetary (interest rate) and fiscal policy instruments (budget revenue and expenditure and their structure). The paper notes that rising oil prices are accompanied by an increase in energy exports earnings and budget revenues, and this makes it possible to increase funding of the national economy, including manufacturing and infrastructure industries, as well as various social programs that contribute to the growth of household incomes and consumer demand (Malkina, 2025).

One of the approaches to forecasting regional economic indicators is the decomposition of macro forecasts: the forecast at the regional level is based on the distribution of national indicators by type of economic activity. For example, A.O. Polynev suggests a methodology for medium-term forecasting of regional GRP growth based on the decomposition of the macro forecast for Russia, where investment dynamics is a key factor (Polynev, 2020). Other scientists consider it more correct to move not from federal forecasts to regional forecasts, but rather from regional to federal forecasts, which allows taking into account the potential and development characteristics of each region (Mikheeva, 2018).

Modern scientific literature uses a number of approaches to predict the socio-economic development of a region. The most common is econometric and regression modeling: models are built that link the resulting indicator with factor indicators. For example, the work (Kalinina, Kalinina, 2012) considers regression analysis as the basic one for forecasting industrial indicators: the predicted value of the performance indicator is obtained by substituting the expected value of the factor indicator into the regression equation.

Another effective predictive modeling tool is time series analysis and trend forecasting, which is used to identify patterns and extrapolate dynamics. For example, A.V. Shchetilov applies analytical alignment (linear and polynomial trends) for retrospective analysis and forecasting in the metalworking and mechanical engineering subsectors until 2030 (Shchetilov, 2025).

A modern, promising tool for predictive modeling is the construction of neural network models. For example, this approach is being implemented to forecast the development of the manufacturing industry in the Voronezh Region (Treshchevskii et al., 2020).

Scenario and expert approaches are effective in conditions of high instability, when formal models quickly lose relevance. For example, in a study of the manufacturing industry, quantitative analysis is complemented by an expert assessment of risk factors (Shchetilov, 2025). In general, a combination of different approaches (econometric, trend-based, neural network, and expert) should be considered the most promising to improve forecast accuracy.

Forecasting works also use other methods of predicting economic processes. For example, scenario forecasts for the industrial complex of the Southern Federal District of the Russian Federation are being developed on the basis of cognitive modeling, and its response to impulse impact are being determined (Makarenya et al., 2024).

A large pool of forecasting works in the foreign literature concerns macro-economic indicators at the national level (such as economic growth rate, inflation rate, budget revenues), which is explained by the need of regulatory authorities. Less frequently, there are works devoted to forecasting a particular industry or a complex of industries in a country or region (Baum et al, 2025; Bodo et al, 2000; Wang et al, 2025; Zervas, Thomakos, 2026). An example is the article (Serban et al., 2021), which examines the GVA of the high-tech industries of the EU countries, assesses the contribution of investments and the number of employees to it. Panel data are used for analysis, and models are evaluated using the generalized method of moments. Another study developed a scenario-based system for monthly forecasting of industrial production in the eurozone

(Georgieva, et al., 2025). Key macro-economic indicators were used for forecasting: the rates of inflation (HICP) and unemployment, as well as the business climate index. As the study result, the authors concluded that industrial production is more sensitive to adverse macro-economic shocks than to positive shocks, which underscores the importance of short-term management of inflation and business sentiment. The paper also substantiates the importance of using dynamic scenario analysis in forecasting, which provides a flexible tool for monitoring the economy in real time.

The work (Akhmadjanov, Hakimov, 2025) built a multifactorial predictive model to estimate the volume of gross output of industrial enterprises in the Andijan region in Uzbekistan from 2024 to 2030 using multiple regression, the elasticity coefficients of which indicate a constant increase in production efficiency, despite fluctuations in the efficiency of the use of fixed assets. In the article (Lu, 2024), an ARIMA model was built for modeling and forecasting the GDP of the Nanyang City District in China. Based on the Pearson correlation coefficients and the analytical hierarchy method, the relationship of the district's GDP with environmental indicators (number of enterprises, employees and industrial pollution) is analyzed, and the significant instability of the region's ecological development is demonstrated.

A completely new approach in our study is to create an add-on to econometric models in the form of digital calculator. This calculator can be considered as part of a more complex digital product – the digital twin of the region. The topic of digital twins is currently becoming increasingly popular for research and development. However, there is some uncertainty in the interpretation of this concept (Singh et al., 2021), which is why this term can refer to various digital objects in various fields of science. The authors believe that the main feature of digital twins, which distinguishes them from digital models, "shadows" and avatars, are automated bidirectional information flows. From the point of view of economics, the natural sphere where the application of this concept arises first is production. The paper (Warke et al., 2021) analyzes research on the topic of digital twins in the field of "smart" production, and (Turan et al., 2022) describes a specific example of the introduction of a digital twin into the production process in the form of a digital application and shows that this allows optimizing material costs. The article (Pobuda, 2020) notes that at the macro level of individual countries' economies, agent-based simulation becomes an effective tool for building digital twins that could be used to make strategic management decisions.

Literature analysis shows that, despite the significant scientific interest of scientists in the problem of forecasting, there is a clear shortage of modern research devoted to forecasting the industrial production indicators of the region with the inclusion of macro-economic shocks and regulatory instruments in econometric models and the formation of different scenarios for the development of the industrial sector in the region. We have not found any works where such models are equipped with a digital calculator integrated with a managed user interface. The present study aims to fill this gap.

Data and methods

The object of the study is the indicator of the shipment of own-made products by type of economic activity "Manufacturing" (excluding VAT, excise taxes and similar mandatory payments) in the Nizhny Novgorod Region (million rubles), and the subject is its medium-term forecasting. The choice of the indicator is due to the fact that it is one of the main operational indicators of industrial activity, available on a monthly basis, obtained on the basis of the primary reporting of enterprises. In addition, it characterizes not only the production, but also the sale of products, that is, it indicates their demand in the market.

The theoretical basis of the research consists of the main provisions of economic theory and system analysis, as well as the results of fundamental and applied research by foreign and Russian scientists in the field of macro-economics and economic and mathematical modeling. We used methods of mathematical statistics and econometrics to solve specific problems.

To describe the dependent variable Y, the shipment of own-made products by type of economic activity is "Manufacturing" (excluding VAT, excise taxes and similar mandatory payments) in the Nizhny Novgorod Region in millions of rubles[3] – it was formed a set of factors x_1, x_2,..., x_m, which were further tested for input into the model. The initial choice of factors is based on theoretical assumptions: it takes into account the traditional form of the Cobb – Douglas production function, supply and demand factors, and monetary conditions in the region, which is confirmed by the analysis of scientific literature (Bazhanov, Oreshko, 2019; Domnich, 2023; Malkina et al., 2025). The final selection of factors is determined by their statistical significance in the analyzed specifications. The data covered the period from 2017 to 2025. Table 1 shows the system of indicators.

We used Google Colab, a cloud service for interactive computing in the Python programming language, to conduct statistical analysis and build econometric models.

The first step in preparing the data for analysis was to bring the indicators at current prices to the constant prices of the base year. We chose 2017 as the base year, which is the initial year of the data set. For deflation, either producer price indices for the type of economic activity "Manufacturing" or consumer price indices in the Nizhny Novgorod Region were used, depending on the nature of the factor being studied.

