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HYBRID MODELING OF REGIONAL ECONOMIC GROWTH BASED ON ARIMA AND QUANTILE REGRESSION

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Abstract. This study explores the forecasting of regional economic growth using a hybrid econometric approach that combines time-series analysis and scenario modeling based on ARIMA and quantile regression. Taking the Surkhandarya Region as an empirical case, the differential effects of investment and the employed population on Gross Regional Product (GRP) dynamics are evaluated across low (25th quantile), medium (50th quantile), and high (75th quantile) growth phases. The findings reveal that lower-growth periods are predominantly driven by extensive labor utilization, whereas higher-growth phases demonstrate significantly greater investment efficiency and elasticity. The proposed hybrid forecasting model provides high-precision estimates for regional economic development scenarios for the period 2026–2031.

Keywords: Gross Regional Product (GRP), economic growth, ARIMA model, quantile regression, hybrid forecasting, investment, labor resources, Surkhandarya Region.

Annotatsiya. Ushbu tadqiqotda vaqt qatorlari tahlili va ARIMA hamda kvantil regressiyasiga asoslangan ssenariy modelash tirishni birlashtiruvchi gibrid ekonometrik yondashuv yordamida hududiy iqtisodiy o'sishni prognozlash masalasi o'rganilgan. Surxondaryo viloyati empirik misol sifatida olinib, investitsiyalar va band aholi sonining yalpi hududiy mahsulot (YaHM) dinamikasiga differensial ta'siri past (25-kvantil), o'rta (50-kvantil) va yuqori (75-kvantil) o'sish bosqichlari kesimida baholangan. Natijalar past o'sish davrlarida iqtisodiy o'sish asosan mehnat resurslaridan ekstensiv foydalanish hisobiga shakllanishini, yuqori o'sish bosqichlarida esa investitsiyalar samaradorligi va elastikligi sezilarli darajada oshishini ko'rsatdi. Taklif etilgan gibrid prognozlash modeli 2026–2031-yillar uchun hududiy iqtisodiy rivojlanish ssenariylarini yuqori aniqlikda baholash imkonini beradi.

Kalit so'zlar: yalpi hududiy mahsulot (YaHM), iqtisodiy o'sish, ARIMA modeli, kvantil regressiya, gibrid prognozlash, investitsiyalar, mehnat resurslari, Surxondaryo viloyati.

Аннотация. В данном исследовании рассматривается прогнозирование регионального экономического роста с использованием гибридного эконометрического подхода, объединяющего анализ временных рядов и сценарное моделирование на основе ARIMA и квантильной регрессии. В качестве эмпирического примера рассматривается Сурхандарьинская область, а дифференцированное влияние инвестиций и численности занятого населения на динамику валового регионального продукта (ВРП) оценивается на этапах низкого (25-й квантиль), среднего (50-й квантиль) и высокого (75-й квантиль) экономического роста. Результаты показывают, что в периоды низкого роста экономическая динамика преимущественно определяется экстенсивным использованием трудовых ресурсов, тогда как на этапах высокого роста существенно повышаются эффективность и эластичность инвестиций. Предложенная гибридная модель прогнозирования позволяет получать высокоточные оценки сценариев регионального экономического развития на 2026–2031 годы.

Ключевые слова: валовой региональный продукт (ВРП), экономический рост, модель ARIMA, квантильная регрессия, гибридное прогнозирование, инвестиции, трудовые ресурсы, Сурхандарьинская область.

INTRODUCTION

In forecasting regional economic development, conventional econometric models do not always fully capture the complex fluctuations in economic indicators. Furthermore, the Ordinary Least Squares (OLS) method is limited to estimating conditional mean values. In forecasting, factor dynamics are commonly projected using time-series data; however, this approach may not adequately reflect volatility, which can reduce forecast accuracy.

Additionally, scenario-based modeling, including high-, moderate-, and low-growth scenarios, has become increasingly important in economic forecasting, as it enables the assessment of economic performance under varying conditions. Linear, nonlinear, and trend models are frequently used in such scenario analyses.

