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Scenario forecasting of the dynamics of Russian production technologies using spatial SAR models

ABSTRACT

Relevance. The development and implementation of advanced production technologies are the most important factors of economic growth and competitiveness in the modern economy. Predicting their dynamics, taking into account the spatial features of localization, is a difficult and time-consuming task. The spatial effects resulting from the impact of the surrounding territories play a significant role in the dynamics of advanced production technologies in the regions of Russia. Accounting for these effects is necessary when constructing scenario models in conditions of strong spatial heterogeneity of the studied processes. Traditional forecasting methods do not take into account spatial interdependencies and are not able to reflect the influence of surrounding regions on the development of technologies.

Research objective. Assessment and scenario forecasting of the dynamics of advanced production technologies being developed in the regions of Russia using SAR models that allow taking into account spatial effects between regions.

Data and methods. For scenario forecasting of the dynamics of advanced production technologies being developed in the Russian regions, taking into account spatial effects, a methodological approach was developed based on the modeling of the spatial log (SAR) of the processes of their development, autoregressive (ARMA) modeling and forecasting of the key factors of their dynamics. Taking into account spatial effects and heterogeneity, the proposed approach to modeling makes it possible to more accurately predict the dynamics of advanced production technologies in the Russian regions.

Results. The developed methodological approach was tested to form predictive scenarios for the dynamics of advanced production technologies being developed in the regions of Russia. In particular, an inertial forecast scenario was developed, assuming the preservation of current trends in the dynamics of the technologies being developed, as well as two extreme possible scenarios – optimistic and pessimistic. With the help of the spatial SAR model, a significant influence of the number of research organizations on the volume of advanced production technologies generated was confirmed, and in the second group of regions, the influence of the number of technicians who conduct research and development was confirmed.

The novelty of the study is to take into account the spatial features of the localization of the advanced production technologies being developed, as well as the spatial effects resulting from the impact of the surrounding regions on the creation of new technologies. This approach makes it possible to significantly reduce errors in the formation of forecast scenarios in conditions of significant spatial heterogeneity of the initial data.

Conclusions. To intensify the generation of new technologies in the regions of the second group, it is necessary to attract personnel with technical specialties. The dynamics of the technologies being developed in the first group of regions with a powerful research potential are also influenced by the number of research personnel and the amount of attracted financial resources for fundamental and applied research. To increase the activity of these regions in the development of advanced technologies, it is necessary to form and develop relationships with the surrounding regions.

KEYWORDS
advanced production technologies, science, technologies, modeling, spatial SAR model

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Сценарное прогнозирование динамики российских производственных технологий с использованием пространственных моделей SAR

АННОТАЦИЯ
Актуальность. Разработка и внедрение передовых производственных технологий — важнейшие факторы экономического роста и конкурентоспособности в современной экономике. Прогнозирование их динамики с учетом пространственных особенностей локализации представляется сложной и трудоемкой задачей. Пространственные эффекты, возникающие в результате воздействия окружающих территорий, играют существенную роль в динамике передовых производственных технологий в регионах России. Учет данных эффектов необходим при построении сценарных моделей в условиях сильной пространственной неоднородности исследуемых процессов. Традиционные методы прогнозирования не учитывают пространственные взаимозависимости и не в состоянии отразить влияние окружающих регионов на развитие технологий.
Цель исследования. Оценка и сценарное прогнозирование динамики разрабатываемых передовых производственных технологий в регионах России с использованием SAR-моделей, позволяющих учитывать пространственные эффекты между регионами.
Данные и методы. Для сценарного прогнозирования динамики разрабатываемых передовых производственных технологий в российских регионах с учетом пространственных эффектов был разработан методический подход, основанный на моделировании пространственного лага (SAR) процессов их разработки, авторегрессионного (ARMA) моделирования и прогнозирования ключевых факторов их динамики. Благодаря учету пространственных эффектов и неоднородности, предложенный подход к моделированию позволяет более точно прогнозировать динамику передовых производственных технологий в российских регионах.
Результаты. Разработанный методический подход был апробирован для формирования прогнозных сценариев динамики разрабатываемых в регионах России передовых производственных технологий. В частности, был разработан инерционный прогнозный сценарий, предполагающий сохранение текущих тенденций в динамике разрабатываемых технологий, а также два крайних возможных сценария — оптимистичный и пессимистичный. С помощью пространственной модели SAR подтверждено значительное влияние количества научно-исследовательских организаций на объем генерируемых передовых производственных технологий, а во второй группе регионов и влияние численности техников, которые проводят научные исследования и разработки. Новизна исследования заключается в учете пространственных особенностей локализации разрабатываемых передовых производственных технологий, а также пространственных эффектов, возникающих в результате воздействия окружающих регионов на создание новых технологий. Такой подход позволяет значительно снизить погрешности при формировании прогнозных сценариев в условиях значительной пространственной неоднородности исходных данных.
Выводы. Для активизации генерации новых технологий в регионах второй группы необходимо привлечь кадры технических специальностей. На динамику разрабатываемых технологий в первой группе регионов с мощным научно-исследовательским потенциалом оказывают влияние и численность исследовательских кадров, объем привлекаемых финансовых ресурсов на фундаментальные и прикладные исследования. Для повышения активности данных регионов в разработке передовых технологий необходимо формировать и развивать взаимосвязи с окружающими регионами.

