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Assessing the role of Digital Transformation and Innovation Infrastructure in Regional Economic Growth in Khorezm Region

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Abstract: This paper estimates the contribution of digital infrastructure, ICT-sector wages, household income, investment dynamics and the small-business structure to gross regional product (GRP) and produces a scenario forecast for Khorezm region for 2026–2030. Because only five annual observations are available for Khorezm, a six-factor log-linear model is estimated on a pooled panel of the 14 regions of Uzbekistan for 2021–2024 (56 observations) and then calibrated to the region. The model explains 95.2% of GRP variation ($R = 0.976$; $F = 161.7$). Internet subscriber base (elasticity 0.84) and per capita income (0.94) are the dominant drivers. A potential realisation coefficient is proposed: Khorezm produces about 11% less output than its factor endowment predicts, ranking 13th of 14 regions. In the baseline scenario Khorezm's GRP reaches 139.3 trillion UZS by 2030.

Keywords: regional economic growth, gross regional product, digital infrastructure, internet penetration, household income, panel regression, potential realisation coefficient, scenario forecast, Uzbekistan, Khorezm.

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1. Introduction

Over the past five years regional development policy in Uzbekistan has combined two priorities: rapid expansion of digital connectivity under the “Digital Uzbekistan – 2030” strategy and the reduction of regional disparities under the “Uzbekistan – 2030” strategy. Both rest on an implicit assumption that more connectivity, higher incomes and more investment translate more or less automatically into higher regional output.

Khorezm region is an instructive case for testing that assumption. Between 2021 and 2025 its GRP more than doubled in nominal terms, from 29.7 to 63.0 trillion UZS, with real growth of 7.9% in 2025. The number of internet subscribers rose by more than half and per capita household income nearly doubled. Yet at a government meeting in March 2026 it was explicitly noted that the region's results do not fully correspond to its potential. This raises a quantitative question: how large is the gap between what Khorezm's factor endowment should produce and what the region actually produces.[1]

Answering the question econometrically meets an immediate obstacle. For 2021–2025 only five annual observations exist for the region, while a six-factor regression

requires seven parameters. A model estimated on the Khorezm series alone is therefore not merely imprecise but mathematically undefined. Correlations computed on such a short series are also misleading, because all indicators share a common upward trend.

The paper therefore pursues three objectives: to estimate the joint effect of six digital and socio-economic factors on regional output using the cross-regional panel; to measure how far Khorezm deviates from the output level predicted by its factors; and to use the calibrated model to forecast Khorezm's GRP for 2026–2030 under alternative scenarios.[2]

2. Materials and Methods

The theoretical basis of the study combines three strands. The first is neoclassical and endogenous growth theory, in which output depends on the accumulation of physical and human capital and on technology. Mankiw, Romer and Weil showed that augmenting the Solow model with human capital explains most of the cross-country variation in income levels, which justifies including income and skill-related variables alongside investment [3].

The second strand treats telecommunications and broadband as a productive infrastructure with network externalities. Röller and Waverman, using a simultaneous-equations approach for OECD countries, found a significant causal link from telecommunications penetration to output, with returns strongest once a critical mass of users is reached [4]. Czernich et al. estimated that a 10 percentage point increase in broadband penetration raised annual per capita growth by 0.9–1.5 percentage points [5]. Koutroumpis confirmed the critical-mass effect [6], while Kolko, working at the local level, found that broadband is associated with employment growth but not necessarily with higher incomes per resident [7]. The latter result is important here: penetration and scale of use are distinct concepts and can enter a regression with different signs.

The third strand concerns demand-side and structural factors. Aschauer's work on the productivity of public capital [8] and the convergence literature of Barro and Sala-i-Martin [9] frame investment as a lagged driver of regional output. Chami, Fullenkamp and Jahjah showed that remittance flows are largely compensatory and consumption-oriented rather than a source of productive capital [10], which is directly relevant for Khorezm, where the share of remittances in household income rose from 22.8% to 31.1% in 2025 [11].

For Uzbekistan, regional studies remain predominantly descriptive or use single-factor regressions on short series. Yormonqulova analysed regional disparities and investment for 2021–2024 [12], and Khorezm-specific work has estimated the elasticity of industrial output with respect to investment at 1.24 [13]. However, multi-factor models that combine digital and socio-economic variables, explicitly address the short-sample problem and quantify a region's unrealised potential are largely absent. This paper addresses that gap.