The use of econometric models requires that the time series contain a sufficient number of observations, and the indicators included in the model have the same frequency. We should also consider that information related to earlier periods of time is less relevant for current analysis due to the rapidly changing institutional and macro-economic environment. Therefore, the study used data for a more modern period (corresponding to the functioning of the Russian economy under the sanctions regime), but on a monthly basis. Since monthly statistics are not available for all indicators, it has become necessary to convert annual or quarterly data to a monthly format. The spline interpolation method recommended in the scientific literature was chosen (Vlasenko, 2019; Portilla et al., 2025; Ribeiro, Castro, 2022) to accomplish this task. Similar transformations were applied to two indicators of fixed assets, population, current assets, investments and average per capita monetary income. The dynamics of these indicators does not imply too rapid and sharp fluctuations during the year (and in the case of investments during the quarter), which makes the considered methodology quite appropriate. In addition, final forecasts are generated by aggregating monthly data by year, which reduces the impact of interpolation on the forecast.

At the final stage of data preprocessing, the time series was checked for seasonality and, if necessary, the time series was cleared of the seasonal factor using statistical filtering. To bring the time series to a stationary form, they were determined by taking logarithmic differences for all indicators except for indicators of macro-economic conditions. The additive time series model was considered as the basis at this stage:

$$Y_t = T_t + S_t + E_t, \tag{1}$$

where T_t – trend,

S_t – seasonal component,

E_t – random component.

[3] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/57722 (accessed: 07.02.2026).

Table 1. Indicators presumably affecting industrial production in the Nizhny Novgorod Region

Variable	Naming of the indicator	Units of measurement	Duration of the time interval and frequency of measurement	Average	Minimum	Maximum	Standard deviation
In the Nizhny Novgorod Region							
Capital_res	Availability of fixed assets at the residual book value for the full range of organizations at the beginning of the period by type of economic activity “Manufacturing”[1)]	billion rubles	2017–2024; annual	383.3	319.5	464.0	55.5
Capital	Availability of fixed assets at full book value for the full range of organizations at the beginning of the period by type of economic activity “Manufacturing”[1)]	billion rubles	2017–2024; annual	872.9	658.0	1143.6	178.8
CurrentAssets	Value of current assets of large and medium-sized organizations at the beginning of the period by type of economic activity “Manufacturing”[2)]	billion rubles	I quarter 2017 – I quarter 2025; quarterly	936.4	554.5	1689.6	350.5
Investment, Investment12, Investment24	Investments in fixed assets by all forms of ownership: for the current period, with a lag of 1 and 2 years by type of economic activity “Manufacturing”[3)]	billion rubles	I quarter 2014 – IV quarter 2024; quarterly	23.1	4.6	80.6	16.6
Credit	Volume of loans to resident legal entities and individual entrepreneurs by type of economic activity “Manufacturing”[4)]	billion rubles	January 2017 – June 2025; monthly payments	23.3	6.3	70.7	14.6
Labour	Average number of employees (excluding external part-timers) in the full range of organizations by type of economic activity “Manufacturing”[5)]	thousand people	January 2017 – May 2025; monthly	253.8	246.3	270.0	4.8
Population	Permanent population at the beginning of the year [6)]	million people	2016–2024; annual	3.15	3.05	3.24	0.07
Incomes1	Average per capita monetary income of the population with a lag of 1 month [7)]	thousand rubles	I quarter of 2016 – I quarter of 2025; quarterly	40.0	28.0	73.4	11.6
*Inc*Popul*	Total monetary incomes of the population (own compilation)	billion rubles	January 2017 – January 2025; monthly	124.2	90.4	216.1	28.9
RetailTrade1	Retail trade turnover with a lag of 1 month [8)]	million rubles	December 2016 – June 2025; monthly	76,922	49,035	120,889	18,536
Inflation	Monthly average value of consumer price indices for goods and services [9)]	%	February 2016 – June 2025; monthly	6.3	-1.3	21.4	4.1

End of Table 1

Variable	Naming of the indicator	Units of measurement	Duration of the time interval and frequency of measurement	Average	Minimum	Maximum	Standard deviation
PPI	Producer price indices by type of economic activity "Manufacturing" (compared to the previous month) [10)]	%	January 2017 – August 2025; monthly	100.7	94.6	106.1	1.7
In the Russian Federation							
Dollar	Average monthly official exchange rate of the U.S. dollar against the ruble [11)]	rubles per U.S. dollar	January 2017 – July 2025; monthly	73.1	56.4	103.7	12.8
KeyRate, *KeyRate1*, …, *KeyRate6*	Key rate for the current month and with a lag of 1 to 6 months [12)]	% per annum	January 2016 – June 2025; monthly	9.9	4.3	21.0	4.7
RealKeyRate, *RealKeyRate1*, …, *RealKeyRate6*	Real key rate for the current month and with a lag of 1 to 6 months (calculated by the authors taking into account inflation)	% per annum	February 2016 – June 2025; monthly	3.4	-6.6	13.3	4.7
Urals,	Urals oil price [13)]	thousand rubles	January 2017 – February 2025; monthly	4.7	1.1	8.6	1.5
Urals$		$		64.7	15.1	98.0	14.2

[1)] Territorial body of the Federal State Statistics Service for the Nizhny Novgorod Region. Available at: https://52.rosstat.gov.ru/folder/32667 (accessed: 07.02.2026).
[2)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/59586 (accessed: 07.02.2026).
[3)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/58090 (accessed: 07.02.2026).
[4)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/38366 (accessed: 07.02.2026).
[5)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/57848 (accessed: 07.02.2026).
[6)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/31557 (accessed: 07.02.2026).
[7)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/57039 (accessed: 07.02.2026).
[8)] EMISS. Government statistics. Available at: https://52.rosstat.gov.ru/folder/204282 (accessed: 07.02.2026).
[9)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/31074 (accessed: 07.02.2026).
[10)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/57609 (accessed: 07.02.2026).
[11)] EMISS. Government statistics. Available at: https://www.fedstat.ru/indicator/42108 (accessed: 07.02.2026).
[12)] Bank of Russia. Available at: https://cbr.ru/statistics/ddkp/infl/?UniDbQuery.Posted=True (accessed: 07.02.2026).
[13)] Infotables.ru. Available at: https://infotables.ru/statistika/95-tseny-tarify/1325-tsena-na-neft-tablitsa#urals (accessed: 07.02.2026).
Source: own compilation.

This method of component analysis is basic and has been studied in detail in the literature (for example, Tindova, Lesneva, 2023). We should note, however, that when constructing ARIMAX models, both purified and non-purified seasonality data were used, because the model specification allows identifying the seasonal factor. In the considered data set, the indicators of industrial product shipments were subject to seasonal influence.

The next step of the research was the construction of econometric models. The traditional form of the Cobb – Douglas production function was chosen as the theoretical basis, which is reduced to an additive form by logarithm and is further used to model the dependence of output on production factors (Kapitanova, Zinyakov, 2023).

$$\ln y_t = \beta_0 + \beta_1 \ln x_{1t} + \cdots + \beta_j \ln x_{jt} + \cdots + \beta_n \ln x_{mt} + \varepsilon_t. \quad (2)$$

where y_t is the shipment of products of own production by the type of economic activity "Manufacturing";

x_{jt} – variables included in the model;

β_j – coefficients of the models;

ε_j – random residuals of the corresponding models;

$j = \overline{1,m}$; m –number of variables included in the model.

