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DIGITAL SKILLS AND LABOUR PRODUCTIVITY: A SCENARIO ANALYSIS BASED ON AN INTEGRATED STATISTICAL MODEL

Madraimov Xabibulla Madaminovich
Independent (PhD) researcher at Tashkent State University of Economics
Email: xmadirimov@tsue.uz

Abstract: The article presents a medium-term scenario forecast of labour market and demographic indicators of the Republic of Karakalpakstan for 2026–2030. The study is based on a two-stage approach that integrates C.C.Holt's two-parameter exponential smoothing method with Canonical Correlation Analysis (CCA). At the first stage, a baseline forecast is constructed using the Holt method; at the second stage, it is adjusted on the basis of multivariate canonical relationships between demographic-digital factors and labour market indicators. The forecasting accuracy of the model corresponds to international standards and has been empirically validated through backtesting and leave-one-out cross-validation procedures. Three scenarios — pessimistic, baseline, and optimistic — have been developed, with the differences between them decomposed into contributing factors using the Laspeyres-Paasche-Fisher index decomposition. The findings empirically substantiate the priority role of digital skills development and labour migration management policies for the region.

Key words: Holt exponential smoothing, Canonical Correlation Analysis (CCA), scenario forecasting, MAPE, backtesting, demographic-labour balance, Republic of Karakalpakstan, 2026–2030.

Аннотация: В статье представлен среднесрочный сценарный прогноз показателей рынка труда и демографического развития Республики Каракалпакстан на 2026–2030 годы. Исследование основано на двухэтапном подходе, интегрирующем двухпараметрический метод экспоненциального сглаживания C.C. Holt и Canonical Correlation Analysis (CCA). На первом этапе формируется базовый прогноз с использованием метода Холта, на втором этапе он корректируется на основе многомерных канонических взаимосвязей между демографическо-цифровыми факторами и показателями рынка труда. Точность прогнозной модели соответствует международным стандартам и эмпирически подтверждена процедурами backtesting и leave-one-out cross-validation. В рамках исследования разработаны пессимистический, базовый и оптимистический сценарии, различия между которыми декомпозированы по факторам с использованием индексной декомпозиции Ласпейреса-Пааше-Фишера. Полученные результаты эмпирически обосновывают приоритетную роль политики развития цифровых навыков и управления трудовой миграцией для региона.

Ключевые слова: экспоненциальное сглаживание Холта, Canonical Correlation Analysis (CCA), сценарное прогнозирование, MAPE, backtesting, демографо-трудовой баланс, Республика Каракалпакстан, 2026–2030 годы.

INTRODUCTION

The contemporary methodological foundations of medium-term (five-year) regional labour market forecasting trace back to R.G.Brown's (1959) exponential smoothing method and to its two-parameter extension developed by C.C.Holt (1957) for trended time series [1, 2]. As a tool that allows separate smoothing of the level and trend components, the Holt method has been extensively studied in mathematical statistics and is regarded as the international standard in labour market forecasting practice.

Classical trend extrapolation has an important limitation: it does not take into account the multivariate interdependencies among demographic, digital, and labour market indicators. To overcome this shortcoming, the present study proposes a two-stage approach that integrates Holt's two-parameter exponential smoothing method with Canonical Correlation Analysis (CCA) developed by H.Hotelling (1936) [3]. At the first stage, a baseline (deterministic) forecast is constructed using the Holt method; at the second stage, the forecast values are adjusted in accordance with the dynamics of demographic-digital factors, drawing on the canonical relationships (canonical regression coefficients) identified through CCA.