3. Result and Discussion

The Table 1. empirical analysis uses a balanced panel of the fourteen administrative units of Uzbekistan – twelve provinces, the Republic of Karakalpakstan and Tashkent city – for 2021–2024, giving 56 observations. Three regional series (internet subscribers, internet subscribers per 100 population and wages in information and communication) are taken from the open SIAT database of the Statistics Agency under the President of the Republic of Uzbekistan. GRP, per capita income, investment growth and the small-business employment share are drawn from official regional statistics [14]. The 2025 values for Khorezm are used for out-of-sample validation [15].

Table 1. System of model variables

Symbol	Indicator	Unit
Y	Gross regional product, current prices	billion UZS
X1	Internet subscribers, total	thousand
X2	Internet subscribers (individuals) per 100 population	units
X3	Average wage in information and communication	thousand UZS
X4	Per capita total household income	thousand UZS
X5	Growth rate of fixed capital investment, lagged (t–1)	%
X6	Small-business share in employment, lagged (t–1)	%

The model is specified in log-linear (Cobb–Douglas type) form:

$$\ln(Y)_{it} = \beta_0 + \beta_1 \cdot \ln X1_{it} + \beta_2 \cdot \ln X2_{it} + \beta_3 \cdot \ln X3_{it} + \beta_4 \cdot \ln X4_{it} + \beta_5 \cdot X5_{i,t-1} + \beta_6 \cdot X6_{i,t-1} + \varepsilon_{it} \quad (1)$$

Where i denotes the region and t the year. Coefficients β_1 – β_4 are elasticities; β_5 and β_6 are semi-elasticities of the percentage-valued variables. Investment growth and the small-business share enter with a one-year lag, since their effect on output materialises with delay and the lag reduces simultaneity. The model is estimated by ordinary least squares. Inference is reported with both conventional and region-clustered standard errors. Multicollinearity is checked by variance inflation factors (VIF), heteroskedasticity by the Breusch–Pagan test, normality of residuals by the Jarque–Bera test and functional form by the Ramsey RESET test [15].

To transfer the panel estimates to Khorezm, a region-specific deviation is computed as the mean residual of the region, $\bar{\varepsilon}_i$. Its exponent defines the potential realisation coefficient:

$$PRC_i = \exp(\bar{\varepsilon}_i) \approx Y_{\text{actual}} / Y_{\text{predicted}} \quad (2)$$

A value below one means that the region produces less output than its factor levels predict. For forecasting, factor paths for 2026–2030 are set under three scenarios, substituted into the estimated equation and anchored to the actual 2025 GRP of Khorezm. An exponential trend fitted to 2021–2025 serves as a benchmark.