Since economic indicators have certain specifics due to the existence of lags and the spider web effect, the model has been expanded to include lag values of dependent and explanatory variables.

The study tested two types of time series models:

– autoregression-moving average model with additional regressors (ARIMAX)

$$y_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i y_{t-i} + \sum_{j=1}^{q} \beta_j \varepsilon_{t-j} + \sum_{k=1}^{m} \gamma_k x_{t-k} + \varepsilon_t. \quad (3)$$

– autoregression and distributed lag model (ARDL)

$$y_t = a_0 + \sum_{i=1}^{p} a_i y_{t-i} + \sum_{j=0}^{q} b_j x_{t-j} + \varepsilon_t. \quad (4)$$

The autoregression and distributed lag model is a special case of the autoregression moving average model, taking into account additional regressors, and is placed in a separate category only due to different methods of technical implementation of the modeling process. These types of models are often used to describe various socio-economic processes, which is confirmed in the literature (Pilnik et al., 2018; Rizki, Didenko, 2025; Ji, 2025; Sahoo et al., 2025). The advantages of the ARDL model are that it is the most suitable way to describe short time series, allows evaluating long-term and short-term effects (cointegration), and also works with series of the order I(0) and I(1) in a mixture. The ARIMAX model demonstrates good predictive accuracy over small time intervals, as well as flexibility in accounting for seasonality and trends, which makes it possible to use it for both initial time series and deseasonalized and detrended data. It is also theoretically possible to use other time series models (for example, VAR, HVAR, DFM, neural network models). At the same time, vector autoregression models require stationarity of all series, which must necessarily be long enough. In addition, with a large number of variables, degrees of freedom are lost. Dynamic factor models are difficult to interpret and adjust with a short history. Neural network methods do not allow identifying the influence of individual variables and do not work well on small samples.

The model should include factors that correspond to the Cobb – Douglas production function, such as capital (fixed assets) and labor (number of employees or population). Other factors that describe the resource base of industrial enterprises in the Nizhny Novgorod Region (investments, volume of loans and current assets) can also be included in the model; demand factors (retail trade turnover, per capita and total household incomes) and macro-economic conditions (key interest rate with a lag of 0 to 6 months, inflation, dollar exchange rate and oil price). A set of different combinations of these groups was formed, according to which a search of possible specifications was carried out. Further, the algorithm was slightly different for the two types of models, due to the specifics of the technical tools.

For the ARIMAX models, the order of the AR and MA components ranged from 0 to 3, and the order of the differences from 0 to 2. To account for possible under-adjusted seasonal fluctuations, the order of the seasonal components was from 0 to 2. Further, using cycles and logical checks, those models were selected, all factors in which are significant according to t-statistics, there is no autocorrelation in the balances (according to the Ljung – Box test) and heteroscedasticity (according to the Breusch – Pagan test), and the signs of the coefficients for capital and labor are positive (due to the type of production function). Among all the constructed models, those with a real key rate with a negative coefficient were selected, which is also conditioned by theoretical assumptions. A similar check was performed on data that was not seasonally adjusted. SARIMAX models were also built, allowing both to include exogenous factors and to take into account seasonality. The final selection of the models was based on the Akike (AIC), Bayes (BIC) and Hennan – Quinn (HQIC) information criteria for each set.

ARDL models were based only on desezonalized data. We used the function of automatically selecting the optimal model order based on the criteria of information efficiency when analyzing the data: Akike (AIC), Bayesian (BIC) or Hennan – Quinn (HQIC). Among all the models built, we selected those that include the necessary components – indicators describing capital, labor, and the macro-economic situation, and they are significant according to t-statistics. Only intermediate lags can be insignificant because the chosen Python toolkit does not allow them to be excluded.

Results of the research

Table 2 shows the two selected best ARIMAX models that meet all the above quality criteria.

Table 3 presents the two best ARDL models selected according to the algorithm described above.

The residuals of the ARDL models were tested for heteroscedasticity using the ARCH-LM test, which applies the Lagrange multiplier (LM) method to detect autoregressive conditional heteroscedasticity (ARCH) in the residuals for lag 1–10. This test showed that the residuals have a uniform variance (homoscedastic). Due to the fact that the ARDL model combines elements of dynamic regression with lagged dependent variables and lags of exogenous variables, the basic assumptions of conventional autocorrelation tests are violated, and their use to test autocorrelation in residuals becomes incorrect. Therefore, the study analyzed autocorrelation and partial autocorrelation functions (ACF and PACF), which indicate the absence of visible patterns in the residual, and it can be assumed that autocorrelation is absent in both models.

We should note that for the constructed models, the Jarque – Bera test results indicate a deviation from the hypothesis of a normal distribution of residuals. However, for ARIMAX class models, this requirement is unnecessary due to the fact that the parameter estimates are consistent and asymptotically normal when the stationarity conditions are met and there is no serial correlation in the residuals. In addition, standard errors consistent to heteroscedasticity and autocorrelation (HAC) were used to evaluate the significance of the model coefficients.

Based on the results of the root mean square error (RMSE) estimation, both ARDL models were selected for all the constructed models, on the basis of which a medium-term strategic forecast for the period up to 2027 was built. The average forecast for two ARDL models was used as the final result.

Table 2. ARIMAX models for the indicator of shipment of manufacturing products at constant prices

Variable	ARIMAX model for seasonally adjusted data	ARIMAX model for seasonal data
Capital	0.70 (0.07)	0.94 (0.04)
Labour	2.33 (0.02)	
Population		3.39 (0.00)
RealKeyRate4	-0.01 (0.06)	
Inflation		-0.01 (0.00)
Urals$		0.01 (0.00)
RetailTrade1		1.53 (0.00)
ar.L1	-0.78 (0.00)	
ma.L1	0.56 (0.03)	0.46 (0.00)
sigma2	0.01 (0.00)	0.02 (0.00)
AIC	-109.78	-104.37
BIC	-96.12	-87.27
HQIC	-104.34	-97.49
RMSE	10173.03	8320.63
Ljung – Box test	0.00 (0.99)	0.01 (0.91)
Breusch – Pagan test	0.84 (0.66)	1.45 (0.33)
Jarque – Bera test	39.57 (0.00)	22.35 (0.00)

Note. The p-values are shown in parentheses. The null hypothesis of the Ljung – Box test indicates the absence of autocorrelation in the residuals. The null hypothesis of the Breusch – Pagan test assumes homoscedasticity of the data. The Jarque – Bera test uses as a null hypothesis the assumption that the residuals have a normal distribution.
Source: own compilation.

Table 3. ARDL models for the indicator of shipment of manufacturing products at constant prices

Variable	Model 1	Model 2
Y.L1	0.55 (0.00)	0.56 (0.00)
Y.L2	0.27 (0.01)	
Capital.L0		0.63 (0.00)
Population.L0		370.15 (0.00)
Population.L1		-371.14 (0.00)
Inflation.L0	-0.002 (0.05)	
RetailTrade1.L0	0.89 (0.00)	
RetailTrade1.L1	-0.74 (0.00)	
Urals$.L0		0.0001 (0.9)
Urals$.L1		0.003 (0.01)
AIC	-242.65	-221.45
BIC	-228.14	-204.43
HQIC	-236.82	-214.61
RMSE	4763.85	5111.64
Jarque – Bera test	23.92 (0.00)	9.24 (0.00)

Note. The p-values are shown in parentheses. L0, L1, and L2 are used to indicate the current period, lag 1 and lag 2, respectively.
Source: own compilation.