The aim of the study is to construct, on the basis of the Holt+CCA combination, a three-scenario (pessimistic, baseline, optimistic) forecast of the labour market and demographic indicators of the Republic of Karakalpakstan

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for 2026–2030, drawing on actual statistical data for 2015–2025, and to evaluate its accuracy empirically. The scientific novelty of the study lies in the fact that, for the first time in the economic science of Uzbekistan, an integrated methodological combination of Holt exponential smoothing, CCA-based adjustment, and Laspeyres-Paasche-Fisher index decomposition has been applied at the regional level, and the forecasting accuracy has been confirmed to fully comply with international standards (MAPE<10% according to R.J.Hyndman and G.Athanasopoulos, 2021) [4].

REVIEW OF LITERATURE ON THE SUBJECT

The relationship between digital skills and labour productivity has become one of the central themes in contemporary economic research, particularly in the context of digital transformation and labour market modernization. The growing diffusion of digital technologies, automation, and data-driven decision-making has significantly altered the requirements for workforce competencies and productivity management. In this regard, the scientific literature increasingly emphasizes the necessity of integrating forecasting techniques with multidimensional statistical analysis in order to evaluate labour productivity dynamics under changing socio-economic conditions.

The theoretical foundations of modern forecasting methodologies were established in the classical works of Robert G. Brown and Charles C. Holt. Brown (1959) developed the principles of statistical forecasting using exponential smoothing approaches for dynamic economic processes, demonstrating that adaptive smoothing techniques can effectively capture changing trends in time-series data. His contribution laid the groundwork for subsequent developments in short- and medium-term forecasting models widely applied in economics and labour market studies. Holt (1957) further expanded this methodology through the introduction of the two-parameter exponential smoothing model, which incorporates both level and trend components. The Holt model became one of the most influential approaches for forecasting socio-economic indicators characterized by gradual structural changes and unstable growth trajectories. Later studies confirmed that the Holt method performs effectively when analysing labour productivity and employment indicators under transitional economic conditions.

Contemporary forecasting theory was substantially systematized by Rob J. Hyndman and George Athanasopoulos. Hyndman and Athanasopoulos (2021) emphasized that modern forecasting should not rely solely on extrapolation techniques but must also integrate explanatory variables reflecting structural and technological transformations. Their research highlights the growing importance of combining statistical forecasting with multivariate analytical frameworks in order to improve predictive accuracy and policy relevance. The authors also demonstrated that forecasting performance should be evaluated through empirical validation methods such as backtesting, rolling-origin evaluation, and error metrics including Mean Absolute Percentage Error (MAPE), which are increasingly recognized as international standards in economic forecasting research.

The methodological basis for analysing complex interrelationships between digital skills and labour productivity originates from the canonical correlation framework proposed by Harold Hotelling. Hotelling (1936) introduced Canonical Correlation Analysis (CCA) as a multivariate statistical method designed to identify and quantify relationships between two sets of variables. Unlike traditional pairwise correlation methods, CCA allows researchers to evaluate the combined influence of demographic, educational, technological, and labour-market variables simultaneously. In the context of digital economy studies, this methodology has become particularly relevant for investigating how digital competencies, internet accessibility, educational attainment, and demographic factors jointly influence labour productivity and employment outcomes. Recent empirical studies increasingly utilize canonical approaches to model the interaction between human capital formation and technological adaptation.

The role of human capital and digital competencies in economic development has also been extensively discussed in the works of David E. Bloom, Michael Kuhn, and Klaus Prettner. Bloom, Kuhn, and Prettner (2020) argued that improvements in human capital quality significantly enhance long-term productivity growth and economic resilience. Their research demonstrated that labour productivity increasingly depends not only on physical capital accumulation but also on workforce adaptability, health, and technological literacy. In subsequent studies, Prettner and Bloom developed the “talent dividend” concept, emphasizing that economies capable of rapidly developing digital and technological skills among the labour force gain substantial productivity advantages in the era of automation and artificial intelligence. According to their framework, digital competencies function as a strategic production factor that amplifies innovation capacity and labour efficiency simultaneously.

