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# Drivers of Economic Growth of the Nizhny Novgorod Region: Modeling GRP Using Data from Twin Regions

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**Abstract.** Identification of development trends and growth potential of Russian regions in the new conditions requires the elaboration of advanced approaches to modeling the main economic indicators. The aim of the article is to carry out an econometric modeling and analysis of the GRP of the Nizhny Novgorod Region using data from twin regions. The selection of twin regions was based on the similarity of industry structures, level of development and trends. Using panel data for 16 regions of the Nizhny Novgorod Region cluster for 2000–2022, the Cobb – Douglas functions with lagged variables were constructed, estimated by the maximum likelihood method with correction for group heteroscedasticity. As a result of the modeling, a positive influence of supply factors (accumulated fixed assets, current investments, number of employees), demand factors (income per capita in the past period) on the current GRP was established. The scale and structure of budget expenditures of the region also play an important role in increasing the GRP in the cluster under consideration. The average annual key interest rate of the Bank of Russia, as well as its change, have a negative impact on the GRP. In addition, the GRP of the cluster regions is positively related to the price of Brent crude oil, which indicates the historical dependence of the Russian economy on the oil sector, and the dollar to ruble exchange rate, which affects the price component of the GRP via the pass-through effect, as well as import substitution processes. The obtained results can be the basis for designing forecasts and scenarios for the development of the region

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in the future, determining the consequences of regulatory impacts at the regional level and the effects of uncontrolled macroeconomic parameters. Further development of the study is possible through the inclusion of high-frequency data, the elaboration of models with more advanced specifications, including structured and aggregated ones, as well as separate modeling of the inflationary and real components of GRP, which together will allow for the creation of more accurate short-term forecasts.

**Key words:** region, gross regional product, econometric modeling, factors, clustering, twin regions, budget expenditures, key rate of the Bank of Russia.

**Problem statement**

In recent years, the Russian economy has faced unprecedented sanctions pressure from a number of developed countries. In these conditions, it is extremely important both at the level of the country and individual regions to determine the potential for economic growth and import substitution. To understand the available opportunities, it is necessary to study resources, their dynamics and efficiency in terms of their impact on the main production indicators (primarily gross regional product), as well as trends in the development of regions in retrospect. It is important to develop adequate approaches to its modeling, allowing assessing the impact of supply, demand, macroeconomic and institutional environment factors on its level and dynamics to identify past trends and dependencies of gross regional product.

One of the problems of modeling the regional economy is the shortness of time series based on annual indicators, i.e. insufficient observations. This is especially true for Russian regions, for which the period of market history lasts just over three decades. Moreover, before the 1998–1999 crisis, the economy was in a transitional state, developed according to other trends, and the statistics of that time are incomplete. Therefore, at present modeling is possible and appropriate based on the 2000–2022 data. But this time interval also has its own structural breaks, mainly related to the 2008–2009 and 2014–2015 crises, the 2020 pandemic and the beginning of the SMO in 2022. In addition, due to the active development of the military and civilian sector in recent years, the economy of most regions has completed its Keynesian stage; it has become labor deficient and is in an overheated state, i.e. in a state of full employment. This means that previous trends cannot be unambiguously extrapolated to the future, which limits the forecasting possibilities. Meanwhile, the main trends of regional economies due to the rigidity (inflexibility) of sectoral, technological and institutional structures, the effects of state and path dependence remain relatively unchanged, which makes their study relevant and valuable for further analysis.

The aim of our research is econometric modeling and analysis of the gross regional product of the Nizhny Novgorod Region based on pooled time series and spatial sampling by regions of the same cluster as the Nizhny Novgorod Region.

To achieve this aim, we solved the following tasks: 1) to identify a cluster of regions similar to the Nizhny Novgorod Region in terms of GRP per capita, sectoral structure of the economy and development trends; 2) to establish the indicators that can explain the change in GRP of regions belonging to the same cluster as Nizny Novgorod region and the lags of their influence; 3) to model the region's GRP based on panel data; to establish the nature and degree of influence of supply, demand, macroeconomic conditions and individual tools of fiscal and monetary policy on it.

**Literature review**

A number of studies by Russian and foreign authors are devoted to modeling and forecasting regional indicators. They used different approaches. ARIMA models (AutoRegressive Integrated Moving Average) are often used for modeling GRP and its subsequent short-term forecasting (Peng, 2023; Jijo, 2025). The advantage of such models is the possibility to take into account previous development trends and changing volatility of the modeled indicator. In ARIMA models, the current GRP depends on its own historical trends, but exclude the factors affecting it (changing resource and demand constraints, macroeconomic conditions and regulatory tools). Therefore, a more advanced approach is the one based on the construction of ARIMAX models – with the inclusion of a number of exogenous variables (Ugoh, 2021; Haydier et al., 2023). An important limitation of both approaches, however, is the need for a large number of observations. Models of this type are better realized on high-frequency, usually monthly data, but for many socio-economic indicators official statistics do not provide them. In addition, such data often contain seasonal and institutional components.