КЛЮЧЕВЫЕ СЛОВА
передовые производственные технологии, наука, технологии, моделирование, пространственная модель SAR

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使用空间SAR模型对俄罗斯生产技术动态进行情景预测

摘要
现实性：先进生产技术的开发和实施是现代经济增长和竞争力加强的最重要因素。根据本地化的空间特征预测其动态是一项复杂而耗时的任务。周边地区所产生的空间效应在俄罗斯各地区先进生产技术的动态发展中发挥着重要作用。在所研究过程的空间异质性较强的条件下构建情景模型时，有必要考虑这些影响。传统的预测方法没有考虑空间上的相互依存关系，无法反映周边地区对技术发展的影响。
研究目标：利用可考虑地区间空间效应的 SAR 模型，对俄罗斯各地区先进生产技术的发展动态进行评估和情景预测。
数据与方法：为了在考虑空间效应的情况下对俄罗斯各地区先进制造技术的发展动态进行预测，我们开发了一种基于其发展过程的空间滞后建模（SAR）、自回归（ARMA）建模及其动态关键因素预测法。考虑到空间效应和异质性，文章所提出的建模方法能够更准确地预测俄罗斯各地区先进制造技术的动态。
研究结果：作者对所开发的方法进行了测试，以便生成俄罗斯各地区先进生产技术发展动态的预测方案。在方案中，研究者特别设计了在假设保持当前技术发展动态趋势的情况下的惯性预测方案，以及两种极端可能方案——乐观和悲观。通过使用空间 SAR 模型，证实了研发机构的数量对先进制造技术生成量的重要影响。并且证明了在二线地区中，研发技术人员数量的影响力很大。 这项研究的新颖之处在于考虑了已开发的先进生产技术本地化的空间特性，以及周边地区对新技术创造的影响所产生的空间效应。在初始数据具有显著空间异质性的条件下，这种方法可以大大减少预测方案形成过程中的误差。
结论：要激活二线地区新技术的产生，就必须吸引具有技术专长的人才。在一线具有强大研究潜力的地区，技术开发的动态也受到研究人员数量以及基础研究与应用研究的财政资源影响。为了提高这些地区开发先进技术的积极性，有必要与周边地区建立和发展关系。

关键词
先进制造技术、科学、技术、建模、空间 SAR 模型

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Introduction

One of the key factors in the development of an innovative economy, as well as the formation of technological sovereignty, is the development of advanced production technologies and their introduction into the real economy. The positive impact of advanced production technologies on the development of the country's economy was identified by such researchers as (Dezhina, 2014; Denisjuk, Markov, 2008; Miller, 2015; Mamleeva et al., 2021; Kapitcyn et al., 2017), etc. There are risks associated with the complexity of integrating these technologies into business processes, their low payback (Zinov'eva, Rostova, 2022), the presence of high regional heterogeneity in the dynamics of the development of advanced production technologies (Jakushev, 2021), significant heterogeneity of their creation in various industries (Kudrjakov, 2019). As noted in (Brilliantova et al., 2020), about a third of production technologies are acquired abroad and only 20% of organizations develop them independently.

However, forecasting the dynamics of the development of advanced production technologies in conditions of regional heterogeneity is a difficult task. Spatial effects arising from interaction with neighboring territories play an important role in shaping the development of technologies in individual regions. Traditional forecasting methods do not sufficiently take into account spatial interconnections and are unable to adequately assess the impact of surrounding regions on the development of technologies in a particular region. Therefore, the scientific problem is the need to develop methods and models that take into account spatial factors to more accurately predict the dynamics of the development of advanced production technologies in the regions of Russia.

Thus, the development of advanced production technologies within the country is a prerequisite for the formation of technological sovereignty and the development of the real sector of the economy. Accordingly, based on the relevance and significance of the problem, the purpose of this work is to assess and scenario forecast the dynamics of advanced production technologies being developed in the regions of Russia using SAR models that allow taking into account spatial effects between regions.

To achieve the goal, the following tasks were identified: a review of scenario modeling methods that take into account regional heterogeneity and spatial effects; the development of a methodological approach to assess the influence of factors on the dynamics of advanced production technologies; and the construction of scenario forecasts, taking into account the spatial effects arising from the surrounding regions that are also developing these technologies. Solving these problems will make it possible to more accurately assess the impact of factors on the development of advanced production technologies and form predictive scenarios of their dynamics, taking into account spatial effects for the period up to 2025.

Theoretical framework

Various methods of scenario forecasting of socio-economic processes are used in the scientific literature: compartmental models (SEIR), models using panel data, neural networks, spatial autoregression models, etc.

In conditions of spatial heterogeneity, machine learning-based compartmental modeling (SEIR) is often used to model the spread of any diseases and epidemics. This method, for example, was used in the work (Hou et al., 2021) to reconstruct the trajectories of the spread of COVID-19 in two counties of Wisconsin. The authors investigated the relationship between the spread of COVID-19 and mobility and demographic processes in conditions of spatial heterogeneity within the same district.

In conditions of strong spatial heterogeneity, other approaches are also used, in particular, spatial autocorrelation analysis. It was used (Naumov et al., 2021) in assessing the socio-economic consequences of COVID-19 in the regions of Russia. The researchers applied an approach involving spatial clustering of regional systems according to the incidence of COVID-19, conducted using spatial autocorrelation indices, various spatial weight matrices, and Anselin's mutual influence matrix based on statistical information from the Federal State Statistics Service of the Russian Federation. A spatial cluster with a high level of COVID-19 infection, with a strong zone of influence and stable links with the surrounding regions was identified. These methodological approaches take into account the spatial heterogeneity of the studied processes, but do not allow modeling the influence of various factors of the internal and external environment on their dynamics.

The ability to assess the impact of factors is provided by regression modeling methods using panel data. The basics of regression analysis of panel data are considered in the works (Sarafidis, Wansbeek, 2012) and (Chudik, Paserun, 2013), where the concepts of weak and strong cross-sectional dependence are considered, as well as methods for evaluating and outputting large panel data models. The studies (Maddala, 1987) and (Finkel, 1995) focus on specific applications: Maddala considers the evaluation of models with a bounded dependent variable, and Finkel considers causal analysis in panel data. These methods were applied in the study (Kasimova, 2020) to analyze the impact of agricultural production on gross regional product (GRP) and forecast it until 2021. Modeling based on panel data was used to assess the impact of public policies on the dynamics of GDP per capita and GDP growth rates, as well as to identify the regional heterogeneity of «new areas of the national level that contribute to economic growth» (Dang, Zhu, 2022). Their empirical studies show that new areas at the national level contribute to the economic growth of cities, and the effect can last at least 5 years. The FRED-SD database, based on panel series on the labor market, production, and housing, was developed to predict socioeconomic processes at the regional and national levels in the United States (Bokun et al., 2021).

