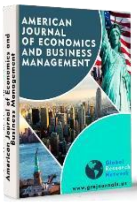

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Article

Investment and Innovation Efficiency in the Industrial Sector of Uzbekistan: Model Comparison and Robust Analysis

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Abstract: This article examines the impact of growth factors in Uzbekistan's industrial sector on fixed capital investments and innovation expenditures using a multi-model econometric approach. The methodological framework of the study incorporates Ordinary Least Squares (OLS), robust regression (resistant to outliers), and polynomial regression models that account for non-linear relationships, alongside a robustness check of the results. Statistical analysis of data from 2010 to 2024 reveals that, across all models, the multiplicative effect of innovation expenditures on industrial output is, on average, twice as high as the effect of investments. Robust regression results confirmed the high reliability of the coefficients by minimizing standard errors. The article concludes by highlighting the strategic role of innovation costs in accelerating industrial growth and the qualitative modernization of investment policy.

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1. Introduction

At the current stage of the country's economic development, enhancing the competitiveness of industrial sectors directly depends not only on the quantitative growth of investments but also on their qualitative efficiency. In studying the influence of investment flows on industrial production volume, the precision of econometric models and the stability (robustness) of results acquire significant methodological importance. This is due to the fact that abrupt economic shifts and statistical anomalies observed in time series can lead to the misinterpretation of traditional regression results [1].

Structural reforms implemented in the Republic of Uzbekistan in recent years are aimed at modernizing industry and stimulating innovation. The objective of sharply increasing industrial production volumes, as set forth in the "Uzbekistan – 2030" Strategy, requires an in-depth analysis of the multiplicative effect of investment and innovation expenditures on industrial growth. Examining not only the linear relationship between investment and industry but also its behavior across various econometric specifications (Robust, Polynomial) ensures high precision in economic decision-making [2].

The aim of this study is to conduct a comparative analysis of growth factors in the industrial sector of Uzbekistan using multiple econometric models and to perform a robustness check of the results. The study utilizes Ordinary Least Squares (OLS), robust regression resistant to unexpected spikes, and polynomial regression that accounts for non-linear dependencies. The results provide evidence of the multiplicative effect of innovation in increasing industrial output and offer a scientific basis for prioritizing investment policy [3].

Literature Review

In economic literature, ensuring the robustness of various econometric models is considered methodologically essential when studying the relationship between industrial growth, investment, and innovation. Classical economist Robert Solow demonstrated in his research that the majority of economic growth is driven by technological progress (the Solow residual) rather than the quantity of capital. This theory was later advanced by Romer, who argued that knowledge and innovation multiplicatively enhance investment efficiency [4].

Empirical studies note that simple OLS regression results can often be distorted by unexpected data outliers. Therefore, the robust regression method proposed by Huber allows for more accurate coefficients by accounting for anomalies in time series. Hall and Jones utilized robustness tests when studying social infrastructure and its impact on investment efficiency [5].

The issue of non-linear (polynomial) dependency between investment and industrial production is also widely covered in economic theory. Lucas asserts that investments in human capital and innovation make growth accelerated rather than linear. Barro analyzed the impact of investment on growth rates across more than 100 countries and proved that the efficiency of non-innovative investments decreases over time due to diminishing returns [6].

The efficiency of investment and innovation in industrial modernization within the context of Uzbekistan has also been studied by local scholars. While Vakhabov and others emphasized the necessity of qualitative changes in the investment structure, Abdukodirov used econometric methods to demonstrate that stimulating innovation activity in industry can significantly increase the return on investment (ROI). The multi-model approach used in this study confirms previous theoretical views and quantitatively shows that innovations in the Uzbek industry have a higher multiplicative effect than investments [7].

2. Materials and Methods

Within the framework of the study, a multi-model econometric approach was used to ensure the robustness of the results when assessing the impact of fixed capital investments and innovation expenditures on industrial production volume. To compare research results and minimize model specification errors, three distinct regression methods were selected.

Ordinary Least Squares (OLS): This model serves as the baseline and was used to determine the linear relationship between variables. The general form of the model is as follows:

$$Indust_t = \beta_0 + \beta_1 Invest_t + \beta_2 Innov_t + \epsilon_t$$

Robust Regression Model (M-estimator): Given that sharp growth trends (outliers) in time series—particularly in recent years—can negatively affect the results and residual variance, the robust regression method was applied. This model reduces sensitivity to unexpected spikes (anomalies) and increases the accuracy of the coefficients.[8]

Polynomial Regression Model: A second-order polynomial model was used to test whether the relationship between investment and industrial growth is non-linear, meaning its impact on the sector accelerates (economies of scale) as the volume of investment increases:

$$Indust_t = \gamma_0 + \gamma_1 Invest_t + \gamma_2 Invest_t^2 + \gamma_3 Innov_t + \mu_t$$

Database and Reliability: The analysis was conducted based on statistical data from the Republic of Uzbekistan for the period 2010–2024. The quality of the models was evaluated using the coefficient of determination R^2, adjusted R^2, F-statistics, and the Residual Standard Error. All calculations were performed using the **MASS** (for robust modeling) and **stargazer** (for comparative tables) packages of the R programming language. Statistical significance levels were established at error margins of 1%, 5%, and 10% [9].