However, because these models reflect different effects on a single outcome, they do not always allow economic processes to be evaluated within a unified framework. Therefore, developing an approach that accounts for complex fluctuations in explanatory variables while simultaneously evaluating different scenarios within a single model is of particular importance.

LITERATURE REVIEW

The issues of forecasting regional economic growth and macroeconomic indicators have been extensively studied by leading scholars in the fields of economic-mathematical modeling and econometrics. The Ordinary Least Squares (OLS) method, widely used in traditional econometric modeling, primarily estimates the conditional mean of the dependent variable and may not fully capture fluctuations and heteroskedasticity across different phases of economic cycles. In analyzing autocorrelation and inertial processes in time-series dynamics, the ARIMA family of models, developed within the Box–Jenkins methodology, is recognized as an effective tool for modeling stochastic fluctuations through autoregressive and moving-average components.

However, since the economic performance of regions and economic entities is neither balanced nor uniform, the effects of explanatory factors on the dependent variable may differ substantially across different points of its distribution. To address this methodological limitation, the quantile regression approach proposed by R. Koenker and G. Bassett enables the estimation of asymmetric relationships not only at the conditional mean but also across different quantiles of the dependent variable, such as the 25th, 50th, and 75th quantiles.

In contemporary research, integrating stochastic time-series models such as ARIMA with the scenario-based capabilities of quantile regression, thereby forming a hybrid forecasting approach, is considered a promising direction for capturing factor heterogeneity and forecast uncertainty in complex regional economic systems within a unified econometric framework.

RESEARCH METHODOLOGY

To represent economic growth, the level of Gross Regional Product (YaHM) was selected as the dependent variable. As is well known, regional economies differ significantly from one another: while agriculture, industry, or construction may dominate in one region, the services sector and exports may be more developed in another. Under these circumstances, selecting factor variables that are universal across all regions becomes complex, and no more than 2–3 explanatory factors can be chosen to prevent a loss of degrees of freedom. Therefore, indicators common to all regions, namely investments ($Invest_t$) and the employed population ($Mehnat_t$) - were selected as the key explanatory factors. Furthermore, as established in production function models, these two variables are sufficient to represent the economy.

Step 1 – Data Preprocessing. At this stage, the raw values of the variables are transformed into logarithmic form. This transformation allows the modeling results to be interpreted in percentage terms and helps address problems associated with raw values, such as the increasing fluctuations of indicators like Gross Regional Product over time. Such expanding fluctuations may lead to increasing variance and, consequently, heteroskedasticity. Logarithmic transformation reduces the scale of the data, thereby mitigating heteroskedasticity and contributing to the normalization of the data distribution.

Step 2 – Stationarity Testing. In empirical modeling, stationarity testing is sometimes overlooked; however, it is essential for preventing spurious regression. If two variables are statistically unrelated but follow similar deterministic trends, failure to test for stationarity may lead to the false conclusion that a strong relationship exists between them, resulting in the modeling of independent variables as if they were related. Furthermore, standard statistical inference relies on Student's t -test and Fisher's F -test, both of which require stationary time series. Therefore, at this stage, the log-transformed variables are tested using the Augmented Dickey–Fuller (ADF) test to determine their order of integration.

Step 3 – Constructing ARIMA Models for Explanatory Variables and Forecasting. Once the order of integration of the explanatory variables has been determined, ARIMA models are specified. These models are highly adaptable to economic fluctuations and unexpected external shocks. Within the ARIMA framework, the Autoregressive (AR) component captures the past growth inertia of the factors; the Integrated (I) component accounts for structural shifts and non-stationarity; and the Moving Average (MA) component smooths the dynamics of random shocks and external disturbances. Together, these components enable the model to adapt effectively to various fluctuations, including cyclical economic movements [4].

The mathematical specification of the ARIMA model is expressed as follows [2]:

$$\phi(B)(1 - B)^d X_t = c + \theta(B)\varepsilon_t, \quad (1)$$

where B is the lag operator; ϕ and θ are the autoregressive and moving average coefficients, respectively, and ε_t - represents the white noise error term.