In the case of modeling GDP, GRP and other socio-economic indicators, it is objectively necessary to operate with short time series, which does not allow taking into account all the many factors affecting them. In addition, factors often show multicollinearity. To solve these problems, foreign researchers use the principal components analysis, which allows creating composite variables through the first principal components, covering the largest variance of attributes (Dias et al., 2015; Zhemkov, 2021). In Russian studies, the problem of shortness of time series was solved in a different way – by including all or some regions with similar indicators in the sample. The selection criteria were the size of GRP, and dummy variables were introduced for regions with different levels of GRP or independent regressions were constructed (Ivchenko, 2019).

Another frequently used approach to modeling GDP and GRP is the construction of production functions in which gross product depends on labor, capital, investment and other factors. One of the most popular is the Cobb – Douglas production function (Malkina, 2015; Vavilova, Zerari, 2024; Baranov et al., 2023); it is the power-type function, which is transformed into a linear form by logarithmization, which makes it possible to apply the least squares method for its estimation. An alternative option is the construction of the R. Solow model, which can also be based on the Cobb – Douglas function, but it takes into account a limited number of factors. For example, in (Kutyshkin, 2021) the one-sector R. Solow model of economic growth is applied to simulate the gross regional product of the Yamal-Nenets Autonomous Area. There are other types of production functions, such as the function with Constant Elasticity Substitution (CES), which allows taking into account the changing relationships between factors. Due to its nonlinearity, its estimation presents certain difficulties, but sometimes methods of approximate linearization are used (Cheremukhin, Gruzdev, 2022).

The choice of the most adequate production function for modeling GRP of this or that region is an independent research task. For example, the article (Skuf'ina, Baranov, 2017) addressed the question of finding the optimal production function when modeling GRP of the regions of the North and the Arctic. The following alternatives were considered: 1) multiplicative production function; 2) Cobb – Douglas power function; 3) production function with constant elasticity of substitution. The authors concluded that the CES function is better for four of the fifteen regions under consideration and the Russian Federation as a whole, the Cobb – Douglas function is better for one region, and no function is suitable for eight regions.

There are also other approaches to modeling GRP and GDP. For example, the article (Kuznetsov, Kuligin, 2022) develops a model of gross regional product based on the finite-time scheme of the integro-differential equation using economic and mathematical methods.

One of the advanced and rather time-consuming ways of GRP modeling is a structured approach based on separate modeling of industries or sectors of the economy and subsequent synthesis of the results. The application of such an approach allowed (Eremin, 2024) determining the potential for increasing the GRP of the Novgorod Region by changing the structure of investment, taking into account the calculated multipliers for different types of industries. Another paper (Dubovik et al., 2022) uses regression modeling and the Box – Cox transformation to estimate the contribution to GRP of the Bryansk Region of three major industries – agriculture, manufacturing, wholesale and retail trade. Some studies are devoted to modeling complex economic systems with the identification of the leading sector of the regional economy – a specific industry according to OKVED (Afanas'ev, Gusev, 2023).

Another variant of the structured approach to modeling the regional product involves separate modeling of demand (consumption, investment, government purchases and net exports) and supply components and bringing them together (Lombardini, 2024) or modeling the behavior of individual types of economic entities and then synthesizing them into a single model (Jokubaitis et al., 2021).

When modeling gross product, in addition to the lack of data, authors face the problem of changing methods of calculating indicators, which often makes statistical data incomparable (Mikheeva, 2022). To solve this issue, either recalculation of indicators according to new methodologies, which is a non-trivial task, or use of correction factors or introduction of dummy variables for new periods is used.

An important research task is the selection of factors affecting GRP. Researchers are guided by both basic provisions and concepts of economic theory and available data. The final selection of variables is made on the basis of their significance, multicollinearity, etc. testing. Usually, fixed assets, fixed capital investment, employment or labor costs are considered as factors affecting GRP. For example, in (Crespo–Cuaresma et al., 2010) using Bayesian model averaging (BMA) for a class of quantile regressions, it is shown that the main determinants of real GRP growth in EU countries with country fixed effects are fixed capital investment, labor skills and initial gross domestic product per capita, but the influence of these factors is distinctive in different quantiles. Using panel data for European countries, the work (Ghosh, Samanta, 2021) tested GRP models of different specifications: with random, fixed effects, cross-sectional data and with heteroskedasticity. The model with random effects showed the best result. The authors concluded that such indicators as investment, change in labor force and budget surplus have forecasting power for GDP.