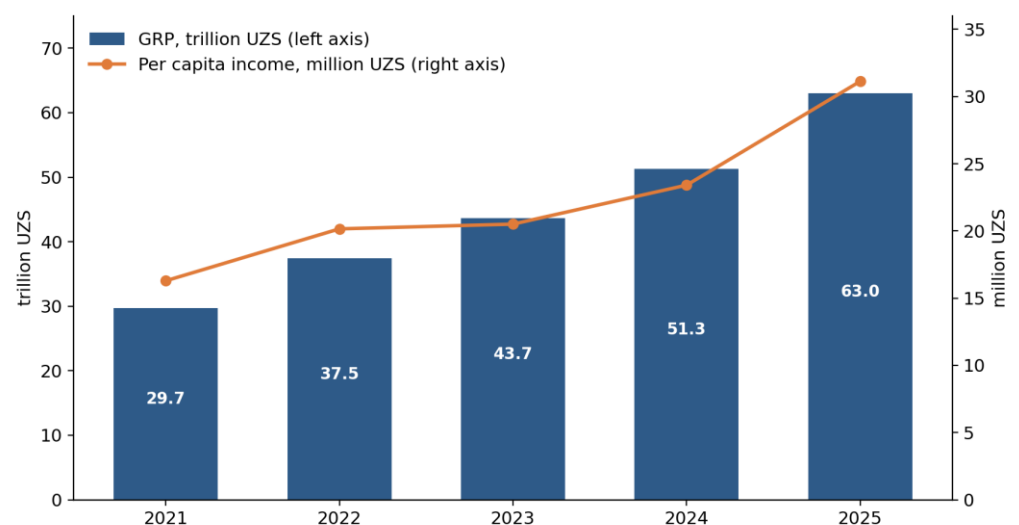
3.1 Scientific novelty

The Table 2. contribution of the paper is threefold. First, it resolves the short-sample problem of regional forecasting in Uzbekistan by estimating a multi-factor model on the cross-regional panel and calibrating it to an individual region, instead of fitting an undefined regression to five data points. Second, it introduces the potential realisation coefficient as a diagnostic indicator that separates a region's factor endowment from its effectiveness in converting that endowment into output, and ranks all fourteen regions on this basis. Third, it validates the model out of sample against 2025 data and identifies remittance-driven income growth as the main source of divergence between income and output, which directly affects the design of regional policy.[16]

Table 2. Key indicators of Khorezm region, 2021–2025

Indicator	2021	2022	2023	2024	2025	CAGR, %
GRP, bn UZS	29,737.2	37,474.3	43,666.7	51,261.0	62,987.5	20.6
Internet subscribers, thousand	1,185.9	1,328.4	1,482.3	1,628.0	1,850.7	11.8
Internet subscribers per 100	60.2	66.2	72.0	76.7	76.8	6.3
ICT wage, thousand UZS	2,964.8	4,041.4	7,735.6	7,826.9	8,381.5	29.7
Per capita income, thousand UZS	16,292.2	20,155.2	20,509.2	23,410.8	31,136.0	17.6
Population (1 January), thousand	1,893.3	1,924.2	1,958.1	1,995.6	2,032.4	1.8
Investment growth rate, %	139.3	94.2	121.0	-	-	-
Small-business employment share, %	79.1	78.1	78.5	-	-	-

Figure 1. Over 2021–2025 Khorezm’s GRP grew by a factor of 2.1 in current prices, the internet subscriber base by 1.56, ICT wages by 2.8 and per capita income by 1.9. Two features deserve attention. Internet penetration stalled in 2025 at 76.8 subscribers per 100 population, indicating that the extensive phase of connection is largely complete. Per capita income jumped by 33% in 2025, but a substantial part of this increase came from remittances rather than from regional production.

**Figure 1.** GRP and per capita income of Khorezm region, 2021–2025

The Table 3. chart shows a **steady increase in both GDP and per capita income from 2021 to 2025**. GDP rose from **29.7 trillion UZS in 2021 to 63.0 trillion UZS in 2025**, while per capita income also increased, reaching its highest level in 2025. Overall, the figures indicate **strong economic growth and improving income levels** over the five-year period.[17]

Table 3. Descriptive statistics of the panel, 2021–2024 (N = 56)

Variable	Mean	Std. dev.	Min	Max
ln(Y)	10.981	0.570	9.733	12.547
X1, thousand	1,998.4	1,258.1	595.4	6,433.1
X2, per 100	71.73	26.33	47.50	173.20
X3, thousand UZS	5,975.7	2,556.1	2,824.2	14,938.8
X4, thousand UZS	20,124.1	8,987.5	11,731.8	60,594.4
X5, %	108.82	19.51	69.90	148.30
X6, %	73.47	9.84	49.40	82.20

The Table 4. panel is strongly heterogeneous. Tashkent city records the maximum values of X1, X2, X3 and X4, and its internet penetration exceeds 170 per 100 because, according to the SIAT note, subscribers of several Tashkent region operators are registered in the capital. The small-business share ranges from about 49% in Tashkent city to over 82% in Namangan region.

Table 4. Pairwise correlation of GRP with the factors

Factor	Panel (n = 56)	Strength and direction	Khorezm (n = 5)
X1 – Internet subscribers	0.829	high, positive	0.999
X2 – Internet penetration	0.785	high, positive	0.928
X3 – ICT wage	0.682	moderate, positive	0.886
X4 – Per capita income	0.857	high, positive	0.973
X5 – Investment growth (t–1)	0.053	very weak	–
X6 – Small-business share (t–1)	–0.643	moderate, negative	–

In the panel the closest associations are with per capita income ($r = 0.857$) and the internet subscriber base ($r = 0.829$). The Table 5. Khorezm-only coefficients of 0.89–0.999 illustrate the short-sample problem described above: with five observations moving in the same direction, correlations are inflated by the common trend and cannot be read as evidence of causation. The Table 6. negative correlation with the small-business share reflects the higher output of regions dominated by large enterprises.