Thus, in the final model, the shipment of manufacturing products in the Nizhny Novgorod Region is influenced by the following indicators:

– availability of fixed assets by type of economic activity "Manufacturing" at full book value for a full range of organizations at the beginning of the period (billion rubles): a positive coefficient reflects the effect of the classical production function – capital growth increases output;

– number of permanent population at the beginning of the period (million people): a positive coefficient for the current month's population and a negative coefficient for the lag value, which are close in modulus, may be the result of a high correlation of successive lags, which makes estimates of individual coefficients unstable; the long-term multiplier for the population in terms of cointegration will be close to zero (this means that in the long term, the population has little effect on shipping, which is economically plausible for the Nizhny Novgorod Region, where production is focused not only on domestic demand, but also on interregional supplies and exports);

– retail trade turnover (million rubles): a positive current effect (0.89) and a negative lag effect (-0.74) can be interpreted as the effect of saturation or transfer of demand over time, when growth in the current period is further adjusted and slows down;

– average monthly value of consumer price indices for goods and services (%): a negative coefficient for inflation shows that rising prices reduce real incomes and, consequently, demand for industrial products;

– Urals oil price (U.S. dollar): the positive effect for the Nizhny Novgorod Region, characterized by a poorly developed mining and a fairly highly developed manufacturing industry, is explained by the indirect influence of the budget channel: the growth of oil revenues in the federal budget increases transfers to regional budgets, government procurement and investments in the region.

In practice, future shipment values are of interest, both in comparable and current prices. In particular, the nominal figures are of interest to the tax and budget system. To translate the forecast values for shipments at constant prices into current prices, the forecasting of chain consumer price indices (CPI) and chain producer price indices (PPI) deflators for the Nizhny Novgorod Region was carried out. The projected values of the CPI deflator index were calculated based on the baseline forecast of the socio-economic development of the Nizhny Novgorod region in 2025 (8.8%) and forecasts for 2026 (5%) and 2027 (4.0%)[4]. Next, the dependence of the PPI deflator chain index on the CPI deflator chain index for the Nizhny Novgorod Region was modeled based on monthly data for 2017–2024, and their long-term ratio was determined. *Figure 1* shows the actual data and the constructed logarithmic regression.

The forecast values of the PPI chain deflator indices for 2025–2027 were determined based on the revealed logarithmic dependence and the forecast values of the CPI chain deflator indices for the same period. Calculations of forecast deflator indices made it possible to further bring all indicators modeled in constant prices to current prices.

We made forecasts of the following indicators (model factors) were made at constant and current prices to build a medium-term shipment forecast.

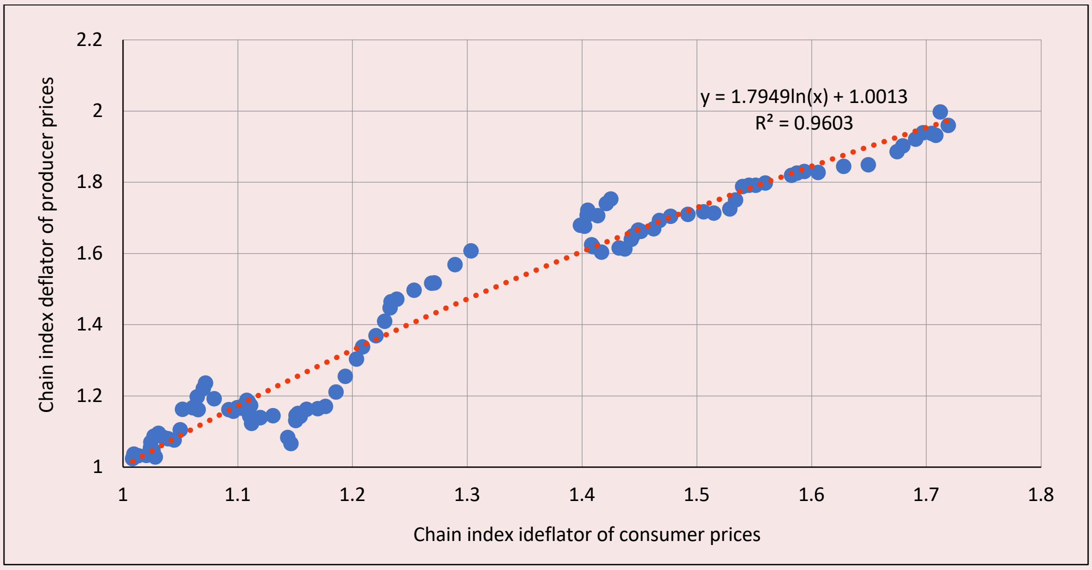
1. Availability of fixed assets by type of economic activity "Manufacturing" at full book value for the full range of organizations at the beginning of the period (billion rubles).

A stationarity check was performed for the time series. The extended Dickey – Fuller Test (ADF) and the Kwiatkowski – Phillips – Schmidt – Shin test (KPSS) showed that the series is stationary in the first differences. According to ACF and PACF, a preliminary model order was determined for the first differences, which was then adjusted to take into account the significance of variables and components.

Table 4 presents the results of the SARIMA model construction in the column "Capital".

[4] The forecast of the socio-economic development of the Nizhny Novgorod Region for the medium term (for 2026 and for the planned period of 2027 and 2028). P. 3, 6. Available at: http://publication.pravo.gov.ru/document/5200202510270003?index=1

Figure 1. Relationship between the chain producer price indices (PPI) and consumer price indices (CPI) in the Nizhny Novgorod Region



Source: own compilation.

Based on the model, we obtained a forecast of fixed assets in constant prices for the period up to 2027. With the help of the previously predicted producer price chain index, it was transformed into a forecast of the indicator at current prices. *Figure 2* shows both in dynamics.

2. Retail trade turnover (billion rubles).

The ADF and KPSS tests proved that the series is stationary in the first differences. The ACF and ACF were constructed for the first differences, and the model order was refined based on the significance of variables and