Some studies include other factors in the production functions, in addition to the traditional ones. For example, in the paper (Ivchenko, 2019), in addition to the standard ones, the author studied such determinants of GRP as social expenditures in the regional budget, the current assets of enterprises and organizations, the balance of income and expenditures of enterprises and organizations, the indicator of purchasing power of the population of the region. In the article (Zhemkov, 2021) oil prices, real exchange rate, growth rates of the world economy and short-term and long-term interest rates on loans were used as factors for the formation of scenario indicators for modeling Russia's GDP. In the article (Zazdravnykh, 2023), an important factor for the growth of real GRP was the rise of new companies and their entry into the regional market.

Sometimes models test the impact of a specific factor on GRP. An example is the work (Fedorova et al., 2020), which studied the impact of inbound tourist flows on GRP of regions and also found positive effects of investment in fixed capital in the previous year and the volume of paid tourist services. The work (Demidova, Kamalova, 2021) investigated the spatial factor concerning the regions' economic development, and using the methods of spatial econometrics found the impact of neighboring regions on the growth of real GRP per capita adjusted for purchasing power parity.

In a number of works, the constructed models include institutional factors and various tools of economic regulation used by the Bank of Russia and the Russian Government. Usually, they solve the task of assessing these tools effectiveness and making recommendations to improve the relevant policy. For example, the article (Malkina, Vinogradova, 2024), using the case of the Nizhny Novgorod region, studied the significance and the degree of influence on the gross regional product of the volume of support from the regional budget in the form of tax benefits, grants and subsidies, as well as subsidizing the interest rate on mortgage programs. The paper also found a positive impact on the GRP of the region of internal R&D expenditures and expenditures on national economy in the consolidated budget of the region, and a negative impact on it of the key interest rate of the Bank of Russia.

Based on the previous studies, in this article, we use a whole pool of indicators that presumably affect GRP of the Nizhny Novgorod Region: resource, demand, macroeconomic and institutional. We solve the problem of short time series by identifying twin regions of the Nizhny Novgorod Region, which are similar to it in terms of a number of development indicators, which is a fundamentally new approach. We also use as a principal model the extended Cobb – Douglas production function including four types of variables and without restrictions on the scale effect, combining it with the distributed lag model to account for the influence of past values of the studied variables on the current GRP.

**Selection of twin regions for modeling**

As we have already noted in the literature review, the lack of data in time series severely limits the ability to model and forecast the performance of each specific region on the basis of its own values. At the same time, it is not quite correct to include all regions in the analysis due to their different sectoral and technological structures, achieved level of development and trends. Therefore, in this article we single out the regions that can serve as perfect twins of the Nizhny Novgorod Region, whose data are used to expand the panel sample.

We propose the formation of twin regions according to three criteria.

1. Similar GRP per capita (based on 2022 data) in the $k$-th region ($Y_k$) and in the Nizhny Novgorod Region ($Y_N$). For this purpose, their absolute difference is determined:

$$SY_{kN} = abs(Y_k - Y_N) \quad (1)$$

2. Similar sectoral structure (based on 2022 data). For its analysis, we used the shares in the gross value added of the following aggregated and combined types of economic activities:

S1 – agriculture, forestry, hunting, fishing and fish farming;

S2 – mining;

S3 – manufacturing industries; provision of electric power, gas and steam; air conditioning; water supply; water disposal, organization of waste collection and utilization, pollution elimination activities;

S4 – building;

S5 – wholesale and retail trade; repair of motor vehicles and motorcycles;

S6 – transportation and storage; activities of hotels and catering enterprises; activities in the field of information and communication;

S7 – financial and insurance activities; real estate activities;

S8 – professional, scientific and technical activities;

S9 – administrative activities and related ancillary services; public administration and military security; social security;

S10 – education; activities in the field of health care and social services; activities in the field of culture, sports, leisure and entertainment; provision of other types of services; activities of households as employers.

To assess the proximity of two sectoral structures, a similarity index to the Nizhny Novgorod Region (region *N*) is calculated for each $k$-th region:

$$SSI_{kN} = \frac{1}{10}\sqrt{\sum_{i=1}^{10}(S_{ki} - S_{Ni})^2}\ , \qquad (2)$$

where:

$S_{ki}$ – share of the $i$-th aggregated industry in the GVA of the $k$-th region;

$i = \overrightarrow{1,10}$;

$S_{Ni}$ – share of the $i$-th enlarged industry in the GVA of the Nizhny Novgorod Region.