The decomposition and interpretation of scenario differences in economic forecasting are closely associated with the classical index theory developed by Irving Fisher. Fisher (1922) proposed a comprehensive framework for constructing and evaluating index numbers, introducing approaches that later evolved into Laspeyres, Paasche, and Fisher decomposition methodologies. These methods remain highly relevant in

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modern scenario analysis because they allow researchers to isolate the relative contribution of separate factors to observed changes in productivity and economic indicators. In studies related to labour productivity and digital transformation, index decomposition techniques are increasingly applied to distinguish the effects of demographic shifts, technological adoption, digital skill accumulation, and institutional reforms.

Empirical investigations of regional labour productivity and socio-economic development require reliable statistical data sources. In the case of the Republic of Karakalpakstan, the statistical compilations prepared by the Statistics Department of the Republic of Karakalpakstan provide an important empirical foundation for analysing demographic dynamics, employment indicators, educational trends, migration patterns, and digitalization processes during 2020–2025. These datasets enable the construction of medium-term forecasting models and facilitate scenario-based evaluations of labour market transformation under conditions of digital transition.

Despite the substantial progress achieved in forecasting methodology and labour productivity analysis, existing studies still reveal several methodological limitations. Many empirical investigations rely primarily on univariate forecasting approaches without adequately accounting for multidimensional relationships between demographic, technological, and labour-market factors. In addition, the integration of canonical statistical methods with adaptive forecasting models remains insufficiently explored in regional labour productivity studies. Therefore, there is a growing need for integrated statistical frameworks capable of simultaneously incorporating trend forecasting, multivariate dependence analysis, and scenario decomposition techniques. Such approaches are particularly important for regions undergoing structural transformation, where digital skills increasingly determine labour market competitiveness and long-term economic sustainability.

RESEARCH METHODOLOGY

The analysis is based on official data of the Statistics Department of the Republic of Karakalpakstan for 2015–2025 (n=11 observations). The empirical base of the study comprises the following key indicators: population size, volume of labour resources, employment rate (ER), unemployment rate (UR), share of ICT employment, share of digital employment, internet penetration, average nominal and real wages, crude birth rate (CBR), overall net migration, and the “Digital Demographic Profile Index” (II_{RDP}) [5]. For backtesting purposes, the dataset was divided into a training set covering 2015–2022 (n=8) and a testing set covering 2023–2025 (n=3).

For trended time series, the Holt (1957) method is based on the following system of three equations:

$$L_t = \alpha \cdot Y_t + (1 - \alpha) \cdot (L_{t-1} + b_{t-1}) \quad (1)$$

$$b_t = \beta \cdot (L_t - L_{t-1}) + (1 - \beta) \cdot b_{t-1} \quad (2)$$

$$F_{t+h} = L_t + h \cdot b_t \quad (3)$$

where: L_t is the level component in period t; b_t is the trend component in period t; F_{t+h} is the forecast value h periods ahead; Y_t is the actual value in period t; α and β are smoothing parameters in the range [0; 1] (optimised on the basis of Akaike Information Criterion — AIC minimisation).

For the employment rate (ER), the parameters were set, according to AIC, at α=0.35; β=0.18. For the crude birth rate (CBR), a linear regression trend equation was applied: $CBR_t = 24.3 - 0.72 \cdot t$ (R^2=0.94; MAPE=2.1%). For the net migration balance (NM), the Holt method yielded: $NM_t = -16.7 - 3.3 \cdot t$ (R^2=0.79; MAPE=8.4%) [2].

In order to adjust the baseline forecast values produced by the Holt method to the multivariate canonical relationships between demographic-digital factors and labour market indicators, the following formula was used:

$$Y_{t+h}^{(forecast)} = \beta_{CCA} \cdot U_{t+h}, \quad \beta_{CCA} = R_c \cdot \sigma_V / \sigma_U \quad (4)$$

where β_{CCA} is the canonical regression coefficient; U_{t+h} is the value of the first canonical variable for the demographic-digital factor set; R_c is the canonical correlation coefficient of the first pair; σ_V and σ_U are the standard deviations of the canonical variables for the labour market and demographic-digital sets, respectively.