Table 5. Estimation results of the six-factor model

Variable	Coefficient	Std. error	t-statistic	p-value	P (clustered)
Constant	2.5765**	1.2737	2.02	0.049	0.248
lnX1 – Internet subscribers	0.8418***	0.0420	20.05	<0.001	<0.001
lnX2 – Internet penetration	–1.5702***	0.1461	–10.75	<0.001	<0.001
lnX3 – ICT wage	0.1838**	0.0716	2.57	0.013	0.171
lnX4 – Per capita income	0.9367***	0.1386	6.76	<0.001	<0.001

X5 – Investment growth (t–1)	0.0013	0.0010	1.23	0.224	0.087
X6 – Small-business share (t–1)	–0.0295***	0.0045	–6.51	<0.001	0.005

The estimated equation is:

$$\ln(Y) = 2.577 + 0.842 \cdot \ln X1 - 1.570 \cdot \ln X2 + 0.184 \cdot \ln X3 + 0.937 \cdot \ln X4 + 0.0013 \cdot X5 - 0.0295 \cdot X6$$

Table 6. Goodness of fit and diagnostic tests

Statistic	Value	Interpretation
Multiple correlation coefficient (R)	0.9757	very close relationship
Coefficient of determination (R ²)	0.9519	95.2% of variation explained
Adjusted R ²	0.9460	robust to number of regressors
F-statistic	161.74 (p < 0.001)	model jointly significant
Standard error of regression	0.1324	average error ≈ 13%
Maximum VIF	7.29	< 10, no severe multicollinearity
Breusch–Pagan test, p	0.123	no heteroskedasticity
Jarque–Bera test, p	0.411	residuals normally distributed
Ramsey RESET test, p	0.911	functional form adequate

The model is statistically strong. R = 0.976 indicates a very close relationship, and R² = 0.952 means that the six factors jointly explain 95.2% of the variation in regional output; the remaining 4.8% is attributable to omitted factors. The F-statistic of 161.7 far exceeds the critical value of 2.29, and none of the diagnostic tests signals a violation of the classical assumptions.[18]

The internet subscriber base is the strongest and most precisely estimated factor: a 1% increase in X1 is associated with a 0.84% increase in GRP (t = 20.05; standardised beta 0.795). Per capita income follows with an elasticity of 0.94 (t = 6.76), confirming the role of domestic demand. The ICT wage has a positive elasticity of 0.18, significant under conventional errors (p = 0.013) but not under clustering (p = 0.171), so this effect should be read with caution.

Internet penetration, positively correlated with GRP in pairwise terms (r = 0.785), enters the multi-factor model with a negative coefficient of –1.570. This is a suppressor effect consistent with Kolko’s findings: holding the absolute number of subscribers constant, higher penetration implies a smaller population and thus a smaller economy. The substantive implication is that connectivity as such does not raise output; what matters is the scale of economically productive use of the network.

Lagged investment growth has the expected positive sign – a 10 percentage point acceleration is associated with roughly 1.3% higher GRP – but is significant only at the 10% level under clustered errors (p = 0.087), consistent with investment returns materialising over more than one year. The table 7. small-business share has a negative semi-elasticity of –0.0295: a one point higher share corresponds to about 2.9% lower GRP. This Table 8. does not imply that small business is harmful, but that regions where

medium and large enterprises carry more weight achieve higher labour productivity. Khorezm's share of 78.5% suggests a clear reserve for firm scale-up.

Table 7. Potential realisation coefficient by region, 2021–2024

Rank	Region	PRC	Output gap, %
1	Tashkent region	1.202	+20.2
2	Namangan	1.180	+18.0
3	Andijan	1.106	+10.6
4	Samarkand	1.072	+7.2
5	Syrdarya	1.043	+4.3
6	Navoi	1.038	+3.8
7	Karakalpakstan	1.026	+2.6
8	Jizzakh	0.996	–0.4
9	Kashkadarya	0.968	–3.2
10	Tashkent city	0.954	–4.6
11	Fergana	0.943	–5.7
12	Bukhara	0.917	–8.3
13	Khorezm	0.893	–10.7
14	Surkhandarya	0.754	–24.6

The potential realisation coefficient reveals substantial differences in how effectively regions convert their factor endowment into output. Tashkent region (1.202) and Namangan (1.180) outperform their predicted levels, while Surkhandarya (0.754) and Khorezm (0.893) lag furthest behind. Khorezm ranks 13th of 14: given its connectivity, income, wages and investment dynamics, the region should have produced around 12% more output. On average over 2021–2024 this corresponds to a gap of about 4.6 trillion UZS per year between predicted (45.1) and actual (40.5) GRP.