3. Similar development trends of the regions. For this purpose, intertemporal correlations of all basic indicators of each k-th region with the Nizhny Novgorod Region are calculated on the basis of annual data for 2000–2022, and their simple average ($Cor_{kN}$) is determined.

For each of the three indicators of each $k$-th region ($SY_{kN}$, $SSI_{kN}$, and $Cor_{kN}$), the rank among all regions is calculated, these ranks are summed and ranked again. Then, the regions with the lowest total rank are selected among all regions. These are the regions closest to the Nizhny Novgorod Region in terms of industry structure, level of development and trends. In other words, these are twin regions, whose indicators further participate in modeling.

*Table 1* presents the selected regions and their indicators.

**Regional GRP modeling**

The region's GRP modeling was conducted on a panel sample, including annual data on 16 regions of the Nizhny Novgorod cluster for 2000–2022. Initially, we tested 18 explanatory variables (for significance, multicollinearity, etc.), of which 12 variables were included in the final models[1]. *Table 2* presents them.

Table 1. Regions of the same cluster with the Nizhny Novgorod Region and their selection indicators

| Region | $Y_k$* (rubles) | Rank | $SSI_{kN}$* | Rank | $Cor_{kN}$ | Rank | Total rank |
|---|---|---|---|---|---|---|---|
| Nizhny Novgorod Region | 739,125 | 1 | 0 | 1 | 1 | 1 | 1 |
| Novosibirsk Region | 693,656 | 9 | 1.456 | 22 | 0.705 | 2 | 2 |
| Arkhangelsk Region | 722,234 | 5 | 1.379 | 20 | 0.642 | 18 | 3 |
| Vladimir Region | 585,131 | 29 | 1.136 | 11 | 0.680 | 4 | 4 |
| Chelyabinsk Region | 673,545 | 14 | 1.292 | 17 | 0.644 | 16 | 5 |
| Kaliningrad Region | 715,359 | 6 | 1.582 | 27 | 0.639 | 19 | 7 |
| Yaroslavl Region | 623,525 | 25 | 0.665 | 2 | 0.620 | 25 | 7 |
| Kaluga Region | 647,307 | 21 | 1.427 | 21 | 0.661 | 12 | 8 |
| Rostov Region | 556,629 | 33 | 1.333 | 18 | 0.672 | 8 | 10 |
| Sverdlovsk Region | 816,092 | 16 | 0.690 | 3 | 0.568 | 40 | 10 |
| Tver Region | 516,489 | 39 | 0.938 | 7 | 0.651 | 15 | 11 |
| Kostroma Region | 480,120 | 46 | 1.135 | 10 | 0.673 | 7 | 13 |
| Tula Region | 674,432 | 13 | 2.123 | 41 | 0.668 | 9 | 13 |
| Leningrad Region | 822,794 | 19 | 1.258 | 16 | 0.581 | 34 | 16 |
| Moscow Region | 901,231 | 30 | 1.200 | 15 | 0.632 | 24 | 16 |
| Ryazan Region | 566,113 | 32 | 1.007 | 8 | 0.601 | 29 | 16 |
| * Data for 2022. | | | | | | | |

[1] Due to multicollinearity or insignificance, the final models did not include the following tested indicators: the population of the region (thousand people), the cost of the consumer basket (rubles), R&D expenditures (million rubles), tax revenues, non-tax revenues, gratuitous revenues to the consolidated budget of the subject of the Russian Federation (million rubles). At the same time, the models included the indicator of own budget revenues (the sum of tax and non-tax revenues) and total budget revenues (determined by summing up all three sources).

Table 2. Indicators for modeling the regional economy and their designations

| Variable | Designation | Variable | Designation |
|---|---|---|---|
| Gross regional product (million rubles) | $GDP$ | Gratuitous receipts to the consolidated budget of the constituent entity of the Russian Federation from other levels of the budgetary system (million rubles) | $BR\_transfers$ |
| Investments in fixed capital (million rubles) | $Invest$ | Expenditures of the consolidated budget of the constituent entity of the RF (million rubles) | $BE$ |
| Value of fixed assets at the end of the year (million rubles) | $Assets$ | Expenditures of the consolidated budget of the constituent entity of the RF on the national economy (million rubles) | $BE\_econ$ |
| Average annual number of employed persons (thousand people) | $Employ$ | Expenditures of the consolidated budget of the constituent entity of the Russian Federation on the social sphere* (million rubles) | $BE\_soc$ |
| Average monthly per capita cash income of the population (rubles) | $Income\_pc$ | Brent crude oil price (U.S. dollars per barrel) | $Brent$ |
| Consolidated budget revenues of a constituent entity of the RF (million rubles) | $BR$ | Average annual key interest rate of the Bank of Russia (%) | $Rate$ |
| Own (tax and non-tax) revenues of the consolidated budget of the constituent entity of the RF (million rubles) | $BR\_own$ | U.S. dollar to Russian Ruble exchange rate (rubles/U.S. dollar) | $USD$ |
| * Expenditures on the following socio-cultural activities were summarized: education, health care, culture, physical culture and sports, and social policy. | | | |