Table 4. Building SARIMA models for predicting factor indicators

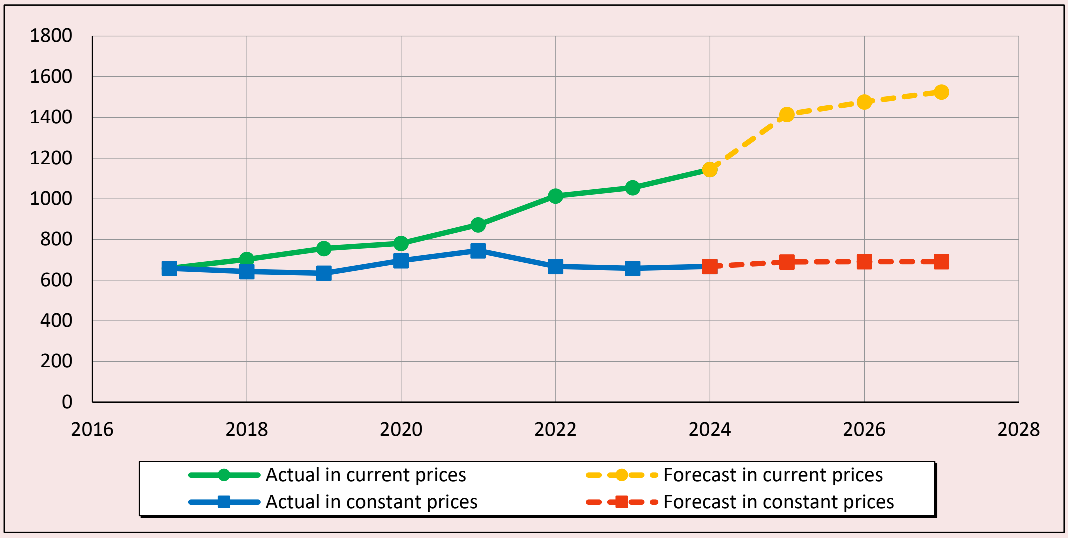
Variable	*Capital*	*RetailTrade1*	*Population*
const			3.19 (0.00)
x			-0.002 (0.00)
ar.L1	0.40 (0.00)	-0.19 (0.00)	1.04 (0.00)
ar.L2	-0.25 (0.00)	-0.09 (0.03)	0.48 (0.00)
ar.L3			-0.01 (0.00)
ar.L4			-0.19 (0.00)
ar.L5			-0.26 (0.00)
ar.L6			-0.43 (0.00)
ar.L7			0.31 (0.00)
ar.L8			0.10 (0.00)
ar.L9			0.12 (0.00)
ar.L10			-0.08 (0.00)
ar.L11			-0.42 (0.00)
ar.L12			0.35 (0.00)
ma.L1			0.08 (0.00)
ma.L2			0.05 (0.00)
ma.L3			0.03 (0.00)

End of Table 4

Variable	*Capital*	*RetailTrade1*	*Population*
ma.L4			0.02 (0.00)
ma.L5			0.01 (0.00)
ma.L6			0.01 (0.00)
ma.L7			-0.002 (0.00)
ma.L8			-0.01 (0.00)
ma.L9			-0.01 (0.00)
ma.L10			-0.001 (0.00)
ma.L11			0.01 (0.00)
ma.L12			0.02 (0.00)
ar.S.L12		0.49 (0.00)	
ma.S.L12		-0.36 (0.02)	
sigma2	102.67 (0.00)	$1.53 \cdot 10^7$ (0.00)	$6.64 \cdot 10^{-9}$ (0.00)
AIC	723.30	1981.30	-1467.70
BIC	730.99	1994.37	-1398.18
HQIC	726.41	1986.59	-1439.59
Ljung – Box test	0.01 (0.91)	4.26 (0.04)	32.88 (0.00)
Breusch – Pagan test	0.61 (0.16)	0.47 (0.03)	0.54 (0.08)
Jarque – Bera test	66.26 (0.00)	113.69 (0.00)	6.30 (0.04)

Note. The p-values are shown in parentheses. L1, L2, etc. are used to indicate the lags of the autoregressive component (ar) and the moving average (ma).
Source: own compilation.

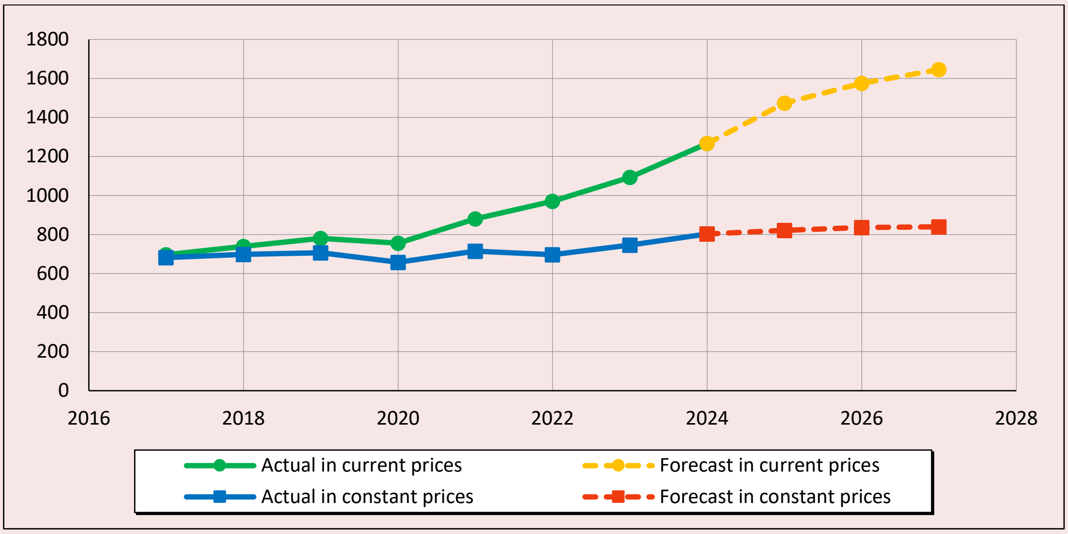
Figure 2. Forecast for the value of fixed assets, billion rubles



Source: own elaboration.

components. There is seasonality in the data, which was taken into account in the model specification. The results of the SARIMA model construction are presented in Table 4 in the column "RetailTrade1". Based on the model, a forecast of retail turnover in constant prices for the period up to 2027 was obtained. The projected values of the chain index, the consumer price deflator, were used to convert it to current prices. *Figure 3* shows the forecasts.

Figure 3. Forecast for retail trade turnover, billion rubles

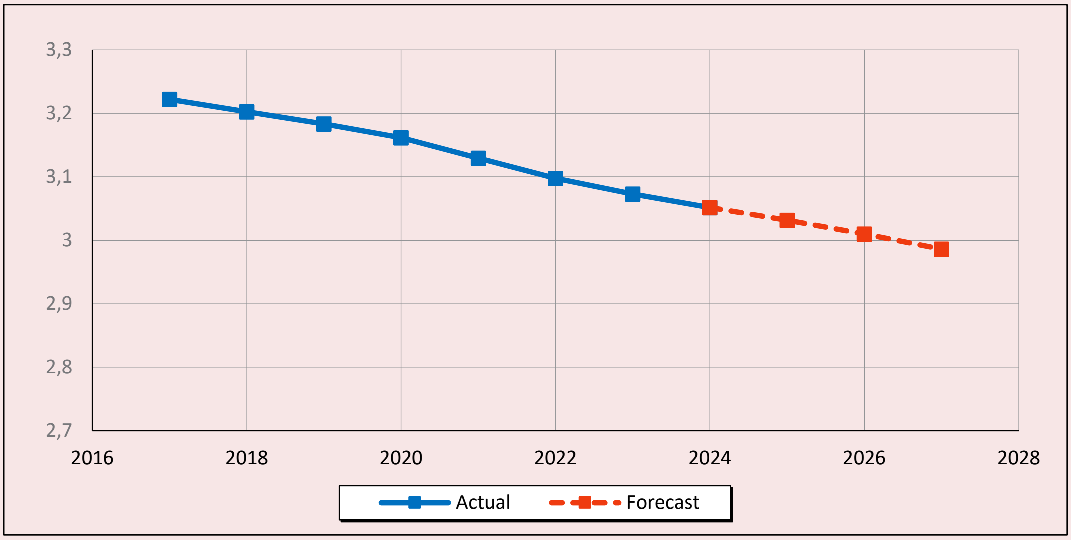


Source: own elaboration.

