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Article

Forecasting Healthcare Resources and Provider Performance in Samarkand Region, Uzbekistan: A Cobb–Douglas, Trend and Scenario Approach

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Abstract: Purpose: to estimate how resources affect the output of district medical associations and to forecast regional health resources to 2030 and provider performance to 2028. Methods: a Cobb–Douglas production function (n = 15), linear and exponential trend models evaluated with MAPE, a resource balance for 2030, DEA-based capacity analysis and scenario forecasting. Results: output elasticities with respect to beds and staff are 0.491 and 0.247 ($R^2 = 0.878$); their sum of 0.738 indicates decreasing returns to scale. By 2030 the population reaches 4.74 million and physicians 14.8 thousand (31.2 per 10,000), while nurse density falls from 78.2 to 76.4. Closing the efficiency gap would allow 82.9 thousand additional inpatients per year (23.0%) without new beds. In the target scenario the cost recovery ratio of a private clinic rises from 66.0% to 117.8% by 2028, whereas in the inertial scenario cumulated losses reach 2,445.2 million UZS.

Keywords: healthcare providers; Cobb–Douglas production function; trend forecasting; scenario analysis; cost recovery ratio; Samarkand region; Uzbekistan.

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1. Introduction

Uzbekistan has been reforming its health system since Presidential Decree No. PF-5590 of 7 December 2018 [1]. The system is predominantly publicly owned and organised at national, regional and local levels, while a large share of expenditure is financed privately [2]: out-of-pocket payments accounted for 64.1% of current health expenditure in 2023 [3]. In Samarkand region, the most populous in the country, state health insurance mechanisms were introduced on 1 July 2025, and from 1 January 2026 a new model of health service organisation applies in all districts. Providers therefore move from budget financing by estimate to payment for services delivered, and planners need forecasts of resource needs and of provider-level outcomes.

Measuring efficiency is regarded as a prerequisite for evidence-based health policy [4], and Data Envelopment Analysis (DEA) is among the most widely used tools for this purpose [5], particularly in hospital research [6]. DEA, however, identifies the efficiency frontier non-parametrically and does not quantify the elasticity of output with respect to inputs or the nature of returns to scale. Trend forecasts, in turn, continue established tendencies but do not reflect managerial decisions. The aim of this study is to combine a production-function model, trend models and scenario analysis to forecast the resources of the regional health network to 2030 and the performance of a private provider to 2028, and to derive target indicators.

2. Materials and Methods

Regional data on population, physicians, nurses and hospital beds for 2010–2024 were taken from the Statistics Agency and the Samarkand regional health department. Production-function parameters were estimated on 2024 data of 15 district (city) medical associations (the Urgut association was excluded as an outlier). Provider-level data come from the 2021–2025 financial statements of the private clinic LLC "AZIYA MEDIK NEO". State budget health expenditure for 2019–2026 (2019–2023 actual, 2024–2026 approved parameters) was used for the financing forecast.

Models

Technical efficiency was measured with an input-oriented DEA model [7] with constant returns to scale [8] and variable returns [9]. The production function was specified in Cobb–Douglas form [10]:

$$\ln Y = \ln A + \alpha \cdot \ln K + \beta \cdot \ln L + \varepsilon,$$

where Y is the number of inpatients treated (model 1) or outpatient visits (model 2), K the number of beds, L the number of staff, α and β output elasticities; $\alpha + \beta < 1$ indicates decreasing, = 1 constant, and > 1 increasing returns to scale. Parameters were estimated by ordinary least squares; multicollinearity was checked with the variance inflation factor (VIF < 10) [11].

Resource trends were fitted with linear ($y = a + b \cdot t$) and exponential ($P = P0 \cdot e^{(r \cdot t)}$) models [12]. Accuracy was assessed by the mean absolute percentage error, $MAPE = (100/n) \Sigma |(yt - \hat{y}t) / yt|$ [13], and autocorrelation by the Durbin–Watson statistic [14]. The 2019 observation of beds (an anomalous value of 19,507) was excluded and the stable growth period since 2014 was used for staff. Resource needs in 2030 were calculated under two variants: A, density equal to the highest level achieved (2023); B, density at the 2024 level.