Hybrid methods combining machine learning, deep learning, and artificial intelligence algorithms (Ahmad et al., 2022), as well as time series forecasting methods (Li, Adelmann, 2022), are also used for modeling and scenario forecasting of the dynamics of socio-economic processes. These methods make it possible to estimate the relationship between variables and make predictions, but they are limited by the complexity of assessing the spatial effects arising from the impact of the surrounding territories.

To take into account spatial effects in the modeling of socio-economic processes, the tools

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of spatial econometrics were used (Demidova, 2021; Poljanskaja, 2022; Brady, Irwin, 2011; Varlamova, Kadochnikova, 2023), etc. Darbin's spatial models were used to assess the influence of various socio-economic factors and demand for the dynamics of highway travel (Sun et al., 2022), forecasting the unemployment rate (Fauzi, Wenur, Wasono, 2023), the level of economy and the level of education in China (Zhang, Zhang, 2023), spatial patterns associated with intercity railways, in particular their impact on neighboring cities (Deng, Li, Zhu, 2024), and the influence of social factors on life expectancy (Aulia, Sirait, 2023). The main advantage of this type of spatial models is that they provide an opportunity to assess various types of spatial effects from the impact of the surrounding areas and the distribution of the studied factors in space. A theoretical review of works on spatial modeling showed that this method gave very good results when building models in conditions of spatial heterogeneity of the studied processes. However, researchers make limited use of the capabilities of this toolkit and do not use the built models to predict the dynamics of simulated processes.

Thus, in order to comprehensively assess the impact of various factors on the dynamics of advanced production technologies developed in the regions of Russia, taking into account spatial effects and the formation of forecast scenarios for their dynamics, a methodological approach is needed that systematically uses various data analysis tools.

Data and methods

The proposed methodological approach, taking into account the spatial localization of advanced production technologies developed in Russia, forms regression models for two groups of regions: with the volume of technologies developed above and below the average level in Russia. When modeling, it is supposed to assess the impact of the following factors: the number of research organizations, the number of technicians and researchers engaged in research and development, and the amount of internal costs for basic, applied research and development.

At the initial stage of this study, it is planned to build standard regression models using the pooled method of least squares, with fixed and random effects (1) using panel data on the subjects of the Russian Federation for the period from 2000 to 2021, without taking into account spatial effects. The models developed for two groups of regions (with the volume of developed technologies above and below the average Russian level) will make it possible to assess the differentiated impact of these factors on the creation of new production technologies and solve the problem of spatial heterogeneity of the simulated processes. These models are necessary not only to determine the degree of influence of the assessed factors on the dynamics of the technologies being developed in the regions, but also the presence or absence of unaccounted factors in the model. To check the presence of a spatial lag characterizing the impact of the surrounding territories in the model and assess the spatial effects in the dynamics of the advanced production technologies being developed in Russia, in the next stage, it is planned to build a spatial SAR model for two groups of regions using a weighting matrix of adjacent boundaries between regions (2):

$$V_{it} = \alpha + \mu_i + \gamma_t + \beta_1 X1_{it} + \beta_2 X2_{it} + \beta_3 X3_{it} + \beta_4 X4_{it} + \beta_5 X5_{it} + \beta_6 X6_{it} + \varepsilon_{it}. \quad (1)$$

$$V_{it} = \alpha + \rho W V_{it} + \beta_1 X1_{it} + \beta_2 X2_{it} + \beta_3 X3_{it} + \beta_4 X4_{it} + \beta_5 X5_{it} + \beta_6 X6_{it} + \varepsilon_{it}, \quad (2)$$

where V_{it} is the volume of advanced production technologies developed in the regions, units; WV_{it} – spatially weighted values of the volume of advanced production technologies developed in the regions; $X1_{it}$ – the number of organizations that carried out research and development, units; $X2_{it}$ – number of technicians engaged in research and development, pers.; $X3_{it}$ – number of researchers engaged in scientific research, pers.; $X4_{it}$ – internal expenditures on basic research, mln rub.; $X5_{it}$ – internal expenditures on applied research and development, mln rub.; $X6_{it}$ – internal expenditures on development, mln rub.; α – a set of other factors affecting the volume of developed technologies; β – regression coefficient of the estimated factors of the model; ρ – spatial autoregression coefficient; μ_i – individual effect of the region i, independent of the time t; γ_t – temporary effects for the region i at the time t; ε_{it} – normally distributed random variables over the time t and territories i.

The inclusion of a spatial lag in the model will allow checking the influence of surrounding regions on the creation of technologies, ad-

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justing the assessment of the studied factors, as well as reducing the level of model error, which is important in the formation of forecast scenarios. When constructing this model, the two-step generalized method of moments (GMM) will be used. This method was presented in the paper (Hansen, 1982) and generalized the classical GMM method. The key of this method is the use of weight matrices, which are formed as a result of a two-step or multi-step weighing procedure. In this study, a standard two-step weighing procedure was used: at the first stage, the parameters of the model were estimated using GMM with a single weight matrix, and at the second stage, the covariance matrix of moment functions was estimated using sample data and parameter values found in the first step. To control heteroskedasticity, a weighting covariance matrix of White's standard errors was used in the model. The second key point when building a model using the GMM method is the use of fixed time effects using dummy variables, as well as the transformation of the initial data using the first difference method. When applying this method, the EViews software package was used.

The constructed spatial SAR model will become the basis for the formation of forecast scenarios for changing the dynamics of advanced production technologies being developed.