Step 4 – Constructing the Quantile Regression Model. At this stage, the empirical model representing the production function is estimated using quantile regression.

Economic development does not proceed at a uniform rate; rather, it varies across different phases of the economic cycle. In econometric analyses of regional economic growth, this variation requires separate evaluation of low-, medium-, and high-growth periods. The productivity and efficiency of production factors, particularly investment and labor resources, as well as their effects on economic growth during periods of stagnation or recession, may differ substantially from those observed during high-growth phases.

The standard Ordinary Least Squares (OLS) method estimates relationships at the conditional mean and therefore may not fully capture the specific effects of investment and labor resources under different growth conditions. In this context, quantile regression provides an effective approach for estimating the differentiated effects of production factors across low, medium, and high levels of regional economic growth.

While the Ordinary Least Squares (OLS) method estimates only the conditional mean

$E(Y|X)$, quantile regression establishes a model that expresses the dependence of different quantiles $\tau \in (0,1)$ of the dependent variable on the explanatory variables rather than focusing solely on the mean. Originally introduced by Roger Koenker and Gilbert Bassett in 1978 [5], quantile regression demonstrates how the effects of explanatory factors vary across different points of the conditional distribution, such as the 10th or 90th percentiles. Consequently, it provides robust and reliable estimates even when the data are non-normally distributed or exhibit substantial heteroskedasticity.

For a specific quantile $\tau \in (0,1)$, the general form of the quantile regression model is expressed as follows [6]:

$$Q_y(\tau|x) = x\beta_\tau, \quad (2)$$

where, $Q_y(\tau|x)$ - is the τ -th conditional quantile of the variable y ; x is the matrix of explanatory variables; β_τ - is the vector of parameters to be estimated for the τ -th quantile.

The empirical specification of the model based on investment and labor indicators is expressed as follows:

$$Q_\tau(y_t) = \beta_0(\tau) + \beta_1(\tau)i_t + \beta_2(\tau)l_t \quad (3)$$

Step 5 - Formulating Quantile Regression Forecasts Based on ARIMA Results. In this step, the forecasted values of $\hat{i}_{t+h}$ and $\hat{l}_{t+h}$ obtained via the ARIMA models for horizon h are plugged into the pre-estimated parameters of the quantile regression model. Consequently, the hybrid forecasting equation is specified as follows:

$$\hat{Q}_\tau(y_{t+h}) = \hat{\beta}_0(\tau) + \hat{\beta}_1(\tau)\hat{i}_{t+h} + \hat{\beta}_2(\tau)\hat{l}_{t+h} \quad (4)$$

Based on this model, forecasts across various quantiles are generated.

Step 6 - Transforming Quantile Forecasts. The generated forecasts are essential for the study in both percentage terms and billions of UZS. To transform the log-scale results back into monetary terms (billions of UZS), the following formulation is utilized [1] [3]:

$$\hat{y}_{t+h} = e^{[\hat{\beta}_0(\tau) + \hat{\beta}_1(\tau)\hat{i}_{t+h} + \hat{\beta}_2(\tau)\hat{l}_{t+h}]} \quad (5)$$

To express economic growth, the logarithmic differentiation method was applied. For this purpose, the logarithmic first differences are calculated from the forecasted values:

$$\Delta \hat{y}_{t+h}^{(\tau)} = \hat{y}_{t+h}^{(\tau)} - \hat{y}_{t+h-1}^{(\tau)} \quad (6)$$

Based on the obtained result, the percentage growth rate is calculated as follows:

$$\hat{g}_{t+h}^{(\tau)} = [e^{\Delta \hat{y}_{t+h}^{(\tau)}} - 1] \cdot 100 \quad (7)$$

The key advantage of the proposed enhanced approach is that it incorporates investment and labor values forecasted via ARIMA models as exogenous explanatory factors into the quantile regression framework.