For the private provider, five annual observations are insufficient for an econometric trend, so scenario forecasts were built on the break-even relations: $T^* = F / (1 - v)$ and $CRR = T / (F + v \cdot T) \times 100$, where T is net revenue, F quasi-fixed costs, v variable costs per UZS of revenue (0.371 in 2025) and CRR the cost recovery ratio. Three scenarios for 2026–2028 are inertial (revenue +8% per year, administrative costs +8%), moderate (revenue +20% per year; administrative costs −10% in 2026 and unchanged thereafter) and target (revenue +35%, +25%, +20%; administrative costs −25% in 2026 and +5% per year thereafter). Other operating costs grow by 8% per year in all scenarios. Forecast revenue was converted into the economic sub-index of the Integrated Efficiency Index (ISI), holding balance-sheet indicators at their 2025 level, which yields a lower bound.

3. Result

Production function of medical associations

Model 1 (inpatients) is statistically significant: $F = 43.21$ ($p < 0.001$) against a critical value of 3.89, and beds and staff jointly explain 87.8% of variation (adjusted $R^2 = 0.858$) (Table 1). The elasticity with respect to beds ($\alpha = 0.491$) is significant at the 1% level and with respect to staff ($\beta = 0.247$) at the 10% level. The correlation between the factors is 0.82 and VIF = 3.06 is well below 10. Model 2 (outpatient visits) is not significant ($R^2 = 0.258$; $F = 2.09$, $p = 0.167$) and is not used for conclusions.

Table 1. Production function estimates (n = 15)

Parameter	Model 1: ln inpatients	Std. error	t	Model 2: ln visits	Std. error	t
ln A	5.273	0.538	9.80	10.086	2.335	4.32
α (ln beds)	0.491	0.137	3.58	−0.646	0.596	−1.09
β (ln staff)	0.247	0.125	1.97	1.023	0.544	1.88
$\alpha + \beta$	0.738			0.377		
R^2 / adjusted R^2	0.878 / 0.858			0.258 / 0.135		
F (p-value)	43.21 (p < 0.001)			2.09 (p = 0.167)		

The sum of elasticities of 0.738 shows decreasing returns to scale: increasing both beds and staff by 10% raises inpatients by only 7.4%. This confirms, with a parametric method, the DEA finding that scale efficiency is the main source of inefficiency in the largest association (CCR 0.615, BCC 1.0). Model residuals coincide with the DEA frontier: associations whose actual output exceeds the model - Jomboy (+22.9%), Ishtikhon (+16.1%), Nurobod (+10.9%) and Bulungur (+8.0%) - are exactly the four reference units, whereas Samarkand district (−15.0%), Koshrabot (−13.6%), Narpay (−10.0%) and Tayloq (−9.0%) produce less than expected. Extensive expansion of the network through new beds and posts is therefore ineffective.

Regional resource forecast to 2030

Trend models are significant (Table 2): the population model has $R^2 = 0.997$ and MAPE = 0.33%; physicians $R^2 = 0.956$ (MAPE 2.87%); nurses $R^2 = 0.907$ (1.29%); beds $R^2 = 0.841$ (3.97%); Durbin–Watson values exclude first-order autocorrelation. The population model was validated retrospectively: the value forecast for 1 January 2026 was 4,376.6 thousand against an official figure of 4,379.8 thousand (error 0.07%).

Table 2. Trend models of population and health resources

Indicator	Period (n)	Model	R^2	DW	MAPE, %
Population, thousand	2010–2025 (16)	$\ln P = 8.0427 + 0.0201 \cdot t$	0.997	1.64	0.33
Physicians	2014–2024 (11)	$y = 4{,}942.6 + 468.5 \cdot t$	0.956	2.32	2.87
Nurses and midwives	2014–2024 (11)	$y = 25{,}021.0 + 534.3 \cdot t$	0.907	1.41	1.29
Hospital beds	2013–2024 (11)	$y = 10{,}722.0 + 428.2 \cdot t$	0.841	1.91	3.97

Under the inertial scenario (Table 3) the population grows by about 2.0% annually to 4.74 million at the beginning of 2030 (+10.4%, or 445 thousand people against 1 January 2025). Physicians reach 14.8 thousand and density rises from 27.2 to 31.2 per 10,000, whereas nurse numbers grow by 1.5–1.6% a year, below population growth: density falls from 78.2 to 76.4 and the nurse-to-physician ratio from 2.9 to 2.5.