This study assumes the formation of three basic forecast scenarios for the dynamics of advanced production technologies being developed in the regions of the first and second groups until 2025: inertial, assuming the preservation in the future of those trends that were established for the period from 2000 to 2022; as well as two extreme possible scenarios – the most optimistic and pessimistic confidence intervals for the predicted dynamics of key factors for 2022–2024 with a reliability level of 95%, determined by autoregressive models using moving averages (ARMA or ARIMA). With the help of autoregressive models, it is possible to establish the most probable dynamics of changes in factors in the future, as well as the corridor of possible fluctuations in their values. The values of factor dynamics found as a result of autoregressive modeling will be substituted into the equations of the spatial SAR model for the first and second groups of regions to form forecast scenarios for changing the dynamics of advanced production technologies being developed. The most probable dynamics of changes in all factors in the model will form an inertial scenario, and the corridor of possible fluctuations in the values of the factors will form the field of the most probable forecast scenarios, ranging from the most pessimistic to the most positive. The novelty of the presented methodological approach is to take into account the spatial features of the localization of the advanced production technologies being developed, as well as the spatial effects resulting from the impact of the surrounding regions on the creation of new technologies. This approach makes it possible to significantly reduce errors in the formation of forecast scenarios in conditions of significant spatial heterogeneity of the initial data.

Results

To achieve this goal, an analysis was made of the spatial heterogeneity of the dynamics of the advanced production technologies being developed in Russia and the construction of scenario forecasts, taking into account the spatial effects arising from the surrounding regions that are also developing these technologies.

Assessment of the spatial heterogeneity of the dynamics of advanced production technologies being developed in Russia

The development of advanced production technologies in Russia is characterized by high spatial heterogeneity. According to 2021 data, almost 21% of all advanced technologies generated were concentrated in Moscow, 14.8% in St. Petersburg, 10% in the Moscow Region, 6.7% in the Sverdlovsk Region, and 5% in the Chelyabinsk Region. A significant amount of advanced production technologies was also developed in the Nizhny Novgorod, Samara, Novosibirsk, Tyumen, Rostov, Belgorod, Voronezh, Saratov, Kaluga, and Ulyanovsk Regions, in the Republic of Tatarstan, Krasnodar, Perm, and Krasnoyarsk Territories. In total, 82.5% of all advanced production technologies were developed in these regions in 2021, while only 17.5% of technologies were developed in the remaining 63 regions. Regions with a high level of generation of these technologies, exceeding the average value in Russia for the period from 2000 to 2021; formed the first group, and regions with a volume of developed technologies below the average level – the second group. The calculations showed that the above-mentioned regions were characterized by a very high level of gener-

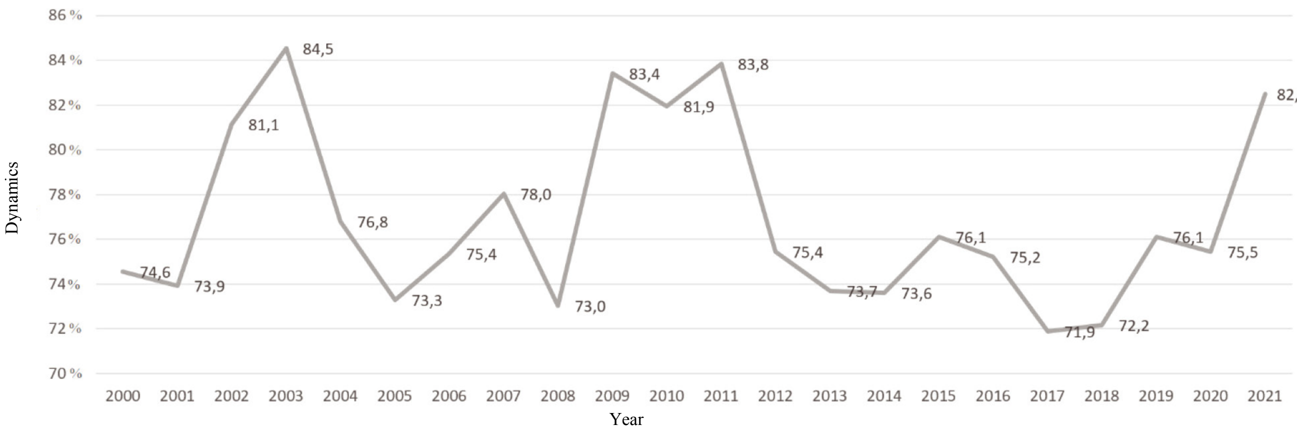

Figure 1. *Dynamics of concentration of all advanced production technologies developed in Russia in the first group of regions for 2000–2021; %*

Source: compiled by the authors on the basis of the statistical collection *Regions of Russia. Social-Economic Indicators*[1]

ation of new technologies during the entire period under review, the volume of their development exceeded the average value in Russia (14 technologies per year in the period from 2000 to 2021).

The level of concentration of advanced production technologies developed in Russia in this group of regions for the entire period under review did not fall below 70%, a significant amount of generated technologies was concentrated in five regions of this group, which indicates an excessively high spatial heterogeneity in the development of advanced technologies in Russia. During the periods of economic and financial turmoil of 2003, 2008-2009, 2015, and 2020–2021, the level of concentration of generated technologies in the regions of the first group increased significantly, and during the periods of economic recovery – decreased (Figure 1).

Such a pattern in the dynamics of technology generation is due, according to the authors' hypothesis, to a reduction in the amount of funding for fundamental and applied research and development in the regions of the second group during periods of economic recessions, and the subsequent migration of research personnel to regions with more favorable conditions for research activities, with more developed scientific potential and infrastructure.[1]

[1] Federal State Statistics Service. Regions of Russia. Social and Economic Indicators. URL: https://rosstat.gov.ru/storage/mediabank/Region_Pokaz_2023.pdf (access date: 11.01.2024)

Scenario spatial model of SAR

To confirm the hypothesis and study the factors affecting the dynamics of advanced production technologies in two groups of regions, regression models with fixed and random effects were built. When constructing them, inflation-free data on the volume of internal costs for basic, applied research and development were used, the stationarity of time series was assessed, and the hypothesis of the absence of a single root in their dynamics was confirmed. The calculated descriptive statistics of the variables for the two groups are presented in Table 1. When calculating them for the first group of regions, 418 observations were used, and for the second group – 1254.