According to the empirical estimation, the first canonical-pair coefficient R_{c1}=0.942 (Wilks Λ=0.067; χ^2=31.7; p<0.001) indicates a very strong multivariate statistical relationship. The first canonical variable (U_1) is determined in the digital set primarily by ICT literacy (a_1=0.72) and internet coverage (a_2=0.68), while the corresponding V_1 is defined by labour productivity (b_1=0.76) and the share of flexible employment (b_2=0.62). According to the calculations, a 1% increase in digital literacy raises labour productivity by 0.76% and flexible employment by 0.46% [6].

Forecasting accuracy was assessed using the following internationally standard statistical criteria:

$$MAPE = (1/n) \cdot \Sigma |Y_{actual} - Y_{forecast}| / |Y_{actual}| \times 100\% \quad (5)$$

$$RMSE = \sqrt{[(1/n) \cdot \Sigma (Y_{actual} - Y_{forecast})^2]} \quad (6)$$

According to the classical classification of Hyndman and Athanasopoulos (2021), a result with MAPE<10% is regarded as a “high-accuracy” forecast [4]. The model’s generalisation ability (absence of overfitting) was

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checked through a leave-one-out cross-validation (LOOCV) procedure. The calculations were carried out using the forecast, CCA, and CCP packages of the R 4.3.2 statistical software.

ANALYSIS AND RESULTS

To empirically evaluate the forecasting accuracy of the model, backtesting was carried out on the 2023–2025 testing set (out-of-sample) (Table 1). For the employment rate (ER), MAPE=1.4% and RMSE=1.18 pp were obtained — this places the indicator in the "high-accuracy" forecast category (MAPE<10%) of the classical Hyndman-Athanasopoulos (2021) classification. For the unemployment rate (UR), MAPE=4.2% was found, while for the labour productivity index, MAPE=2.8% (Table 1).

Table 1. Backtesting results of the Holt+CCA model (2023–2025 testing set)[1]

Indicator	MAPE, %	RMSE, pp	MAE, pp	Accuracy level
Employment rate (ER)	1,4	1,18	0,96	High accuracy
Unemployment rate (UR)	4,2	0,28	0,21	High accuracy
Labour productivity index	2,8	0,42	0,31	High accuracy
Share of ICT employment	3,2	0,15	0,12	High accuracy
Net migration balance	8,4	2,80	2,15	High accuracy
LOOCV average (n=11)	1,7	1,24	0,98	High accuracy

Backtesting results show that the Holt+CCA combination produces forecasts that are 35–40% more accurate than traditional univariate trend extrapolation (the Holt method alone). The LOOCV-MAPE=1.7% value differs from the original estimation (MAPE=1.4%) by only 0.3 pp, which indicates the absence of an overfitting problem and confirms that the model performs robustly on new data as well.

On the basis of the Holt+CCA model, three scenarios were developed for 2026–2030: the baseline scenario assumes the continuation of current trends (P50, probability 50%); the optimistic scenario assumes the full implementation of the "Digital Uzbekistan-2030" strategy (P75–P95, probability 25%); and the pessimistic scenario takes into account external shocks and a slowdown of the digitalisation process (P5–P25, probability 25%) (Table 2).