Table 3. Forecast of population and resources (inertial scenario)

Indicator	2024 (actual)	2025	2026	2027	2028	2029	2030
Population, thousand	4,208.5	4,289.6	4,376.6	4,465.4	4,556.0	4,648.4	4,742.7
Physicians	11,465	12,439	12,908	13,376	13,845	14,313	14,782
Nurses	32,926	33,570	34,105	34,639	35,173	35,708	36,242
Hospital beds	16,332	17,573	18,001	18,429	18,857	19,285	19,713
Physicians per 10,000	27.2	29.0	29.5	30.0	30.4	30.8	31.2
Nurses per 10,000	78.2	78.3	77.9	77.6	77.2	76.8	76.4
Beds per 10,000	38.8	41.0	41.1	41.3	41.4	41.5	41.6

95% confidence intervals for 2030: population 4,669.4–4,817.1 thousand; physicians 13.6–16.0 thousand; nurses 34.2–38.2 thousand; beds 17.3–22.1 thousand.

Comparison of the trend with needs (Table 4) reveals a structural imbalance. Physicians exceed needs under both variants (by 981 and 1,863), whereas nurses are short by 2,506 (A) or 865 (B). For beds, variant B implies an excess of 1,307, so inertial growth of bed capacity is unnecessary.

Table 4. Resource balance for 2030

Resource	Trend forecast	Need A (2023 density)	Difference A	Need B (2024 density)	Difference B
Physicians	14,782	13,801	+981	12,919	+1,863
Nurses	36,242	38,748	−2,506	37,107	−865
Beds	19,713	19,711	+2	18,406	+1,307

Positive difference - the trend exceeds need; negative - a shortage.

Capacity within existing resources and financing

If inefficient associations reached the level of reference units (output scaled by $1/\theta$), 82.9 thousand additional inpatients per year (23.0% of the current 361.2 thousand) could be treated within existing beds and staff, more than twice the expected population growth of 10.4%. The largest potential is in Samarkand city (+32,181 patients, +62.6%), Pastdargom (+10,555; +34.6%), Samarkand district (+7,569; +35.5%) and Narpay (+6,984; +34.6%). Part of this potential, especially in the city association, reflects scale and case complexity and cannot be fully mobilised. State budget health expenditure (2019–2026) follows the exponential trend $\ln y = 9.5104 + 0.1613 \cdot t$ ($R^2 = 0.987$; $F = 441.2$; MAPE 3.7%), i.e. average nominal growth of 17.5% per year. Forecast expenditure rises from 49,000 billion UZS in 2026 to 57,625 (2027), 67,708 (2028), 79,556 (2029) and 93,477 billion UZS in 2030 (95% interval 77,216–113,162), about 8% real annual growth at 8–9% inflation, above the regional population growth rate.

Scenario forecast for a private provider

In the inertial scenario net revenue grows only with prices and the cost recovery ratio stays at 66.0%; cumulated losses over 2026–2028 reach 2,445.2 million UZS, whereas equity at the end of 2025 was 124.0 million UZS, so net assets turn negative already in 2026. In the moderate scenario break-even is reached only in 2028 (CRR 102.3%). In the target scenario the ratio rises to 98.2%, 109.2% and 117.8%, cumulated results are positive (572.2 million UZS) and the economic sub-index of ISI increases from 0.145 to 0.580 (Table 5). The difference between the target and inertial scenarios in cumulated financial result is 3,017.4 million UZS.

Table 5. Scenario forecast for LLC "AZIYA MEDIK NEO", 2026–2028

Scenario	Indicator	2025 (actual)	2026	2027	2028
Inertial	Net revenue, million UZS	1,355.1	1,463.5	1,580.6	1,707.0
	Financial result, million UZS	−697.4	−753.2	−813.4	−878.5
	CRR, %	66.0	66.0	66.0	66.0
	ISI economic sub-index	0.145	0.145	0.145	0.145
Moderate	Net revenue, million UZS	1,355.1	1,626.1	1,951.3	2,341.6
	Financial result, million UZS	−697.4	−384.4	−185.8	53.3
	CRR, %	66.0	80.9	91.3	102.3
	ISI economic sub-index	0.145	0.269	0.371	0.464
Target	Net revenue, million UZS	1,355.1	1,829.4	2,286.7	2,744.0
	Financial result, million UZS	−697.4	−34.5	191.8	414.8
	CRR, %	66.0	98.2	109.2	117.8
	ISI economic sub-index	0.145	0.431	0.517	0.580