The formed models for two groups of regions cannot be recognized as reliable, since there is heteroscedasticity in them, the normality of the distribution of errors is violated, structural shifts in the dynamics of individual indicators are observed, and there is a cross-sectional dependence in the panel data. In all the constructed models, a significant level of the constant was noted, which characterizes the totality of all unaccounted factors, as well as a significant amount of residual dispersion. Since the statistical analysis of the data confirmed the high level of spatial heterogeneity in the development of advanced production technologies, it is necessary to take into account the emerging spatial effects from the impact of surrounding regions when modeling these processes. To take them into account for two groups of regions (with a high and low volume of advanced production technologies being developed), spatial

Table 1

Descriptive statistics of model variables

1 group / 2 group	V_{it}	WV_{it}	$X1_{it}$	$X2_{it}$	$X3_{it}$	$X4_{it}$	$X5_{it}$	$X6_{it}$
Mean	45 / 4	49 / 6	131 / 23	2754 / 204	16,615 / 1104	848 / 87	1028 / 59	3595 / 173
Median	25 / 2	33 / 2	65 / 20	1167 / 150	6378 / 728	176 / 44	248 / 28	1242 / 54
Maximum	421 / 53	403 / 106	907 / 85	21,599 / 1077	152,759 / 5071	12,385 / 958	14,648 / 866	32,606 / 3495
Minimum	0 / 0	0 / 0	14 / 3	61 / 1	666 / 34	2 / 0	15 / 0	39 / 0
Std. DEV	55 / 7	52 / 10	175 / 14	4395 / 198	29,745 / 1047	1993 / 133	2422 / 89	6263 / 290
Jarque-Bera	2187 / 8369	2151 / 30,144	1819 / 533	1732 / 1398	2383 / 623	5886 / 9184	6012 / 22,277	2169 / 77,008

SAR models were built using a weighing matrix of spatial weights along adjacent boundaries between regions (Table 2). Statistically insignificant variables were eliminated from the model for the possibility of its use in constructing forecast scenarios for changing the dynamics of the volume generated by advanced production technologies in the short term.

The conducted test by Sargan-Hansen (J-statistic) made it possible to confirm the validity of the spatial modeling tool used, based on the Harke-Ber test – it was found that the distribution of random errors was not normal, and using the Arellano-Bond test – it was revealed that there was no second-order autocorrelation between the residues. The low standard error of the model in

Table 2

Spatial SAR models of the dependence of the volume of developed advanced production technologies on various factors

Variable	First group of regions (coefficient)	Second group of regions (coefficient)
Y (-1)	0.035***	0.054***
WV – Spatially weighted volume of developed advanced production technologies	0.648***	0.671***
$X1_{it}$ – Number of scientific organizations	0.535***	0.081***
$X2_{it}$ – Number of technicians engaged in research	–	0.002***
$X3_{it}$ – Number of researchers	0.0006***	–
$X4_{it}$ – The amount of expenditures on fundamental studies	0.004***	–
$X5_{it}$ – The amount of expenditures on applied scientific research	0.003***	–
Correlation square (V; V mod)	0.639	0.903
S.E. of regression	14.5	1.519
Sum squared resid	74,102.3	2577.3
Sargan–Hansen test (J-statistic)	198.3	36.8
Prob (J-statistic)	0.44	0.29
Jarque-Bera	14,664***	18,948***
Arellano-Bond Serial Correlation Test: AR(1) AR(2)	 –8250** 5903.7	 –734.5*** 122.4
Durbin-Watson stat	2.3	2.2
Schwarz criterion	6.28	3.16
Akaike info criterion	6.01	3.05

both the first group of regions (14.5) and the second (1.5), as well as the close to zero value of the constant characterizing the influence of other factors on the dependent variable, indicate the importance of including the spatial lag in this model. Both models made it possible to establish the presence of positive spatial effects in the dynamics of the technologies being developed and confirmed the hypothesis that regions surrounded by centers for the generation of new technologies will also develop at a higher rate. The growth in the volume of technologies developed in a particular region will contribute to the growth of this indicator in the surrounding regions. This is evidenced by positive regression coefficients of a spatially weighted variable characterizing the presence of a spatial lag in the volume of advanced production technologies being developed in both the first (0.648) and second (0.671) groups of regions.

The coefficient of spatial autoregression in the second model, built by regions with the volume of advanced production technologies developed below the average Russian level, turned out to be higher than the same parameter calculated for the first group of regions with a high volume of generated technologies. This suggests that the spatial features of the location have a more significant impact on the dynamics of the advanced production technologies being developed in the regions of the second group. Being surrounded by regions with a powerful research potential (the first group), these regions receive an important advantage – access to a developed scientific infrastructure and the ability to attract the necessary skills from neighboring regions for research projects to develop advanced technologies.

The spatial aspects of the location have a less significant impact on the dynamics of advanced production technologies developed in the regions of the first group, however, in this group of regions there are significant spatial effects arising from the impact of surrounding regions. By developing interregional spatial interconnections, the regions of the first group, which have all the necessary resources to develop advanced technologies, will generate them more efficiently.

The formed SAR model made it possible to confirm the significant influence of the number of research organizations on the volume of advanced production technologies generated in the first group of regions. In the second group of regions, this factor also contributes to the growth of the volume of generated technologies, but since the level of concentration of scientific organizations in this group of regions is low, the degree of its influence is less significant. With the help of a spatial model built for the second group of regions, the influence of the number of technicians who conduct research and development was also established. Therefore, the generation of new technologies in the regions of the second group will be facilitated by the involvement of technical specialists who are involved in the development and direct implementation of advanced technologies in the production process. As a result of the simulation, it was revealed that the research personnel and the amount of attracted financial resources for fundamental and applied research in the second group of regions did not affect the dynamics of the generated advanced production technologies. The regions of this group do not have as significant research potential as the regions of the first group, which is why the variables corresponding to these factors were statistically insignificant. Therefore, in the second group of regions, it is more relevant not to expand the research potential, but to attract personnel to create technologies based on existing developments.