3. Number of permanent residents at the beginning of the year (million people).

The non-stationarity of the time series in the first differences was confirmed by ADF and KPSS tests, therefore a linear trend was included in the model specification. Due to the fact that this series was filled up by interpolation with splines, its structure is very specific, therefore, 12 lag values are included in the model, overlapping the artificial generation of values within a year. Table 4 presents the results of the ARIMA model construction in the column "Population". Based on the model, a population forecast was obtained for the period up to 2027 (*Fig. 4*).

Figure 4. Forecast for the population, million people



Source: own compilation.

The forecasts of the Government of the Nizhny Novgorod Region and the Bank of Russia, respectively, were used for the other two parameters, the average monthly value of consumer price indices for goods and services (%) and the price of Urals crude oil (U.S. dollar per barrel).

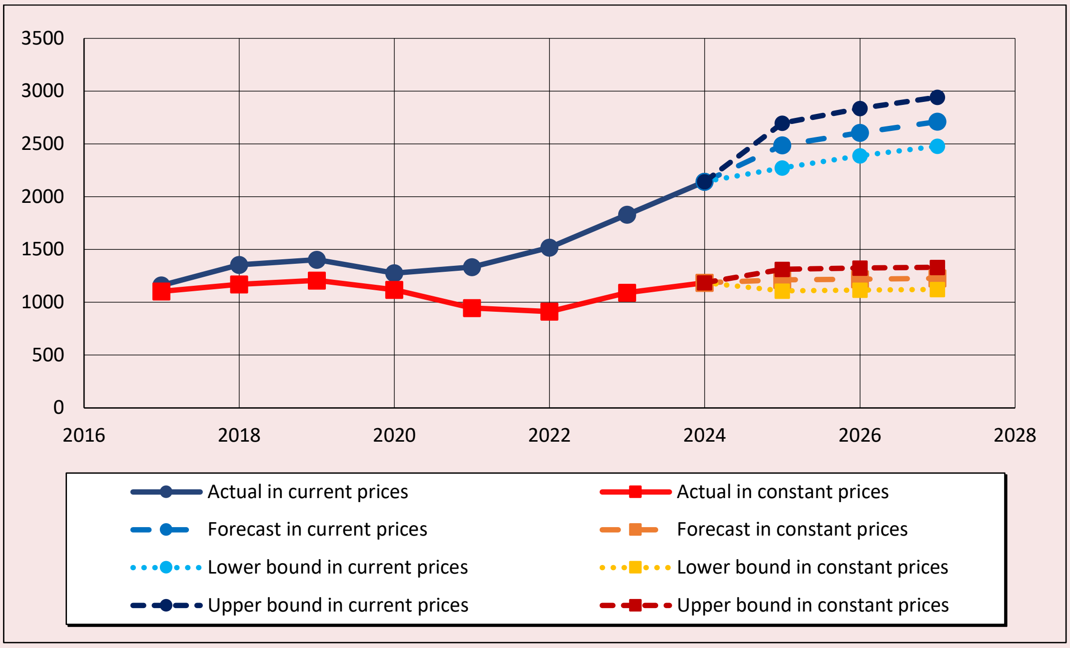
Based on the forecasts of the explanatory variables and estimates of the coefficients of the models, the predicted values of shipments of manufacturing products were calculated (*Tab. 5, Fig. 5*). The confidence interval (95%) was obtained using the bootstrap method.

Table 5. Forecasts of shipments of products of the manufacturing industry of the Nizhny Novgorod Region, billion rubles

Year	Urals oil price, U.S. dollar per barrel *	Inflation rate,%**	Shipment, Y, billion rubles***		Shipment growth, %***		95% confidence interval for shipment at current prices, billion rubles***
			at current prices	at constant prices	at current prices	at constant prices	
2025	58	8.8	2 486.897	1 212.534	16.03	2.24	2273.862 – 2696.101
2026	55	5	2 606.893	1 218.992	4.83	0.53	2388.783 – 2837.037
2027	60	4	2 711.332	1 227.423	4.01	0.69	2479.263 – 2942.760

Sources: * Forecasts of the Bank of Russia (Main directions of the unified state monetary policy for 2026 and the period 2027 and 2028. Moscow: Central Bank of the Russian Federation, 2025. P. 3. Available at: https://www.cbr.ru/about_br/publ/ondkp/on_2026_2028/; ** Forecasts of the Government of the Nizhny Novgorod Region (Forecast of the socio-economic development of the Nizhny Novgorod Region for the medium term (for 2026 and for the planned period of 2027 and 2028). P. 3, 6. Available at: http://publication.pravo.gov.ru/document/5200202510270003?index=1); *** own compilation.

Figure 5. Actual and forecast values of shipments of manufacturing products in the Nizhny Novgorod Region, billion rubles