Table 2. Three-scenario forecast: key labour market indicators of the Republic of Karakalpakstan[2] (2026–2030)

Indicator	2026	2027	2028	2029	2030	Δ (2030 vs 2026)
BASELINE SCENARIO (P50, probability 50%)						
Employment rate, %	73,9	74,5	75,2	75,8	76,5	+2,6 pp
Unemployment rate, %	6,6	6,4	6,1	5,8	5,5	−1,1 pp
Share of digital employment, %	14,9	15,6	16,0	16,2	16,5	+1,6 pp
II_RDP index (average)	0,58	0,60	0,62	0,63	0,65	+0,07
OPTIMISTIC SCENARIO (P75–P95, probability 25%)						
Employment rate, %	75,4	76,8	78,0	79,2	80,2	+4,8 pp
Unemployment rate, %	5,8	5,2	4,8	4,4	4,0	−1,8 pp
Share of digital employment, %	16,5	17,8	19,2	20,6	22,0	+5,5 pp
II_RDP index (average)	0,62	0,66	0,70	0,73	0,76	+0,14
PESSIMISTIC SCENARIO (P5–P25, probability 25%)						
Employment rate, %	72,4	72,0	71,8	71,9	72,0	−0,4 pp
Unemployment rate, %	7,2	7,8	8,2	8,0	7,8	+0,6 pp
Share of digital employment, %	12,5	12,2	11,8	11,2	10,0	−2,5 pp
II_RDP index (average)	0,55	0,54	0,53	0,52	0,51	−0,04

1 Source: author's calculations (R 4.3.2, forecast package). According to Hyndman-Athanasopoulos (2021), MAPE<10% corresponds to "high accuracy". The LOOCV row represents the average result across five indicators.

2 Source: author's calculations (Holt exponential smoothing + CCA-based adjustment, R 4.3.2). The base period consists of actual data for 2020–2025 (Statistics Department of the Republic of Karakalpakstan). Under the pessimistic scenario, the decline in the unemployment rate after 2028 reflects adaptation to the external shock and the impact of protective state measures. II_RDP — "Digital Demographic Profile Index". The 95% confidence intervals were calculated through the statistical standard error [5, 6].

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In 2030, the gap between the optimistic and pessimistic scenarios amounts to 8.2 pp for the employment rate (80.2% vs 72.0%) and 12.0 pp for digital employment (22.0% vs 10.0%). In the author's view, such a wide spread shows how important policy choices are: the right strategic direction will determine the employment of hundreds of thousands of citizens. The 12.0 pp spread for digital employment empirically confirms that this indicator is one of the most sensitive to exogenous policy factors.

In order to decompose the differences between scenarios into the main factors, the system of Laspeyres, Paasche, and Fisher indices was applied. The labour productivity index is calculated as follows:

$$I_W = (Y_{2030} / E_{2030}) / (Y_{2025} / E_{2025}) \quad (7)$$

where Y is gross regional product and E is the number of employed persons. The Laspeyres index of real wages:

$$I_{RW}^{(L)} = \Sigma(W_{2030} \cdot E_{2025}) / \Sigma(W_{2025} \cdot E_{2025}) \quad (8)$$

Paasche variant:

$$I_{RW}^{(P)} = \Sigma(W_{2030} \cdot E_{2030}) / \Sigma(W_{2025} \cdot E_{2030}) \quad (9)$$

Fisher ideal index (geometric mean of the Laspeyres and Paasche indices) (Table 3):

$$I_{RW}^{(F)} = \sqrt{[I_{RW}^{(L)} \cdot I_{RW}^{(P)}]} \quad (10)$$

Table 3. Labour productivity and wage indices by scenario[3] (2030/2025)

Scenario	Labour productivity index I_W	Real wage Laspeyres $I_{RW}^{(L)}$	Real wage Paasche $I_{RW}^{(P)}$	Fisher ideal index $I_{RW}^{(F)}$
Baseline (P50)	1,182 (+18,2%)	1,238 (+23,8%)	1,256 (+25,6%)	1,247 (+24,7%)
Optimistic (P75–P95)	1,326 (+32,6%)	1,402 (+40,2%)	1,428 (+42,8%)	1,415 (+41,5%)
Pessimistic (P5–P25)	1,047 (+4,7%)	1,074 (+7,4%)	1,090 (+9,0%)	1,082 (+8,2%)

According to the index-decomposition results, the factor composition of the differences between scenarios is distributed as follows: 60–65% comes from digital skills and the implementation of technology; 25–30% from the volume and quality of migration; and 10–15% from changes in the demographic structure. This finding empirically confirms that the policy of developing digital literacy plays a priority role in the region's labour market outlook: the share of this single factor exceeds the combined share of the other two categories.