3. Results and Discussion

Figure 1. Results of the multivariate econometric analysis show that fixed capital investments and innovation expenditures are the fundamental factors determining industrial production volume in Uzbekistan. The coefficient of determination R^2 in all three models used in the study exceeds 0.996, indicating a very high capability of the selected variables to explain industrial growth [10].

Влияние на промышленную продукцию: Сравнение моделей

	Зависимая переменная:		
	Промышленная продукция (млрд. сум)		
	OLS	robust linear	OLS
	МНК (OLS)	Робастная	Полиномиальная
Инвестиции	1.641***	1.655***	
	(0.042)	(0.029)	
Инвестиции (полином, 1-й порядок)			890,504.600***
			(26,545.650)
Инвестиции (полином, 2-й порядок)			19,554.310
			(21,608.990)
Инновации	4.394***	3.227***	5.185***
	(1.069)	(0.742)	(1.387)
Константа	6,787.560	10,986.600**	241,923.100***
	(6,734.674)	(4,673.423)	(9,951.655)
Observations	15	15	15
R2	0.996		0.997
Adjusted R2	0.996		0.996
F Statistic	1,695.661*** (df = 2; 12)		1,113.651*** (df = 3; 11)
Note:			Примечание: *p<0.1; **p<0.05; ***p<0.01

Figure 1. Results of Comparative Regression Analysis of Factors Influencing Industrial Production Volume.

According to the results of the classical **OLS model** (Model 1), an increase in investment by 1 billion UZS leads to an increase in industrial output by 1.641 billion UZS, while an increase in innovation expenditures by 1 billion UZS results in an industrial output growth of 4.394 billion UZS. However, the results of the **robust regression** (Model 2), conducted to mitigate the influence of statistical anomalies and sharp spikes in time series, provide a clearer picture. The innovation impact coefficient in this model was 3.227, indicating that the influence of innovation costs on the sector is stable and high, whereas the OLS results might be slightly overstated due to outliers. The reduction of the **Residual Standard Error** from 16.653 to 8.016 in the robust model confirms that its results are statistically more reliable [11].

One of the most significant aspects of the study is the exceptionally high multiplicative effect of innovation costs relative to industrial production. Across all three models, the innovation coefficient was significantly higher than the investment coefficient (3.227 > 1.655 in the robust model) [12]. This implies that investments directed toward innovation are twice as effective as traditional capital investments in ensuring industrial growth. This result empirically proves that it is strategically vital not only to increase capital volume during economic modernization but also to focus on its innovative component [13].

The **polynomial regression** results (Model 3) show that the impact of investment on industrial growth is linear. The fact that the quadratic term coefficient is not statistically significant suggests that, at this stage, the impact of investment on industrial production primarily follows a linear progression. In conclusion, innovation costs act as an "accelerator" for Uzbekistan's industry [14]. While investments provide the baseline growth, innovations provide multiplicative strength in terms of quality. The coefficients obtained from the robust analysis confirm that stimulating innovation is the shortest and most effective path to increasing industrial competitiveness [15].

4. Conclusions

A comparative analysis of development factors in Uzbekistan's industrial sector using three different econometric specifications (OLS, Robust, and Polynomial) led to the following fundamental conclusions:

- **First**, the **Robustness Check** proved that the impact of investment and innovation on industrial growth is not accidental and is not distorted by data outliers. The results obtained via the robust regression model are more precise (with a standard error twice as small as OLS), ensuring the scientific validity of the analysis.
- **Second**, the most critical finding concerns the multiplicative efficiency of innovation expenditures. In all models, the coefficient of innovation impact on industrial output (3.227) was significantly higher than the impact of investment (1.655). This means that capital directed toward innovation in Uzbekistan’s industry yields, on average, twice the economic efficiency of traditional capital investments. Consequently, the fastest way to accelerate economic growth is not merely increasing total investment volume, but expanding its innovative component.
- **Third**, the polynomial model results indicated that industrial growth is currently predominantly **linear**. This suggests that economies of scale have not yet been fully realized. To further develop the sector, it is necessary to transition from linear growth to an accelerated growth model by deepening technology investments.

In conclusion, investment serves as the "driving force," while innovation acts as the "growth catalyst" for Uzbekistan's industrial sector. The study empirically confirms that strengthening state policy to stimulate innovation—specifically by expanding tax incentives for innovation costs and supporting technology transfer—will allow industrial output to increase faster than anticipated.

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