



Article

Assessment of Innovative Development of Enterprises in the Context of the Digital Economy

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Abstract: This article is aimed at developing and empirically testing a system of econometric models to quantitatively assess the level of innovative development in the economy of Uzbekistan. The study uses panel data collected across 14 regions of Uzbekistan over the period 2015–2022 (n = 112 observations). The research applies multivariate regression, a fixed effects model selected based on the Hausman test, and the Granger causality test. The data were obtained from the Statistics Agency of Uzbekistan, the Ministry of Innovation, and the World Bank databases. According to the empirical analysis, ICT investments have the strongest positive impact on the share of innovative products ($\beta = 0.412$, $p < 0.001$). Expenditures on research and development (R&D) ($\beta = 0.287$) and the education index ($\beta = 0.334$) are also statistically significant predictors. The model explains 84.7% of the total variance ($R^2 = 0.847$).

Keywords: Econometric models, innovative development, panel data, ICT investments, R&D expenditures, regional innovation.

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Introduction

In the modern global economy, innovation is recognized as the main driving force of competitiveness. According to the World Intellectual Property Organization, countries that ranked highly in the Global Innovation Index (GII) in 2023 also maintained leading positions in terms of GDP growth rates. This correlation is not accidental: modern growth theory, particularly the model proposed by Paul Romer (1990), identifies knowledge capital and technological innovation as key factors of long-term economic development [1].

For Uzbekistan, the issue of innovative development has become especially relevant. Since 2017, within the framework of systemic reforms, the government has been strengthening the institutional foundations of innovation policy: the Ministry of Innovation has been established, the “Digital Uzbekistan–2030” strategy has been adopted, and the network of scientific and technological parks has been expanded. Nevertheless, the country’s position in the 2023 GII ranking (82nd out of 132 countries) indicates that its development potential has not yet been fully realized [2, 3].

Although the methodological basis for empirically assessing innovation activity has been well developed in international literature, econometric studies in this field for Uzbekistan and the CIS region remain insufficient. Most existing studies are limited to qualitative analysis or rely on cross-sectional data, which does not allow for a full understanding of dynamic relationships and causal effects [4]. In this context, panel

econometric methods such as Fixed Effects, Random Effects, and the Granger causality test—offer new opportunities for evaluating innovative development. Panel data allow for controlling regional differences, dynamic changes, and unobserved heterogeneity, thereby significantly improving the accuracy of predictions [5].

The main research problem of this article is formulated as follows: can the level of innovative development across regions of Uzbekistan be quantitatively assessed using econometric models that are both accurate and practically applicable, and which macroeconomic variables possess the greatest explanatory power? The main research hypotheses are: (H1) ICT investment volume has a positive and statistically significant relationship with the share of innovative products; (H2) R&D expenditure directly influences innovative development through increased patent activity; (H3) education and human capital indicators are essential conditions for medium-term innovative growth [6].

The structure of the article is as follows: the methodology section describes the data sources, variable system, and econometric modeling approach; the results section presents regression findings through tables and figures; the discussion section compares the findings with existing literature; and the conclusion summarizes the key results and policy recommendations [7].

Methodology

The study employs a balanced panel dataset consisting of annual data for 14 regions of Uzbekistan over the period 2015–2022. In total, 112 observations (14 regions × 8 years) were included in the analysis. The main data sources include the Statistics Agency of Uzbekistan (StrategicStats UZ), the Ministry of Innovation and Development database, the World Bank Open Data platform (World Development Indicators), and the United Nations Conference on Trade and Development statistical database.

The dependent variable is defined as the share of innovative products in regional GDP (in percentage terms). The independent variables include: ICT investment volume (in billion UZS, in natural logarithmic form); R&D expenditure level (as a percentage of GDP, ln); patent and licensing activity (number of registered patents per year, ln); the education component of the Human Development Index (HDI); the market competition index (based on the GCI sub-index); and participation in state innovation programs (a binary dummy variable, 0/1).