A distributed lag model, ADL(q,k), was selected based on assumptions about the lag effects of a number of variables:

$$y_t = a_0 + \sum_{i=1}^{k} \sum_{j=0}^{q} b_{kj} x_{k\,t-j} + \varepsilon_t,$$

where:

$(i = \overrightarrow{1,k})$ – exogenous variable number;

$(j = \overrightarrow{1,q})$ – lag of exogenous variable $x_{k\,t-j}$.

It is worth noting that models of this type can be built not only for time series, but also for panel data interpreted as pooled time series. The autoregressive distributed lag (ARDL) model can be used as an alternative and more advanced model. Its advantage is a more successful solution to the problem of autocorrelation of residuals and sometimes heteroscedasticity. However, the coefficients in such a model will no longer reflect the full impact of the factors concerning the production function and therefore are less interpretable.

The model was based on the Cobb – Douglas production function, which was transformed into a linear form by logarithmization. Thus, in the above formula all variables were represented in logarithmic form. Optimal lags for exogenous variables were chosen taking into account the significance of the coefficients in the regressors and the requirements of the model to the normality of residuals.

The Wald test indicated the presence of group heteroskedasticity in the fixed effects model, while the Breusch – Pagan test indicated the presence of heteroskedasticity in the residuals of the random effects model. Also, autocorrelation in the residuals was found in both cases. To eliminate heteroscedasticity as much as possible, the models were estimated using iterative weighted least squares method with selection of weights based on maximization of the likelihood function. *Table 3* presents the modeling results and the corresponding tests.

All presented in Table 3 models are significant by Fisher's criterion, coefficient estimates are significant by Student's criterion (and for most at the *p-value* < 0.001 level). The residuals are normally distributed. According to the variance of residuals (S.E. of regression), all models have high predictive power.

Table 3. ADL models of regional GRP: maximum likelihood estimates with group heteroscedasticity; dependent variable ln GDP, 16 cross sections, 352 observations

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|---|---|---|---|---|---|---|
| | **Coefficient (standard error), significance** | | | | | |
| $const$ | –1.456 (0.185)*** | –0.975 (0.196)*** | –1.226 (0.155)*** | –1.326 (0.150)*** | –1.268 (0.135)*** | –1.399 (0.148)*** |
| $\ln Invest_t$ | 0.132 (0.016)*** | 0.147 (0.017)*** | 0.147 (0.015)*** | 0.143 (0.015)*** | 0.129 (0.015)*** | 0.145 (0.015)*** |
| $\ln Assets_{t-1}$ | 0.102 (0.014)*** | 0.099 (0.015)*** | 0.092 (0.014) *** | 0.097 (0.014)*** | 0.104 (0.013)*** | 0.110 (0.014)*** |
| $\ln Employ_t$ | 0.460 (0.026)*** | 0.495 (0.024)*** | 0.437 (0.024)*** | 0.455 (0.024)*** | 0.449 (0.021)*** | 0.474 (0.023)*** |
| $\ln Income\_pc_{t-1}$ | 0.202 (0.027) *** | 0.210 (0.027) *** | 0.181 (0.026) *** | 0.199 (0.025)*** | 0.204 (0.022) *** | 0.210 (0.024)*** |
| $\ln BR_t$ | 0.175 (0.029)*** | - | 0.129 (0.030)*** | 0.104 (0.031)*** | - | - |
| $\ln BR\_own_{t-1}$ | 0.297 (0.038)*** | 0.293 (0.032)*** | 0.254 (0.036)*** | 0.259 (0.036)*** | 0.368 (0.029)*** | 0.324 (0.030)*** |
| $\ln BE\_econ_{t-1}$ | - | 0.026 (0.013)** | - | - | - | - |
| $\ln BE\_soc_{t-1}$ | –0.107 (0.034)*** | - | - | - | - | - |
| $\ln Brent_t$ | 0.167 (0.018)*** | 0.127 (0.016)*** | 0.149 (0.018)*** | 0.150 (0.018)*** | 0.152 (0.017)*** | 0.163 (0.018)*** |
| $\ln USD_t$ | 0.463 (0.025)*** | 0.454 (0.024)*** | 0.460 (0.024)*** | 0.460 (0.024)*** | 0.452 (0.023) *** | 0.474 (0.024)*** |
| $\ln Rate_t$ | - | –0.051 (0.019)*** | - | - | - | - |
| $\Delta \ln Rate_t$ | –0.078 (0.018)*** | - | –0.077 (0.018)*** | –0.078 (0.018)*** | –0.072 (0.017)*** | –0.084 (0.018)*** |
| $\Delta \ln BR_t$ | - | - | - | - | 0.323 (0.039)*** | - |
| $\Delta \ln BE_t$ | - | - | - | 0.151 (0.045)*** | - | 0.204 (0.043)*** |
| $\Delta \ln BE\_soc_t$ | - | 0.152 (0.050)*** | 0.097 (0.050)** | - | - | - |
| Log-likelihood | 447.176 | 433.023 | 444.604 | 447.595 | 462.765 | 443.686 |
| Akaike criterion | –829.853 | –844.045 | –867.209 | –873.191 | –905.530 | –867.371 |
| Schwarz criterion | –855.440 | –801.545 | –824.709 | –830.691 | –866.894 | –828.735 |
| Hannan-Quinn | –872.353 | –827.132 | –850.296 | –856.278 | –890.155 | –851.996 |
| S.E. of regression | 0.076 | 0.080 | 0.076 | 0.077 | 0.074 | 0.078 |
| χ2 test / Chi-square(15) | 46.381 | 45.373 | 45.580 | 48.738 | 56.170 | 52.671 |
| *p-value* [1] | 4.625e-005 | 6.686e-005 | 6.200e-005 | 1.933e-005 | 1.134e-006 | 4.373e-006 |
| χ2 test / Chi-square(2) | 0.536 | 0.129 | 0.185 | 0.733 | 2.766 | 1.203 |
| *p-value* [2] | 0.765 | 0.938 | 0.912 | 0.693 | 0.251 | 0.548 |