In the first group of regions, based on the spatial SAR model, it was revealed that in addition to the number of research organizations, the dynamics of the technologies being developed were influenced by the number of researchers and the amount of attracted financial resources for fundamental and applied research. The powerful research potential concentrated in these regions has a strong impact on the generation of new technologies. The regions of the first group are provided with research personnel, have a developed scientific and engineering infrastructure, a significant part of all financial resources of Russia directed to fundamental, applied research and development is concentrated here. Hence, the formation and development of ties with the surrounding regions will increase the activity of the territorial systems of the first group in the development of advanced production technologies. Their expansion will also have a positive impact on the development of the regions of the second group due to the spatial effects that were established as a result of building a spatial model.

The statistical significance of the model parameters, lower values of standard errors and residual variances in the model, and information cri-

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Table 3

Results of regression analysis of the impact of the volume of developed advanced production technologies on the dynamics of the volume of shipped goods and rendered services for two groups of Russian regions using panel data with fixed effects

	First group of regions		Second group of regions	
Variable	Coefficient	P-value	Coefficient	P-value
const	10.26***	<0.0001	9.99***	<0.0001
Ln(Vit)	0.502***	<0.0001	0.34***	<0.0001
R-squared	0.42		0.15	
S.E. of regression	0.66		1.18	
Sum squared resid	176.4		1688.2	
F-statistic	14.9	<0.0001	3.74	<0.0001
Akaike info criterion	865.7		4047.5	
Schwarz criterion	946.4		4345.3	
Durbin-Watson stat	2.08		2.05	
Breusch-Pagan test statistic	0.46	0.443	2.88	0.089
Hausman test statistic	7.03	0.008	10.5	0.001
Wald test for heteroskedasticity	12.3	0.873	73.2	0.072
Test for normality of residual	5.77	0.061	83.13	0.051
Wooldridge test for autocorrelation in panel data	0.09	0.756	2.66	0.107

teria indicate that spatial SAR models are optimal for assessing the influence of factors on the dynamics of advanced production technologies being developed. These models will be used to form forecast scenarios of their dynamics until 2025.

To assess the impact of the volume of advanced production technologies developed in the regions of Russia on the dynamics of the volume of shipped goods and services rendered, a regression analysis was carried out using panel data for the previously identified groups of regions. Its results are provided in Table 3.

Regression analysis shows that the advanced technologies being developed in the first group of regions have a more significant impact on the dynamics of the volume of goods shipped and services rendered than in the second group of regions, and this is confirmed by the elasticity coefficients by factors in the presented models (3):

First group of regions:

$$Ln(VP_{it}) = 10.26 + 0.502 \cdot Ln(V_{it})$$

Second group of regions:

$$Ln(VP_{it}) = 9.99 + 0.34 \cdot Ln(V_{it}),$$

where $Ln(VP_{it})$ is the natural logarithm of the volume of shipped goods and services by enterprises of all types of economic activity in the constituent entity of the Russian Federation, million rubles; $Ln(V_{it})$ – the natural logarithm of the volume of developed advanced production technologies in the constituent entity of the Russian Federation, units.

The increase in the volume of technologies developed in the regions of the first group by 1% contributes to an increase in the volume of shipped goods by 0.502%, while in the second group of regions – by only 0.34%. Significant research potential is concentrated in the regions of the first group, there is a developed infrastructure for the generation and implementation of advanced production technologies in various spheres of economic activity. That is why, when developing the state scientific, technical, and industrial policies and the spatial strategy of Russia, it is necessary to take into account the spatial priorities of supporting research institutions to accelerate the development and implementation of technologies.

Forecast scenarios of the dynamics of advanced production technologies being developed in the regions of the first and second groups until 2025.

To form forecast scenarios, autoregressive modeling of the dynamics of key factors of the SAR scenario model using a moving average (ARMA) was used. This choice of the type of autoregressive modeling was due to the presence of stationarity in the time series for all estimated

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variables in the spatial model. Since when using the method of generalized moments in the formation of a scenario spatial SAR model, data were transformed using sequential differences of the first order, the same transformed data were used in the course of autoregressive modeling of the dynamics of key factors.

As a result of autoregressive modeling, the most probable vector of the dynamics of the key factors of the scenario spatial model was established, taking into account the preservation of the trends noted during the period of 2000–2021 in the future (Figure 2). It was found that in the regions of the first group, with a high volume of advanced