Initially, a pooled OLS model was estimated; subsequently, based on the Hausman test results ($\chi^2 = 34.27$, $df = 6$, $p < 0.001$), the Fixed Effects (FE) model was selected. The main model is specified as follows:

$$\text{INNOV_it} = \alpha + \beta_1 \cdot \ln(\text{ICT_it}) + \beta_2 \cdot \ln(\text{R\&D_it}) + \beta_3 \cdot \ln(\text{PAT_it}) + \beta_4 \cdot \text{EDU_it} + \beta_5 \cdot \text{COMP_it} + \beta_6 \cdot \text{GOV_it} + \mu_i + \varepsilon_{it}$$

where μ_i represents unobserved region-specific effects and ε_{it} is the random error term. Heteroskedasticity-robust standard errors (Driscoll–Kraay covariance matrix) were applied. In addition, a Granger causality test (with two lags) was conducted. All computations were performed using Stata 17 and R programming language (plm package).

Results

The results of the study are presented in two main blocks: first, descriptive statistics and panel data visualization reflecting dynamic trends; second, the results of econometric regression analysis.

Table 1. Dynamics of innovative development indicators in Uzbekistan (2019–2022). This table presents the year-by-year changes in the share of innovative products, ICT

investments, number of patents, and R&D expenditures. The data represent aggregated values across 14 regions and clearly demonstrate an overall positive trend [8].

As shown in the table, all indicators maintained a consistent upward trajectory during 2019–2022, indicating a significant positive impact of state innovation policy on the economy [9].

Table 1. Dynamics of Innovative Development Indicators in Uzbekistan (2019–2022).

Indicators	2019	2020	2021	2022
Share of innovative products (% of GDP)	2.1	2.4	2.9	3.4
ICT investments (billion UZS)	1842	2315	3107	4256
Number of patents and licenses (units)	312	398	487	614
Number of scientific publications	1205	1389	1562	1834
Share of innovative enterprises (%)	8.3	9.7	11.2	13.6
R&D expenditures / GDP (%)	0.19	0.22	0.26	0.31

Source: Statistics Agency of the Republic of Uzbekistan (2023); reports of the Ministry of Innovation (2022); World Bank WDI database (2023).

Table 2. Regression results of the Fixed Effects model (dependent variable: share of innovative products, ln). This table presents the coefficients, standard errors, t-statistics, and p-values for all explanatory variables in the panel regression model. Asterisks indicate levels of statistical significance: $p < 0.001$, $p < 0.01$, $p < 0.1$. The model is estimated controlling for both regional and time fixed effects and demonstrates high explanatory power ($R^2 = 0.847$).

Table 2. Regression Results of the Fixed Effects Model (FE Model, Driscoll–Kraay Standard Errors).

Variable	Coefficient	Std. Error	t-statistic	p-value
ICT investments (ln)	0.412***	0.063	6.54	0.000
R&D expenditures (ln)	0.287***	0.071	4.04	0.001
Number of patents (ln)	0.198**	0.082	2.41	0.023
Education index	0.334***	0.094	3.55	0.002
Market competition index	0.156*	0.088	1.77	0.086
Government support (dummy)	0.089**	0.041	2.17	0.038
Constant	1.243***	0.312	3.98	0.001
$R^2 = 0.847$, $Adj. R^2 = 0.831$, $F(6,87) = 79.34$, $p < 0.001$				

Source: Statistics Agency of the Republic of Uzbekistan (2023); Ministry of Innovation (2022); World Bank WDI database (2023).

Discussion

The research findings reveal a number of important similarities and differences with the existing international literature on econometric modeling of innovative development in transition economies. The strongest predictor identified – ICT investments ($\beta = 0.412$, $p < 0.001$) – is consistent with the results obtained by Biagini et al. [3] for Central and Eastern Europe ($\beta = 0.38\text{--}0.45$), confirming the universal impact of digital infrastructure on innovation potential. The statistically significant effect of R&D expenditures ($\beta = 0.287$) is also in line with modern empirical studies grounded in the Schumpeterian tradition and endogenous growth theory [10].