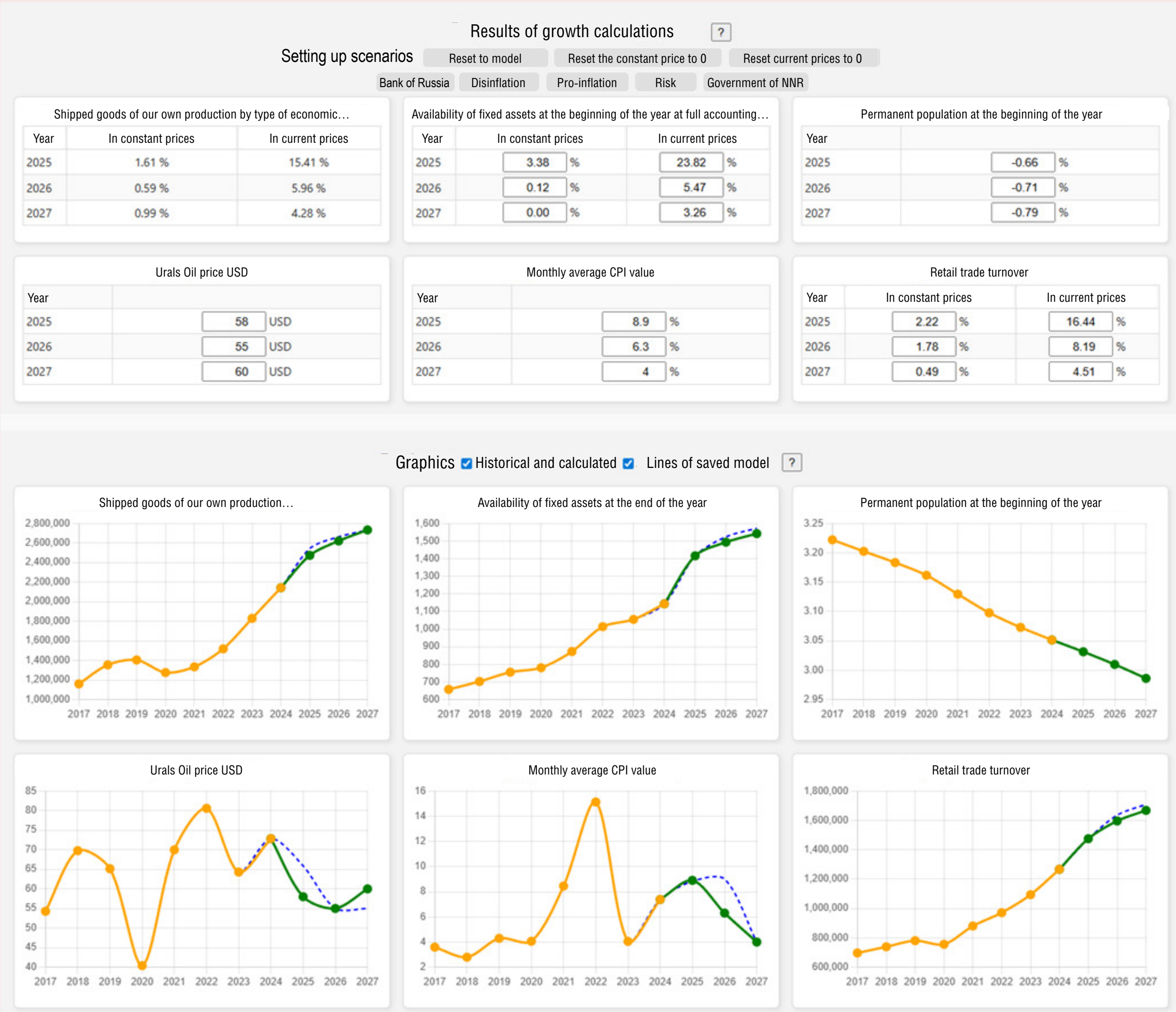


Source: own compilation.

Based on the constructed model using the JavaScript programming language (ECMAScript 2015 – ES6 standard) and HTML5 and CSS3 technologies, a software tool was developed – an interactive economic calculator implemented as a web page and allowing the user to generate and analyze alternative scenarios for the socio-economic development of the region. The calculator contains a digital twin interface for scenario modeling of key economic indicators on the 2025–2027 forecast horizon. it combines in one form a panel for entering scenario parameters, tabular output of historical and forecast values, a graph visualization module, as well as an increment calculation unit designed to quickly compare the result when the input data changes. It provides both a passive mode of use with a number of fixed presets (values that are calculated in advance), and an active mode when the user can change development scenarios using the available sliders.

Figure 6 shows a screenshot of the calculator, where the dotted blue line represents the values

Figure 6. Digital calculator with built-in web interface for forecasting the growth rates of manufacturing industries at current and constant prices



Source: own compilation.

obtained from the model, and the green solid line reflects the forecast based on user changes that are reflected in the tables.

Discussion of the research results

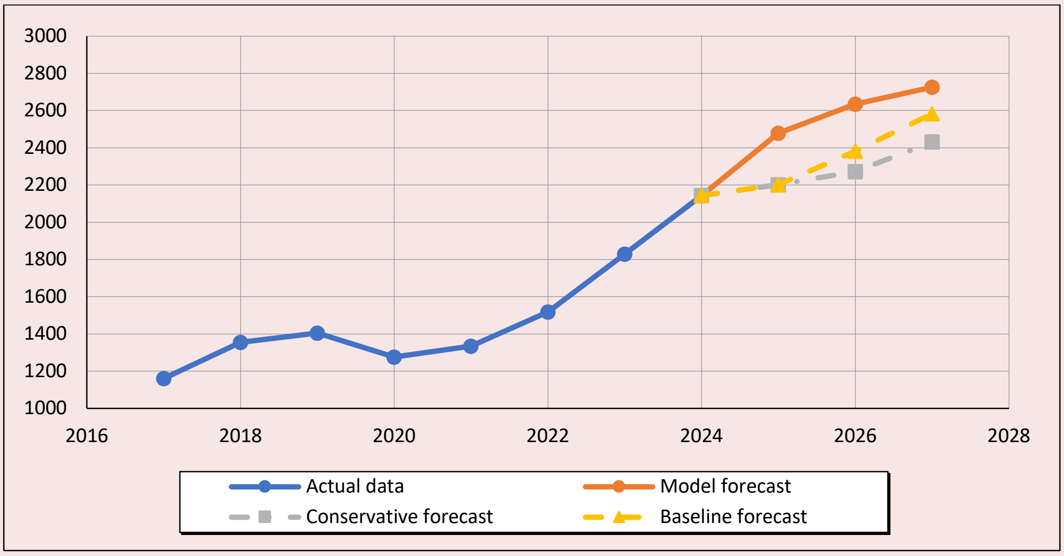
The results were compared with the Forecast of the socio-economic development of the Nizhny Novgorod Region for the medium term to verify the adequacy of the forecasts [5]. There are two scenarios in it: basic and conservative, however, the macro-economic indicators necessary for modeling are indicated only for the basic scenario. Let us calculate the forecast values based on the model constructed as part of the study, taking into account the preservation of the predicted trends for the remaining three indicators. *Table 6* and *Figure 7* present the simulation results in comparison with the forecasts of the Government of the Nizhny Novgorod Region.

Table 6. Comparison of the results of modeling the shipment of manufacturing products with forecasts of the Nizhny Novgorod Region Government

Year	Urals oil price, U.S. dollar per barrel*	Inflation rate in the Nizhny Novgorod Region, %*	Shipment of industrial products, growth, %			
			Government forecasts *		Model forecast ***	
			Basic	Conservative	at current prices	at constant prices
			at current prices			
2025	59**	8.8	2.76	2.76	15.68	1.93
2026	59	5	8.16	3.19	6.29	1.94
2027	61	4	8.47	7.01	3.43	0.13

Sources: * forecasts of the Government of the Nizhny Novgorod Region (Forecast of the socio-economic development of the Nizhny Novgorod Region for the medium term (for 2026 and for the planned period of 2027 and 2028). Available at: http://publication.pravo.gov.ru/document/5200202510270003?index=1); ** data from the Ministry of Economic Development of the Russian Federation for January – June 2025 (Ministry of Economic Development of the Russian Federation. The conjuncture of global commodity markets. Available at: https://www.economy.gov.ru/material/departments/d12/konyunktura_mirovyh_tovarnyh_rynkov/ (accessed: 14.02.2026); *** own compilation.

Figure 7. Comparison of the results of modeling shipments of manufacturing products at current prices with forecasts of the Nizhny Novgorod Region Government, billion rubles



Source: own compilation.

[5] Forecast of the socio-economic development of the Nizhny Novgorod Region for the medium term (for 2026 and for the planned period of 2027 and 2028). Available at: http://publication.pravo.gov.ru/document/5200202510270003?index=1)

The model forecasts turned out to be significantly higher than the forecasts of the Nizhny Novgorod Region Government. In addition, model forecasts show a deterioration in the situation over time, while government forecasts show an improvement in the situation. Currently, there are already first estimates of shipments of industrial products by manufacturing enterprises in the Nizhny Novgorod Region in 2025, according to which the increase in shipments at current prices this year was 5.2%[6], which is higher than the government forecast, but significantly lower than the model forecast. This deviation is mainly due to the higher value of the PPI deflator index in our 2025 forecast (1.135) compared to Rosstat estimates (1.0497)[7]. According to Rosstat estimates, in real terms, the growth rate of shipments in 2025 was 0.22%, which is lower than the model forecast, but higher than the government forecast.