As an out-of-sample check, Khorezm's 2025 factor values ($X_1 = 1,850.7$; $X_2 = 76.8$; $X_3 = 8,381.5$; $X_4 = 31,136$; $X_5 = 111.8$ as the 2020–2023 average; $X_6 = 78.5$) were substituted into the equation together with the regional effect. The model predicts 70.3 trillion UZS against an actual 63.0 trillion UZS, an error of +11.7%. The divergence is explained mainly by the 33% jump in household income, much of which came from remittances and did not translate into regional production [19]. For forecasting, the model was therefore anchored to the actual 2025 value.

3.2 Forecast for 2026–2030

Three table 8. scenarios were constructed for the paths of the factors. The baseline scenario assumes moderate deceleration relative to 2021–2025; the pessimistic and optimistic scenarios bracket it.

Table 8. Scenario assumptions (annual)

Factor	Pessimistic	Baseline	Optimistic
X1 – growth of internet subscribers	5%	8%	11%
X2 – change in penetration	+1.0 p.p.	+1.5 p.p.	+2.0 p.p.
X3 – growth of ICT wage	7%	10%	14%
X4 – nominal income growth	9%	12%	16%
X5 – investment growth rate	100%	110%	120%
X6 – small-business share	78.5%	78.5%	78.5%

The Table 9. benchmark exponential trend for 2021–2025 is $\ln(Y) = 10.138 + 0.1814 \cdot t$ ($R^2 = 0.995$), implying average nominal growth of 19.9% per year.

Table 9. Forecast of Khorezm region GRP, trillion UZS (current prices)

Year	Pessimistic	Baseline	Optimistic	Trend	Baseline 95% interval
2026	69.5	73.6	78.6	75.1	56.8 – 95.4
2027	77.9	86.3	97.1	90.0	66.6 – 111.8
2028	87.4	101.2	120.1	108.0	78.0 – 131.1
2029	98.0	118.7	148.7	129.4	91.6 – 153.8
2030	110.0	139.3	184.2	155.2	107.5 – 180.6
2030/2025, times	1.75	2.21	2.92	2.46	–

The table presents **GDP forecasts for 2026–2030 under three scenarios: pessimistic, baseline, and optimistic.** In all scenarios, GDP is projected to increase steadily, with the **baseline forecast rising from 73.6 trillion UZS in 2026 to 139.3 trillion UZS in 2030.** The Figure 11. optimistic scenario reaches **184.2 trillion UZS**, while the pessimistic scenario reaches **110.0 trillion UZS** by 2030. Overall, the projections indicate substantial potential economic growth over the forecast period.[20]