The key advantage of the proposed enhanced approach is that it incorporates investment and labor values forecast using ARIMA models as exogenous explanatory variables within the quantile regression framework.

ANALYSIS AND RESULTS

ARIMA models were specified to forecast fixed capital investment and the employed population in the economy of Surxondaryo Region. Initially, both series were log-transformed. This transformation stabilizes the series by reducing fluctuations that increase over time. Furthermore, log-transformed variables reflect relative changes rather than absolute levels, which is consistent with the objectives of this study.

To determine the order of integration, the log-transformed series were first examined visually. Both series exhibited an upward trajectory with a deterministic linear trend, indicating non-stationarity in levels. To remove the trend component, first differences were taken, and the stationarity of the first-differenced series was assessed using the Augmented Dickey–Fuller (ADF) test. The resulting p -values confirmed that the first differences of the log-transformed investment and labor series were stationary. Consequently, both variables were identified as integrated of order one, $I(1)$.

Optimal model specifications were determined for both $\ln Invest_t$ and $\ln Mehnat_t$. For $\ln Invest_t$, the Akaike Information Criterion (AIC) and Hannan-Quinn Criterion (HQC) initially suggested an ARIMA(0, 1, 3) specification. However, upon estimation, the parameters of this specification were not statistically significant. The next best fit yielding parsimonious and statistically valid results was achieved with ARIMA(0, 1, 0). For the $\ln Mehnat_t$ factor, an ARIMA(0, 1, 2) model was identified as optimal. However, since the ϕ_1 parameter was statistically insignificant, it was omitted from the specification, leading to the estimation of a restricted ARIMA(0, 1, [2]) model.

The mathematical specification of the ARIMA model for $\ln Invest_t$ is expressed as follows:

$$\Delta \ln Invest_t = 0,236506 + \varepsilon_t \quad (8)$$

For the $\ln Mehnat_t$ model, the mean absolute percentage error (MAPE) was 2,1123%, with a coefficient of determination of 0,95, indicating high explanatory power and model fit. The estimated parameters of the model are statistically significant. Furthermore, the residual normality test yielded a test statistic with a p -value well above the 0,05 significance threshold, confirming that the model residuals are normally distributed.

Next, empirical estimations were conducted for the logarithm of the employed population in the economy. The mathematical formulation of the specified ARIMA(0, 1, [2]) model is as follows:

$$\Delta^1 \ln Mehnat_t = 0.0185514 + 0,749796\varepsilon_{t-2} + \varepsilon_t \quad (9)$$

The model's mean absolute percentage error (MAPE) was 0.19007%, while the coefficient of determination was 0.97, indicating an exceptionally high goodness of fit. All estimated model parameters were statistically significant. Furthermore, the χ^2 normality test applied to the model residuals yielded a p -value substantially greater than the 0.05 significance level, indicating that the residuals were normally distributed.

Thus, the ARIMA models specified for both $\ln Invest_t$ and $\ln Mehnat_t$ meet all diagnostic criteria and are deemed fully suitable for out-of-sample forecasting. Utilizing these models, the projected baseline values for both explanatory variables were generated (Table 1).

Table 1
Forecasted Values¹

Year		Standart error		Standart error
2026	10,269196	0,199238	6,949307	0,015814
2027	10,505702	0,281765	6,961483	0,022365
2028	10,742209	0,345090	6,980034	0,035579
2029	10,978715	0,360387	6,998586	0,045073
2030	11,215222	0,375060	7,017137	0,052890
2031	11,451728	0,389181	7,035688	0,059691

When transformed back into level terms from the values presented in Table 1, the volume of fixed capital investment in the economy of the Surkhandarya Region is projected to reach UZS 28,830.7 billion by the end of 2026 and increase to UZS 94,063.78 billion by 2031. Concurrently, the employed population in the regional economy is forecast to increase from 1,042.4 thousand persons at the end of 2026 to 1,136.5 thousand persons by 2031. These projected factor values serve as exogenous inputs for generating scenario-based economic

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forecasts within the hybrid modeling framework.