The base forecast of the Nizhny Novgorod Region Government is included in the preset scenarios in the digital calculator web application for comparisons with model and user forecasts.

Thus, the presented digital calculator can be used when considering various "what-if" cases and checking various scenarios for future developments in predicting shipments of manufacturing products. For instance, based on the presented model, the impact of various scenarios of changes in macro-economic indicators developed by the Bank of Russia on the studied indicator was additionally analyzed[8]. *Table 7* shows scenario indicators of oil prices and inflation rates, as well as forecasts of shipments at current prices and their increases in current and constant prices calculated using our model. Based on these results, it can be seen how macro-economic factors affect the change in shipments of manufacturing products in the Nizhny

Table 7. Model forecasts based on various scenarios of the Bank of Russia

Year	Urals oil price, U.S. dollar per barrel *	Inflation rate, % *	Projected shipment values **		
			at current prices, billion rubles	increase in current prices, %	growth in constant prices, %
Basic					
2025	58	8.9	2473.529	15.41	1.61
2026	55	6.3	2620.920	5.96	0.59
2027	60	4	2733.085	4.28	0.99
Disinflationary					
2025	58	8.9	2473.529	15.41	1.61
2026	55	6	2617.698	5.83	0.70
2027	60	4	2728.706	4.24	0.95
Pro-inflationary					
2025	58	8.9	2473.529	15.41	1.61
2026	55	6.9	2627.294	6.22	0.36
2027	55	4.5	2711.124	3.19	-0.43
Risky					
2025	58	8.9	2473.529	15.41	1.61
2026	35	9.8	2519.934	1.88	-5.82
2027	30	12.6	2614.595	3.76	-5.33
Source: * scenarios of the Bank of Russia (Main directions of the unified state monetary policy for 2026 and the period 2027 and 2028. Moscow: Central Bank of the Russian Federation, 2025. P. 71, 77, 81, 85. Available at: https://www.cbr.ru/about_br/publ/ondkp/on_2026_2028/; ** own compilation.					

[6] Rosstat. Available at: https://www.rosstat.gov.ru/enterprise_industrial (accessed: 09.02.2026).

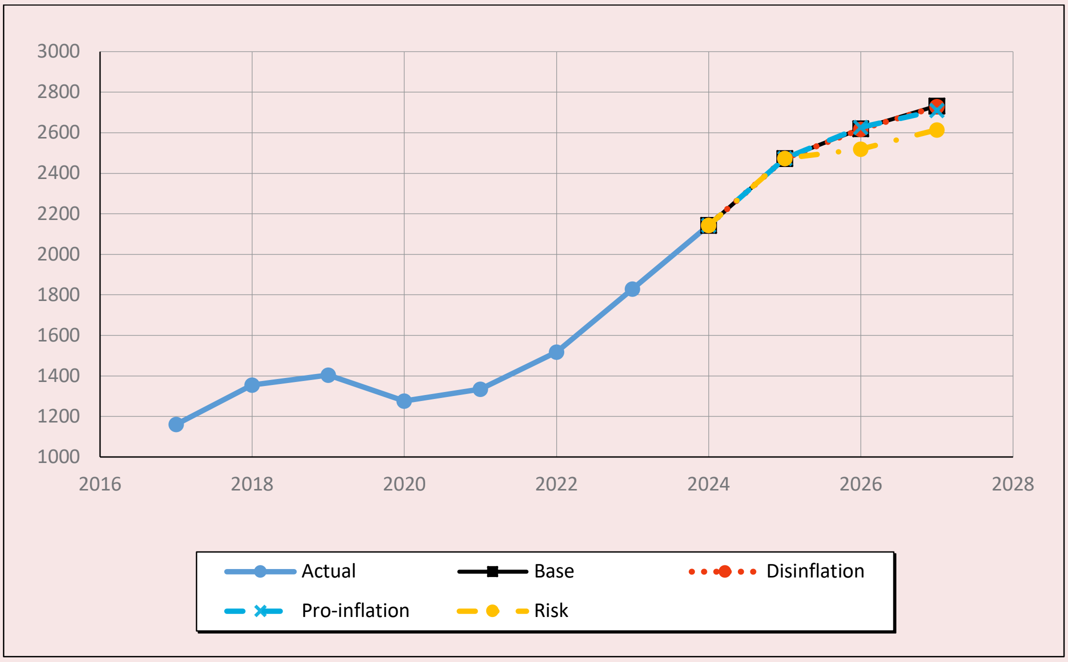
[7] Rosstat. Available at: https://www.rosstat.gov.ru/statistics/price (accessed: 09.02.2026).

[8] The main directions of the unified state monetary policy for 2026 and the period 2027 and 2028. Moscow: Central Bank of the Russian Federation, 2025. Available at: https://www.cbr.ru/about_br/publ/ondkp/on_2026_2028/

Novgorod Region (*Fig. 8*). According to the first estimates, the increase in manufacturing sector production in the Nizhny Novgorod Region in 2025 amounted to 1.1%[9], which turned out to be close to the model forecast based on the scenarios of the Bank of Russia.

It is obvious that the economic situation in the Nizhny Novgorod Region is not described by a single indicator, so the modeling is part of the work to create a larger set of forecast indicators that form an interconnected system and serve as the basis for the digital twin of the Nizhny Novgorod Region. Such a complex will make it possible to understand which current events and possible future changes (including shocks) will lead to certain consequences for the region. Assessing their impact on the regional market will allow authorities to make informed decisions regarding enterprise support, tax incentives, and investment projects. The results of the work were presented to the Ministry of Economic Development and Investments of the Nizhny Novgorod Region. A digital calculator can also be useful for other authorities when conducting a scenario analysis of the consequences of their decisions. For example, the paper (Malkina et al., 2025) presents a simulation of the gross value added of the Nizhny Novgorod Region industry as another key economic indicator of the Nizhny Novgorod Region. The next stage will be the construction of predictive models for other industries and the creation of a generalizing web application that repeats the structure of the interconnections of the Nizhny Novgorod economy and is the digital twin of the region.

Figure 8. Model forecasts based on various scenarios of the Bank of Russia for shipments of manufacturing products of the Nizhny Novgorod Region, billion rubles



Source: own compilation.

[9] The industry of the Nizhny Novgorod region continued to grow in 2025. Kommersant. Volga region. 08.02.2026. Available at: https://www.kommersant.ru/doc/8419004 (accessed: 11.02.2026).

Conclusion

The study showed that the use of econometric autoregressive models with distributed lags makes it possible to effectively predict the level of shipment of manufacturing products in the Nizhny Novgorod Region. We revealed that the main impact on shipment is exerted by such factors as the availability of fixed assets by type of economic activity "Manufacturing", the number of permanent residents at the beginning of the year, retail trade turnover, the average monthly value of consumer price indices for goods and services, as well as the price of Urals brand oil. The constructed models were used as a base for creating a digital calculator, which is a flexible scenario analysis tool combining tabular and graphical representation of data, econometric calculations and a system of user settings. The digital calculator for shipping is part of a more complex product, the digital twin of the region. Its use makes it possible to quickly assess the effects of changes in key macro-economic parameters, compare alternative development scenarios and form analytically sound conclusions about the dynamics of socio-economic indicators of the region. In this regard, this tool is very useful for authorities and other users in planning and optimizing production processes.

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