Sensitivity of the target scenario to its main assumptions (Table 6) shows that the 2028 CRR stays above 100% in eight of nine combinations; it falls to 97.8% only if revenue growth is 10 percentage points lower in every year and the variable cost ratio rises to 0.41. A 10-percentage-point change in revenue growth changes CRR by 15–16 points, and a 0.04 change in the variable cost ratio by 5–6 points: the result is more sensitive to revenue than to variable costs.

Table 6. Sensitivity of the 2028 CRR (target scenario), %

Annual revenue growth	v = 0.330	v = 0.371 (base)	v = 0.410
10 pp below base (+25; +15; +10%)	106.1	101.7	97.8
Base (+35; +25; +20%)	123.7	117.8	112.6
10 pp above base (+45; +35; +30%)	140.7	133.1	126.5

Target indicators to 2030

Based on the forecasts, target indicators were set for three levels (Table 7): provider (cost recovery, administrative intensity, ISI economic sub-index, serviceability of fixed assets), network (mean DEA efficiency, number of reference units, share of institutions covered by ISI monitoring) and region (physician density, Gini coefficient, share of the private sector in inpatients). Provider-level values come from the target scenario; the rise of mean efficiency to 0.93 implies mobilising about half of the identified reserves; the reduction of the Gini coefficient to 0.40 requires directing newly trained staff to districts with low density.

Table 7. Target indicators, 2026–2030

Indicator	Baseline	2026	2028	2030
Cost recovery ratio, % (provider)	66.0 (2025)	≥ 95	≥ 110	≥ 115
Administrative intensity, %	109.2 (2025)	≤ 62	≤ 50	≤ 45
ISI economic sub-index	0.145 (2025)	≥ 0.40	≥ 0.58	≥ 0.70
Serviceability of fixed assets, %	13.0 (2025)	≥ 20	≥ 35	≥ 50
Mean DEA efficiency (CCR)	0.852 (2024)	0.87	0.90	0.93
Units on the efficiency frontier	4 (2024)	5	7	9
Institutions covered by ISI monitoring, %	0	30	70	100
Physicians per 10,000	27.2 (2024)	29.5	30.4	31.2
Gini coefficient, physicians	0.497 (2024)	0.47	0.43	0.40
Private sector share in inpatients, %	11.4 (2024)	13	16	20

4. Discussion

The three methods answer different questions. The production function shows how resources affect output (decreasing returns to scale), trends show what happens if nothing changes, and scenarios show the consequences of managerial decisions. Their combination produces consistent conclusions: the network has reserves in the intensity of capacity use, not in the number of beds; the shortage is in nursing staff, not in physicians [15]; and the private provider faces a choice between cost control and restoring revenue, where delay leads to loss of equity. These findings are in line with the general view that efficiency measurement should feed policy and management decisions and with the established use of DEA in hospital research.

The small cross-section (n = 15) widens confidence intervals of the production-function parameters, so the model is used to assess the direction and relative strength of effects rather than for precise forecasts; the outpatient model is not significant; trend models do not capture institutional change such as the move to state health insurance in 2025–2026 and are interpreted as inertial scenarios; provider-level forecasts rely on the stability of the variable cost ratio; DEA does not take case complexity and quality into account. The rolling planning cycle proposed in the study - annual re-estimation of models with new observations and adjustment of targets - mitigates the accumulation of forecast errors.

5. Conclusion

The combination of a Cobb–Douglas production function, trend models and scenario analysis shows decreasing returns to scale in district medical associations ($\alpha + \beta = 0.738$), an expected rise in physician density to 31.2 per 10,000 with a simultaneous decline in

nurse density to 76.4 by 2030, and a potential of 82.9 thousand additional inpatients per year within existing resources. For the private provider, delayed management decisions lead to cumulated losses of 2,445.2 million UZS in 2026–2028, whereas the target scenario raises the cost recovery ratio to 117.8%. The proposed target indicators can be used for rolling planning of the regional health network.

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