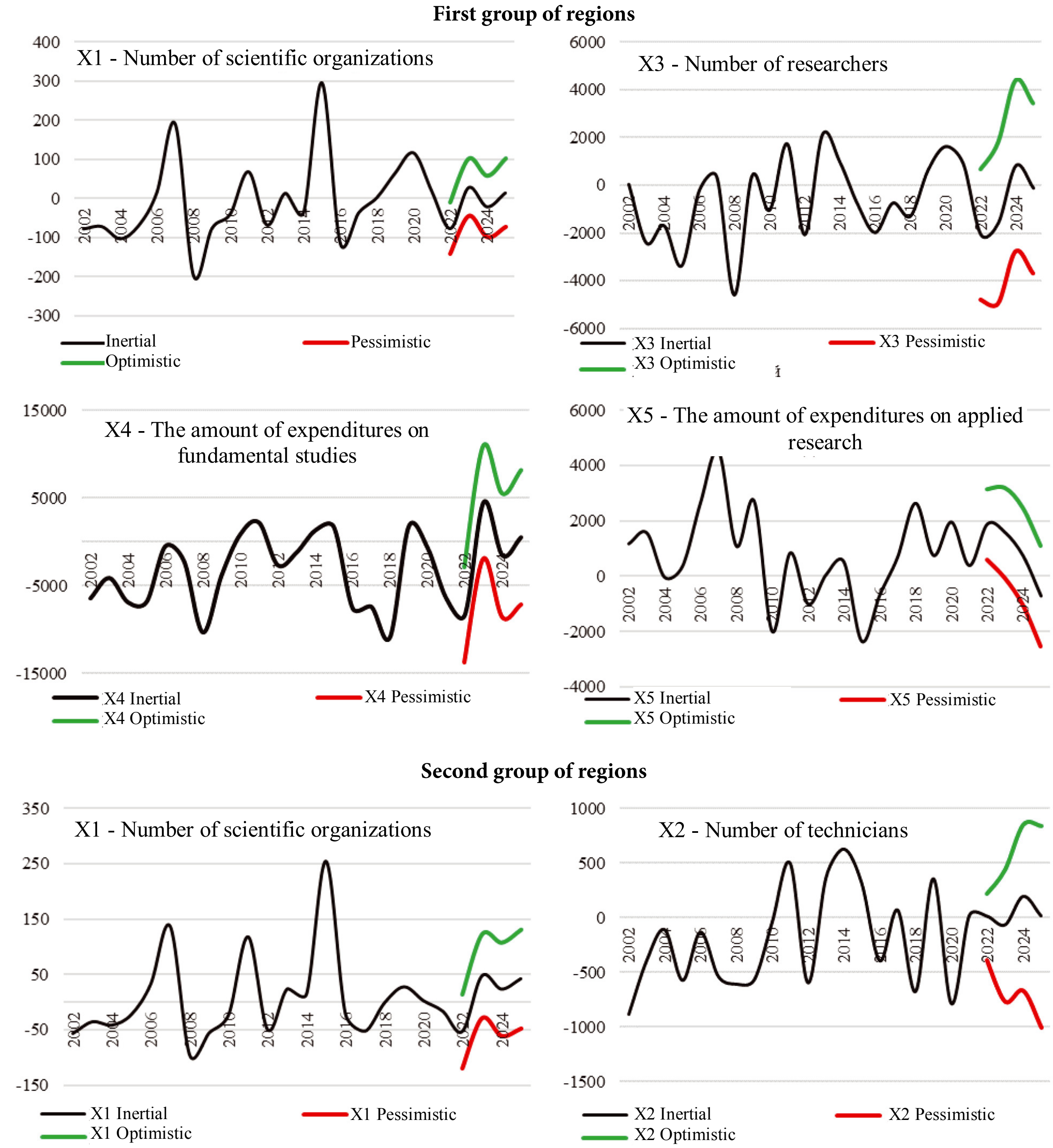

Figure 2. *Forecast scenarios of the dynamics of key factors in the development of advanced production technologies in two groups of regions until 2025.*

Source: compiled by the authors in the Gretl software package

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production technologies being developed, in the case of maintaining the trends noted for the period 2000–2021 (inertial forecast), an increase in the number of organizations that conduct research and development was possible in 2023 by 28 units; and in 2025 – by 15 units; in 2024, a reduction of 21 organizations was possible (Figure 2).

The inertial forecast, built on autoregressive models for all regions of the first group, assumes the preservation of wave-like dynamics in the change in the number of researchers: their reduction by 1,572 people in 2023; an increase of 829 people in 2024 and a decrease of 117 people in 2025. The volume of internal costs for basic research according to the built inertial forecast in 2023 may increase in the regions of the first group by 4519 million rubles; decrease in 2024 by 1535 million rubles, and continue to grow in 2025 by 520 million rubles. A more definite forecast, taking into account the preservation of the marked trends for the entire period under review, was formed according to the dynamics of the volume of internal costs for applied research. It assumes a systematic reduction in the annual allocated costs for applied research: from 1874 million rubles in 2022 to 1564 million rubles in 2023; 725 million rubles in 2024; and in 2025 – a reduction in the allocated funds by 717 million rubles.

In the second group of regions, as shown by autoregressive modeling using a moving average, the increase in research organizations is most likely by 47 units in 2023; by 24 units in 2024, and by 43 units in 2025. The number of technicians, while maintaining in the future the trends noted for the period of 2000–2021, will decrease in 2023 by 66 people; and will increase in 2024 by 193 people; and in 2025 by 16 people. The vector of the most probable change in the dynamics of factors in the scenario spatial model of SAR was used to form an inertial forecast scenario of the dynamics of advanced production technologies being developed in the regions of the first and second groups, assuming the preservation of the marked trends of the past in the future (Figure 3). According to this scenar-