The empirical effects of fixed capital investment and the employed population on the dependent variable, Gross Regional Product (GRP), were subsequently evaluated. Initial model estimations revealed that the intercept (constant term) was statistically insignificant. To address this issue and increase the model's degrees of freedom, the intercept was omitted from the specification. Excluding the constant term reduced the standard errors of the remaining explanatory variables and increased their corresponding *t*-statistics, thereby improving the overall estimation efficiency. The estimation results across different quantiles are presented in Table 2.

Table 2

Results for the 50th Quantile (Median) Regression²

Model Coefficients					
Coefficients	Value	Standart error	t-statistics	p-value	Significance
	0,655653	0,0366310	17,90	<0,0001	***
	0,631394	0,0451537	13,98	<0,0001	***
Overall Statistical Summary of the Model					
Indicator	Value	Indicator		Value	
Dependent variable mean	9,870147	Dependent variable standard deviation		0,912248	
Sum of absolute residuals	1,879346	Sum of squared residuals		0,388053	
Log-likelihood	7,176281	Akaike information criterion		-10,35256	
Schwarz criterion (BIC)	-8,807385	Hannan–Quinn information criterion		-10,27344	

All estimated parameters of the model presented in Table 2 are statistically significant at the 1% significance level ($p < 0.01$). This confirms that the empirical relationships between the explanatory variables and the dependent variable, Gross Regional Product (GRP), are statistically significant and possess strong explanatory power.

Regarding the overall goodness of fit and model selection criteria, the Akaike Information Criterion (AIC), Schwarz Bayesian Information Criterion (BIC), and Hannan–Quinn Criterion (HQC) yielded sufficiently low values. These results support the adequacy of the selected functional specification and indicate that the chosen model provides an appropriate representation of the relationship among the variables.

Furthermore, the residual normality test yielded a test statistic of =1,844 with a *p*-value of 0.39781, which is substantially greater than the conventional 0.05 significance level. Therefore, the null hypothesis of residual normality cannot be rejected, indicating that the model residuals are consistent with a normal distribution.

In addition to the above diagnostic measures, the model's standard error was estimated at 0.1175, which is relatively small. This indicates that the average deviation between the estimated and actual values is limited. Furthermore, the Theil index was estimated at 0.574. Based on these diagnostic results, the model was considered suitable for forecasting purposes.

The residual autocorrelation function (ACF) and partial autocorrelation function (PACF) were also examined. No statistically significant autocorrelation was detected at any lag.

Another important diagnostic issue, multicollinearity among the explanatory variables, was assessed using the Variance Inflation Factor (VIF). In empirical practice, multicollinearity is generally considered problematic when the VIF exceeds 10.0. In the present model, the VIF values did not indicate a level of multicollinearity that could adversely affect the reliability of the estimates. In addition, the Belsley–Kuh–Welsch (BKW) diagnostic produced a condition index of 15.267, which is below the commonly applied critical threshold of 30. This result further supports the absence of severe multicollinearity among the explanatory variables.

Since the model satisfied the specified diagnostic criteria, its parameters were subsequently estimated at the 25th, 50th, and 75th quantiles (Table 3).

Table 3
Kvantil regressiya natijalari³

Model Coefficients					
Coefficients	Value	Standart error	t-statistics	p-value	Significance
I_Invest	0,250	0,634894	0,0438859	14,4669	8.21e-010
	0,500	0,655653	0,0366310	17,8988	4.81e-011
	0,750	0,700848	0,0103162	67,9365	4.85e-019
I_Mehnat	0,250	0,639321	0,0540965	11,8182	1.14e-08
	0,500	0,631394	0,0451537	13,9832	1.28e-09
	0,750	0,587062	0,0127164	46,1658	1.06e-016
Overall Statistical Summary of the Model					
Indicator		Value	Indicator		Value
Dependent variable mean		9,870147	Dependent variable standard deviation		0,12248