Note: value *** *p-value* < 0.01; ** *p-value* < 0.05.

[1] Likelihood ratio test for group heteroscedasticity using cross-sectional analysis. Null hypothesis: units have common error variance.

[2] Test for normality of residuals. Null hypothesis: the residuals are normally distributed.

The best model is selected based on the maximum of the log likelihood function, the minimum of the Akaike, Schwartz, and Hannan – Quinn information criteria. Model 5 satisfies these criteria. However, it is inferior to all other models by the criterion of normality of residuals. According to this criterion, the best model is Model 2.

Meanwhile, the chosen method of model estimation did not allow completely overcoming heteroscedasticity in the residuals. To eliminate it, we additionally constructed the ARDL model (autoregression with distributed lag), which differs from ADL models by including lag values of the endogenous variable. *Table 4* presents it.

The constructed ARDL model meets all quality criteria, moreover, it lacks heteroskedasticity and autocorrelation in the residuals. The signs at variables and their relative influence generally correspond to ADL models. Meanwhile, all the coefficients at exogenous variables are lower in absolute value because their influence was distributed to the lag variables $\ln GDP_{t-1}$ and $\ln GDP_{t-2}$. And hence, they cannot be interpreted as measures of factor elasticities in the production function. Meanwhile, this model fulfills a control function in our study: the compatibility of its substantive results with ADL models allows proceeding further to the interpretation of the results obtained on the basis of the traditional production function.

In general, the constructed models correspond to the main provisions of economic theory. First of all, GRP of the regions of Nizhny Novgorod cluster depends on the available production resources (labor – $\ln Employ_t$, capital – available fixed assets at the beginning of the period – $\ln Assets_{t-1}$) and their change in the current period (level of investment in fixed capital – $\ln Invest_t$).

Table 4. ARDL model of GRP of the region: maximum likelihood estimations taking into account group heteroscedasticity; dependent variable $\ln GDP$, 16 cross sections, 352 observations

| | Coefficient | Standard error | *p–value* | Value |
|---|---|---|---|---|
| $const$ | –0.371 | 0.092 | < 0.0001 | *** |
| $\ln GDP_{t-1}$ | 0.610 | 0.050 | < 0.0001 | *** |
| $\ln GDP_{t-2}$ | 0.084 | 0.038 | 0.0277 | ** |
| $\ln Invest_t$ | 0.081 | 0.010 | < 0.0001 | *** |
| $\ln Employ_t$ | 0.142 | 0.013 | < 0.0001 | *** |
| $\ln BR\_own_{t-1}$ | 0.106 | 0.027 | < 0.0001 | *** |
| $\ln Brent_t$ | 0.110 | 0.012 | < 0.0001 | *** |
| $\ln USD_t$ | 0.237 | 0.021 | < 0.0001 | *** |
| $\Delta \ln Income\_pc_t$ | 0.213 | 0.057 | 0.0002 | *** |
| $\Delta \ln Rate_t$ | –0.046 | 0.015 | 0.0024 | *** |
| $\Delta \ln BR_t$ | 0.261 | 0.033 | < 0.0001 | *** |
| Log-likelihood | 548.223 | | | |
| Akaike criterion | –1074.445 | | | |
| S.E. of regression | 0.050 | | | |
| χ2 test / Chi-square(15) [1] | 21.130 | | 0.133 | |
| χ2 test / Chi-square(2) [2] | 2.493 | | 0.287 | |