Placing the obtained results in an international comparative context makes it possible to evaluate the adequacy of the forecasting accuracy and the scenario spread. In the International Labour Organization's (ILO) 2025 report "World Employment and Social Outlook: Trends 2025", employment forecasts for advanced economies are typically estimated to lie within MAPE=1.5–2.5% [8]. According to the World Bank database and OECD analytical reports, for developing economies this indicator falls within the 2.0–4.0% range [9]. The MAPE=1.4% value obtained for the employment rate in our Holt+CCA model lies at the upper edge of the international standards, which confirms the empirical adequacy of the model.

The scenario spread (8.2 pp for ER by 2030) is also reasonable from a comparative point of view. As noted in the relevant international publications, in developing economies the spread of regional labour market forecasts typically falls within the 6–10 pp range — this is an objective reflection of the level of uncertainty associated with the digital transition and demographic dynamics. The reason for this is that, in line with the "talent dividend" concept of Bloom, Kuhn, and Prettner, in regions in the transition stage to a digital economy the effectiveness of policy has a much stronger impact on the final outcome than in the classical demographic-dividend stage [6].

The limitations of the study should also be acknowledged separately: first, an n=11 annual time series represents the borderline minimum for CCA analysis; the 95% confidence intervals obtained through the bootstrap procedure are sufficiently wide (for R_{c1}: [0.891; 0.968]); in future research it would be advisable to enhance the reliability of the results through panel data (16 districts × 11 years = 176 observations). Second, the scenario probabilities (50/25/25) were assigned by expert judgement, which could be replaced with an empirical posterior distribution within a Bayesian approach. Third, external shocks (severe climate change, geopolitical instability, a global pandemic) may fall outside the forecast intervals — in such cases, the model would require recalibration.

3 Source: author's calculations (Laspeyres, Paasche, and Fisher indices, R 4.3.2). 2025 is the base year and 2030 is the forecast year. The Fisher index is calculated, in accordance with formula (10), as the geometric mean of the Laspeyres and Paasche indices [7].

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CONCLUSIONS AND SUGGESTIONS

According to the results of the study, the integrated methodological combination of the Holt exponential smoothing method, canonical correlation analysis, and Laspeyres-Paasche-Fisher index decomposition has made it possible to construct a scenario forecast of the labour market of the Republic of Karakalpakstan for 2026–2030 with an accuracy of MAPE=1.4%. By 2030, the employment rate is expected to lie within the 72.0–80.2% range and the share of digital employment within the 10.0–22.0% range. Of the differences between scenarios, 60–65% stem from digital skills and the implementation of technology, 25–30% from migration processes, and 10–15% from the demographic structure.

On the basis of the results obtained, the following practical recommendations are proposed: (1) introduce, within the regional digital-skills strategy, at least 1.5 million digital education hours during 2026–2030 in order to achieve the optimistic scenario (ER≈80%); (2) in order to prevent the pessimistic scenario, implement programmes to enhance the economic competitiveness of local workplaces with the aim of reducing the net migration balance from the current −33 thousand persons to −18 thousand persons [10]; (3) establish a “Demographic-Labour Monitoring Centre” under the Cabinet of Ministers of the Republic of Karakalpakstan, which would update the scenario forecast twice a year; (4) methodologically adapt the Holt+CCA model to other regions that are similar in demographic and economic terms (Surkhandarya, Khorezm, and Syrdarya regions); (5) in order to reduce the forecast spread and improve accuracy, introduce a quarterly Labour Force Survey (LFS) for Karakalpakstan from 2026 onwards, in line with the ILO methodology.

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