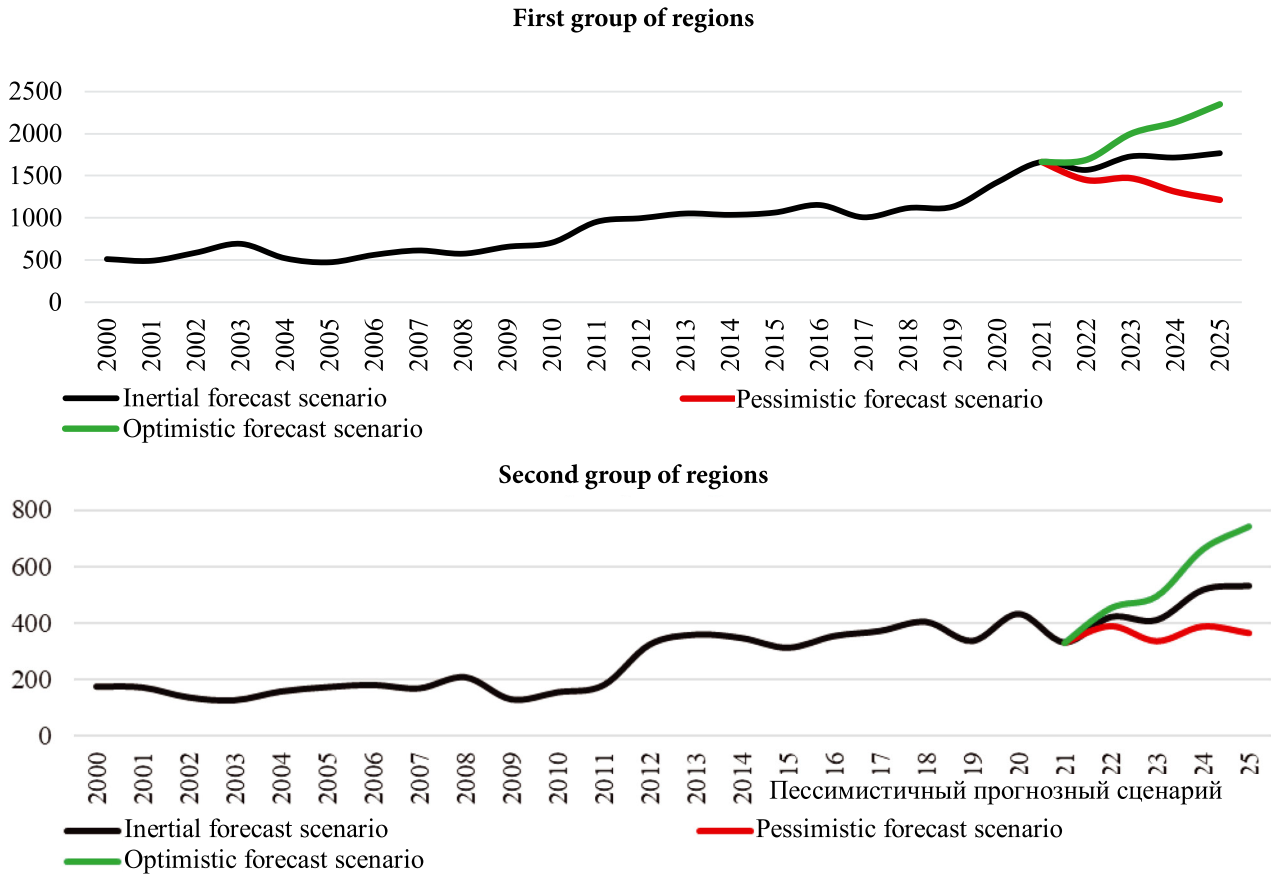

Figure 3. *Forecast scenarios of the dynamics of advanced technologies being developed in the regions of the first and second groups until 2025; units*

Source: compiled by the authors in the Gretl software package

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io, a moderate increase in the volume of advanced production technologies developed in the regions of the first group and its more active growth in the regions of the second group are expected. Thus, in the first group of regions, by 2025, it is possible to develop 1767 units of advanced technologies, which is 12.6% higher than the volume achieved in 2022. At the same time, in the second group, by 2025, it is possible to increase the development of advanced technologies to 530 units, which is 26.1% higher than the level of 2022.

In the second group of regions, fewer advanced technologies are being developed, since the regions do not have such a powerful research potential as the regions of the first group. However, since 2011, the second group of regions has been characterized by the most significant rates of their development. The dynamics confirm the conclusion of this study about smoothing the spatial heterogeneity of the development of advanced production technologies in Russia during periods of economic recovery, about a decrease in their concentration in the regions of the first group.

The optimistic scenario predicts an even more active growth in the volume of advanced production technologies developed in the second group of regions – up to 660 units in 2024 and 740 units in 2025. However, its implementation requires a significant increase in the number of research organizations and the number of engineering personnel (technicians) in the regions of the second group and the number of researchers, the volume of costs for basic and applied research and development in the first group of regions. However, it is difficult to move to this scenario in the context of severe sanctions restrictions, the complexity of importing high-tech equipment, and a decrease in funding for basic and applied research and development. It requires significant financial injections to increase and modernize the scientific potential concentrated in the regions of the first group, that is, the leading research centers of Russia, as well as to develop the scientific infrastructure in the regions that are remote from them.

At present, in the context of deteriorating geopolitical conditions, a pessimistic forecast scenario is most likely, assuming a significant reduction in the volume of generated technologies in the first group of regions – the achievement by 2025 of the volume of developed technologies in 1214 units (Figure 3). This scenario in the first group of regions is possible with a decrease in the number of research organizations by 99 units in 2024 and 72 units in 2025; a decrease in the number of researchers by 2754 people in 2024 and 3687 people in 2025; a decrease in the amount of funding for basic research by 8,555 million rubles in 2024 and 7114 million rubles in 2025; and applied research and development. This scenario will not lead to fatal consequences for the regions of the second group of regions in the dynamics of advanced production technologies being developed, since these regions do not have as powerful research potential, as the regions of the first group.

Conclusions

The constructed SAR models made it possible to establish positive spatial effects in the dynamics of advanced production technologies being developed. In the regions of the second group, the spatial effects were more significant. Their location near regions with powerful research potential significantly affects the development of new technologies in their territory.

With the help of the spatial SAR model, a significant influence of the number of research organizations on the volume of advanced production technologies generated was confirmed, and in the second group of regions, the influence of the number of technicians who conduct research and development was confirmed. To intensify the generation of new technologies in the regions of the second group, it is necessary to attract personnel with technical specialties. The dynamics of the technologies being developed in the first group of regions with a powerful research potential are also influenced by the number of research personnel and the amount of attracted financial resources for fundamental and applied research. To increase the activity of these regions in the development of advanced technologies, it is necessary to form and develop relationships with the surrounding regions.

As a result of the study, an inertial forecast scenario was developed, assuming the preservation of current trends in the dynamics of the technologies being developed, as well as two extreme possible scenarios – optimistic and pessimistic. It should be noted that in the context of sanctions pressure and a difficult geopolitical situation, a pessimistic scenario is most likely, assuming a significant reduction in the volume of technologies developed in the first group of regions by 2025. The pessimistic scenario also assumes a reduction in the number of scientific organizations, researchers, and funding for basic and applied research. Similar trends have already been observed in Russia during periods of economic recessions, which makes this scenario very realistic.

The practical significance of this study lies in the possibility of its use by the authorities to develop strategies for the development of scientific and technological sectors, and can also serve as a basis for mobilizing resources and attracting personnel in the field of science and technology to strengthen the innovation activity and competitiveness of the regions. Further areas of research may be related to an in-depth analysis of the factors influencing the development of advanced production technologies at the municipal level. The existing limitation of the study is that SAR models can be sensitive to the choice of spatial weights and the specification of the model, which can influence the prediction results.

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