Note. Value *** *p-value* < 0,01; ** *p-value* < 0,05.

1) Likelihood ratio test for group heteroscedasticity using cross-sectional analysis. Null hypothesis: units have common error variance.

2) Test for normality of residuals. Null hypothesis: the residuals are normally distributed.

Since all variables in the models are represented in logarithmic form, the coefficient estimates in ADL-models are interpreted as elasticities of GRP with respect to the corresponding exogenous variables, i.e. they show by what percentage GRP will change if this variable changes by 1%, all other things being equal. For example, a 1% change in investment in fixed capital in the current period presumably results in a 0.129–0.147% increase in GRP, ceteris paribus. And a 1% increase in employment leads to a 0.437–0.495% increase in GRP. This result is consistent with the findings of a number of other studies (Kutyshkin, 2021; Baranov et al., 2023), which also found a greater sensitivity of GRP of Russian regions to labor than to capital. At the same time, other studies have demonstrated that the coefficients of output elasticity with respect to labor and capital are different depending on the region under consideration and the period of study (Vavilova, Zerari, 2024; Skufyina, Baranov, 2017). Our result indicates the labor intensity of production in the regions of the same cluster as the Nizhny Novgorod Region (which includes regions with developed manufacturing industry) and the high significance of the problem of staff shortage under the current technological structure of the economy.

The results of modeling proved that the availability of financial resources plays an important role in increasing production in the region. The source of financial resources can be both own, budgetary, and borrowed funds. The volume, as well as the structure of revenues and expenditures of regional budgets play an important role in the regional development. In particular, the constructed models demonstrated the positive influence on the region's GRP of the consolidated budget revenues of the RF constituent entities in the current period ($\ln BR_t$) and own (tax and non-tax) revenues of the consolidated budget of the RF constituent entities in the past period ($\ln BR\_own_{t-1}$). The models also showed the average positive impact on the GRP of budget expenditures on the national economy in the past period ($\ln BE\_econ_{t-1}$) and negative impact of budget expenditures on the social sphere in the past period ($\ln BE\_soc_{t-1}$). At the same time, the increase in social expenditure in the current period compared to the past period ($\Delta \ln BE\_soc_t$) proved to have a positive impact on the current GRP. This can be explained by the fact that social payments are an important component of the income of poorer people, who have a higher propensity to consume. In addition, social expenditures form the revenue of relevant industries and spheres of activity, contribute to the improvement of the human capital quality. The obtained result slightly corrected the estimate of the effects of social expenditures, which was previously exclusively positive (Ivchenko, 2019). This may be due both to the fact that in our case the amount of social expenditures was considered as the total amount of various spendings, and to the peculiarities of the sample of regions and modeling approaches.

As it would be expected, the models showed a positive impact of past period household income ($\ln Income\_pc_{t-1}$) on current period GRP, which is also consistent with the findings of other authors (Ivchenko, 2019; Arpitha et al., 2025). This means that, on average, in the period under consideration, regional production in the Nizhny Novgorod Region cluster depended on consumer demand, i.e., historically, regional economies were rather on the Keynesian than neoclassical segment of the supply curve.

In the constructed models, the average annual rate of the Bank of Russia ( $\ln Rate_t$ ) and especially its change ($\Delta \ln Rate_t$) showed a significant negative impact on the GRP of the region. Thus, the conclusion previously obtained for the Nizhny Novgorod Region (Malkina, Vinogradova, 2024) is applicable to the whole cluster. The Bank of Russia raises the interest rate to fight inflation, but the side effect of this is a slowdown in economic growth. Under tight monetary policy, nominal GRP decreases both in terms of inflationary and real components, which was reflected in the obtained coefficients.

Finally, all models showed a direct dependence of the region's GRP on two weakly controlled macroeconomic parameters – the price of Brent oil and the exchange rate of the U.S. dollar to the Russian ruble. These parameters also turned out to be predictors in the models of Russian GDP presented in the article (Zhemkov, 2021).