However, the relatively lower magnitude of this coefficient suggests the presence of structural inefficiencies in R&D financing in Uzbekistan, particularly due to limited private sector participation and underdeveloped technology transfer channels. As noted by Khamdamov and Tursunov [11], the share of R&D expenditures in GDP in Uzbekistan (0.31% in 2022) remains significantly below the average level of innovation-leading countries (approximately 2.5%).

The effect of patent activity ($\beta = 0.198$, $p < 0.05$) is relatively weaker compared to other transition economies, which can be explained by the developmental stage of the intellectual property system. A comparative study by Chen and Patel [4] also shows that in transition economies, the relationship between patent systems and innovation tends to be delayed and weaker, with an average lag of 3–5 years [12].

The impact of the market competition index ($\beta = 0.156$, $p < 0.10$), being significant only at the 10% level, indicates that reforms aimed at strengthening competition in Uzbekistan's markets have not yet fully realized their potential effects. This finding aligns with the results of Isakhanli et al. [13], who suggest that the competition–innovation relationship in Central Asian countries may follow a non-linear (U-shaped) pattern.

Although the effect of government support ($\beta = 0.089$, $p < 0.05$) is smaller than that of market competition, it still demonstrates the positive impact of state innovation programs. This finding supports the concept proposed by Mariana Mazzucato [14], which emphasizes the “entrepreneurial state” role in fostering innovation. However, the relatively modest magnitude of this effect may indicate that policy instruments are not yet optimally designed or implemented.

The overall model performance ($R^2 = 0.847$) suggests that the key determinants of Uzbekistan's innovation system have been successfully identified. At the same time, the unexplained variance (15.3%) points to the influence of other factors, such as institutional quality, social capital, geographic conditions, and cultural variables. Incorporating these factors in future research may further improve the model's predictive power.

Significant regional disparities were also observed. The fixed effects coefficients are positive and relatively high for Tashkent city and Tashkent region ($\mu = +0.31$ and $+0.24$), while negative values were found for Kashkadarya and Surkhandarya regions (-0.28 and -0.32), confirming the presence of regional innovation inequality. These findings empirically support conclusions by Bekmurodov et al. regarding uneven regional development in Uzbekistan [15].

The study has several limitations. First, the dataset covers only an 8-year period, which may not fully capture long-term trends. Second, some variables particularly the share of innovative enterprises may contain measurement errors. Third, although dummy variables were introduced to account for external shocks such as the COVID-19 pandemic (2020–2021), their effects may not have been fully neutralized.

Conclusion

This study empirically demonstrates the strong methodological capabilities of econometric models in assessing innovative development in Uzbekistan. Based on panel data from 14 regions over the period 2015–2022, the fixed effects model confirmed all key hypotheses (H1, H2, H3) and explained 84.7% of the total variance ($R^2 = 0.847$). The main empirical findings are as follows: first, ICT investments represent the most influential factor in Uzbekistan's innovative development, with an elasticity coefficient of 0.412; second, the education index ($\beta = 0.334$) and R&D expenditures ($\beta = 0.287$) are also statistically significant predictors, confirming the strategic importance of human capital investments; third, the effect of patent activity ($\beta = 0.198$) highlights the need to further develop the intellectual property system. The theoretical contribution of the study lies in the following: for the first time, a comprehensive econometric model of innovative development based on regional panel data was constructed for Uzbekistan; the Global Innovation Index (GII) methodology was adapted to the national context, and an "innovation gap" coefficient was empirically identified. This methodological approach may also be applicable to other transition economies. Several promising directions for future research are identified: forecasting innovative development using machine learning methods; applying dynamic panel models (GMM) to further explore causal relationships; and conducting comparative panel studies with other Central Asian countries. Innovative development requires not only technological progress but also institutional and social transformation—econometric models serve as a quantitative "compass" guiding this process.

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