According to Table 3, the general forms of the quantile regression at different percentiles are as follows:

$$\ln YaHM_{0,25} = 0,6349 \ln Invest + 0,6393 \ln Mehnat \quad (10)$$

$$\ln YaHM_{0,5} = 0,6557 \ln Invest + 0,6314 \ln Mehnat \quad (11)$$

$$\ln YaHM_{0,75} = 0,7008 \ln Invest + 0,5871 \ln Mehnat \quad (12)$$

Analyzing the medium-growth model (11), a 1% increase in investment leads to an average increase of 0.656% in Gross Regional Product (GRP). Similarly, a 1% increase in labor resources results in a 0.631% increase in the median value of GRP.

As shown in Table 3, investment elasticity increases as the quantile rises. This indicates that as the economy transitions from a low-growth phase to a high-growth phase, the impact and efficiency of investment increase significantly. At the same time, the decline in the standard error and the increase in the *t*-statistic at the 75th quantile further demonstrate the growing importance of investment during periods of high economic growth.

An opposite pattern is observed for labor elasticity. As the quantile increases, labor elasticity declines. These contrasting dynamics indicate that during low-growth periods, the regional economy relies more heavily on the labor factor, reflecting a relatively extensive pattern of growth. Conversely, as economic growth accelerates, dependence on labor decreases, while the role of investment becomes more pronounced.

For both factors, the sum of the elasticity coefficients exceeds 1 across all quantiles. This indicates the presence of increasing returns to scale under low-, medium-, and high-growth conditions.

Forecasting was subsequently conducted using models (10), (11), and (12). The forecast values obtained in logarithmic form were transformed back into levels and percentage terms. The results are presented in Table 4.

Table 4
Surkhandarya Region GRP growth forecast⁴

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	Low	Mean	High	Past	O'rta	Yuqori
2026	10,963	11,121	11,277	57 682,0	67 561,9	78 968,2
2027	11,121	11,284	11,450	67 548,4	79 499,0	93 873,2
2028	11,283	11,450	11,626	79 427,5	93 929,5	112 016,3
2029	11,445	11,617	11,803	93 405,0	110 979,4	133 652,7
2030	11,607	11,784	11,980	109 831,2	131 124,2	159 484,2
2031	11,769	11,951	12,156	129 146,2	154 910,1	190 289,1

Based on the Gross Regional Product forecasts presented in Table 4, the following conclusions were drawn.

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CONCLUSION AND SUGGESTIONS

According to the forecast, fixed capital investment in the economy of the Surkhandarya Region is expected to reach UZS 28,830.7 billion by the end of 2026 and increase to UZS 94,063.7 billion by 2031. Meanwhile, the employed population in the regional economy is projected to increase from 1,042.4 thousand persons at the end of 2026 to 1,136.5 thousand persons by 2031.

According to the quantile regression results, the elasticities of economic growth with respect to investment and labor resources vary significantly across different quantiles. During periods of low economic growth, labor elasticity (0.639) was higher than investment elasticity (0.635). This indicates that at the 25th quantile, economic growth is relatively extensive in nature and is driven primarily by labor resources. At higher-growth quantiles, however, the pattern is reversed: investment elasticity increases to 0.701, whereas labor elasticity decreases to 0.587. These results indicate that during periods of slower economic growth, the regional economy relies more heavily on labor resources, whereas during periods of accelerated growth, the role of investment becomes increasingly significant.

The average-growth forecast based on the hybrid forecasting approach indicates that Gross Regional Product (GRP) will reach UZS 67,561.9 billion in 2026 and increase to UZS 154,910.1 billion by 2031.

Overall, the proposed hybrid forecasting approach demonstrates that, under the average-growth scenario, the Gross Regional Product of the Surkhandarya Region is projected to increase from UZS 67,561.9 billion in 2026 to UZS 154,910.1 billion by 2031.

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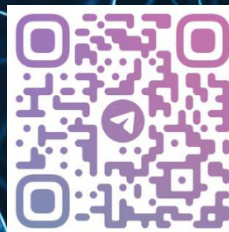
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