Revenues from the oil sector spread throughout the Russian economy, feed the budget system, and create multiplier effects, so the impact of oil price on production in different regions (not only extractive, but also manufacturing) is positive. At the same time, the positive impact of oil price on GRP indicates a significant and permanent dependence of the Russian economy on the state of world oil markets, which, given the instability of these markets and sanctions restrictions on access to them by Russian producers, creates serious risks for regional development.

The U.S. dollar exchange rate to the ruble can be interpreted as a proxy for the price component of GRP. The exchange rate affects the prices of imported goods, the share of which in domestic consumption, according to various estimates, ranges from 24% to 40%. Via the pass-through effect, the exchange rate affects the prices of all goods. In addition, the depreciation of the national currency increases the price competitiveness of domestic production, promotes import substitution within the country and sales of domestic goods on foreign markets, as well as increasing the revenues of the budget system.

Thus, for the regions belonging to the same cluster with the Nizhny Novgorod Region, i.e. twin regions, the dependence of GRP on the factors concerning demand, supply, fiscal and monetary policy tools, as well as a number of poorly controlled macroeconomic factors has been proved, the direction and degree of influence of these factors have been established.

**Conclusion**

In this paper, we have modeled GRP of the Nizhny Novgorod Region using the data of twin regions. The literature analysis has shown different approaches to modeling the main socio-economic indicators of the region: the construction of time series models such as ARIMA and ARIMAX, models with fixed and random effects based on panel data, the construction of production functions of various types, aggregated models. The choice of one or another model depends on the structure of the data. Important problems in modeling are also the choice of explanatory factors (based on theoretical concepts and available data) and overcoming the problem of shortness of time series.

The latter problem can be solved in different ways. In the present study, an approach to increase the number of observations by including data from twin regions in the model is proposed and implemented. Regions of the same cluster as the Nizhny Novgorod Region were selected according to three criteria: GRP per capita, similar sectoral structure of the economy, similar development trends. As a result, a panel sample of 16 industrialized regions with time series for 2000–2022 was formed.

To model GRP of the cluster regions of the Nizhny Novgorod Region, the Cobb – Douglas production function with a distributed lag (ADL) was constructed, which was estimated by the method of iterative weighted ordinary least squares (OLS) with selection of weights based on maximization of the likelihood function. As a result, non-contradictory and partially complementary six models with high explanatory power were obtained. The models are significant by Fisher's criterion, the estimates of all coefficients are significant by Student's criterion, and the residuals of the models are distributed according to the normal law. To eliminate heteroscedasticity and autocorrelation of the residuals, they were supplemented by the construction of ARDL model, which led to the results that were consistent with ADL models.

The constructed models confirmed the greater dependence of GRP of the regions of the cluster under consideration on the labor factor than on the capital factor in the form of accumulated funds and current investments. This means that labor deficit imposes significant limitations on economic growth, the way to overcome it is the development of technological structures that contribute to increasing the capital intensity of national income and capital-labor ratio.

The positive impact on GRP of the state of the budget sphere of the region and the amount of support of the regional economy from the consolidated budget of the subject of federation is proved. At the same time, the ambiguous role of social expenditures has been established: on the one hand, their relatively large value is observed in regions with lower GRP, on the other hand, the increase in these expenditures can have a positive effect on the regional product through the formation of demand for the products of different sectors of the economy. Also, an important driver of economic growth in the region on the demand side is the increase in personal income, behind which, of course, there are other factors. A more precise determination of the relationship between population income and GRP requires the construction of more complex models with forward and backward linkages, probably based on a system of simultaneous equations.

In addition to fiscal policy tools, the models showed the negative impact of the key interest rate of the Bank of Russia and its increase on the GRP of the regions under consideration. Finally, they confirmed the persistent dependence of the economies of the regions under study on oil prices and the ruble-dollar exchange rate.

Thus, GRP of the regions of the same cluster as the Nizhny Novgorod Region is explained by resource, demand constraints, institutional and macroeconomic environment. The obtained results indicate the relative importance of these factors, the effectiveness of different measures of governance, reveal the weaknesses and growth reserves of regional economies. They can be useful in elaboration of a balanced regional development policy in Russian regions specializing in the manufacturing industry and having a sufficiently diversified sectoral structure, such as the Nizhny Novgorod Region.

Further research development is possible through the better specification of models, their construction using high-frequency data of other indicators, creation of structured models (modeling of GRP by types of economic activity or demand components), separate modeling of inflationary and real growth components, use of the principal component analysis to aggregate the influence of a larger number of variables. The refinement of models and approaches in the future will make it possible to develop more balanced approaches to short-term forecasting of GRP and other indicators of socio-economic development of regions.

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