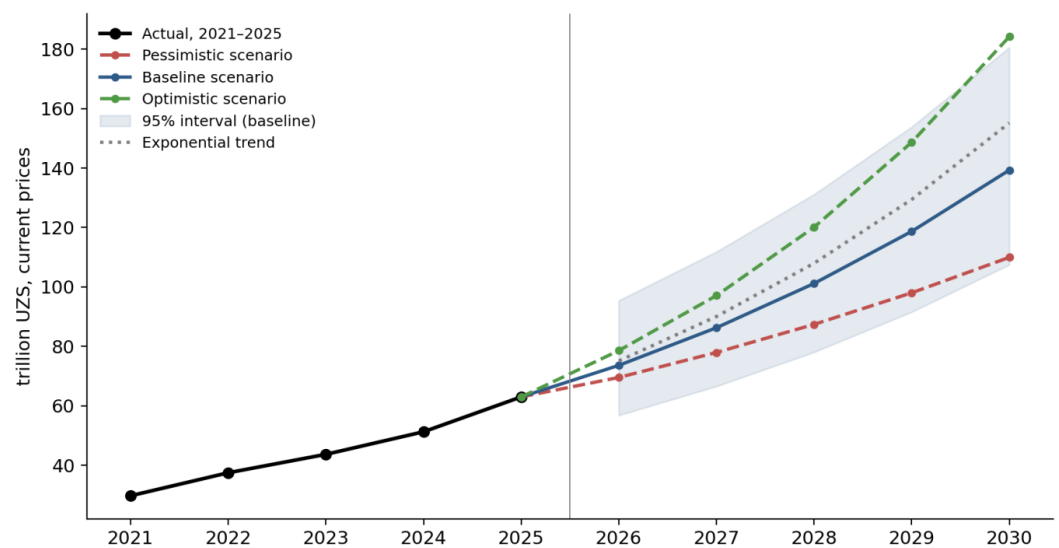


Figure 2. Scenario forecast of Khorezm region GRP, 2026–2030

In the baseline scenario Khorezm's GRP reaches 73.6 trillion UZS in 2026 and 139.3 trillion UZS in 2030, 2.2 times the 2025 level, corresponding to average nominal growth of 17.2%. With a GRP deflator of around 9–10%, this implies real growth of 7–8% per year, in line with the 7.9% achieved in 2025. The pessimistic scenario yields 110.0 trillion UZS and the optimistic one 184.2 trillion UZS by 2030. The exponential trend (155.2 trillion UZS) lies between the baseline and optimistic paths, indicating that if current momentum persists, the outcome could exceed the baseline. The width of the 95% interval (107.5–180.6 trillion UZS in 2030) is a reminder that the forecast is a scenario assessment rather than an official projection.

3.3 Existing opportunities and challenges

Three opportunities emerge from the analysis. First, the high elasticity of output with respect to the subscriber base means that further growth in the number of active digital users – households and, above all, businesses – remains a strong lever, even though basic penetration is close to saturation. Second, the large inflow of remittances represents a substantial pool of household funds that can be channelled into local investment if suitable financial instruments are available. Third, the region's ongoing infrastructure programme, including 1.6 billion USD for roads and water infrastructure and more than one billion USD of investment attracted in 2025, creates conditions for raising the realisation coefficient [21].

Three structural constraints stand against these opportunities. The first is the stagnation of internet penetration combined with a low intensity of productive digital use: connection has outpaced the digitalisation of economic activity. The second is the growing dependence of income on remittances, which supports consumption but weakens the link between income and regional production. The third is the fragmented enterprise structure: with more than three quarters of employment in small business, the region lacks the medium and large firms that deliver higher productivity, which is the most likely explanation for its low realisation coefficient.

3.4 Development mechanisms

The results support a four-block mechanism aimed at raising the potential realisation coefficient rather than simply increasing factor inputs.

The digital-use block shifts policy from connection to application: promotion of e-commerce, online payments and digital platforms in agriculture, tourism and trade, and support for IT outsourcing through the regional branch of IT Park in cooperation with Urgench State University.

The financial block converts remittances into investment through targeted deposit and lending products, co-financing of family businesses and matched grants for migrants returning with capital and skills.

The enterprise-growth block supports the transition of small firms to medium size through access to credit, cluster participation and export services, and prioritises industrial projects with foreign participation, whose productivity is highest.

The monitoring block introduces the potential realisation coefficient into the annual assessment of regional development programmes, so that performance is judged by the conversion of resources into output rather than by the volume of resources allocated.

Several limitations should be acknowledged. First, the panel covers only four years, and with fourteen clusters the justification for cluster-robust inference is approximate; results should therefore be regarded as indicative. Second, all value indicators are in current prices, so the estimated coefficients partly reflect common inflation. Third, internet data for Tashkent city include subscribers of operators registered there but serving Tashkent region, which introduces measurement error. Fourth, regional investment growth and the small-business share for 2024–2025 were not available and were set by assumption. Finally, the estimates are conditional associations rather than causal effects; instrumental-variable or longer-panel designs would be required to establish causality.[22]

4. Conclusion

The study shows that regional output in Uzbekistan is closely linked to the scale of digital infrastructure and to household income: a six-factor model explains 95.2% of cross-regional and temporal variation in GRP, with elasticities of 0.84 and 0.94 respectively. Three conclusions follow for Khorezm. The first concerns effectiveness: the region produces about 11% less output than its factor endowment predicts and ranks

13th of 14 on the potential realisation coefficient, so the priority is better conversion of existing resources rather than their mere expansion. The second concerns the quality of growth: the stalling of internet penetration and the rising share of remittances in income mean that further growth depends on productive use of connectivity and on channelling household funds into investment. The third concerns the outlook: under the baseline scenario GRP will reach 139.3 trillion UZS by 2030, and closing the realisation gap would move the region towards the optimistic path of 184.2 trillion UZS.

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