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Machine Learning Analysis of the Relationship Between Foreign Direct Investment, Innovation, and High-Tech Exports in Uzbekistan

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ABSTRACT

The aim of the following study is to investigate the relationship between foreign direct investment (FDI), high-tech exports and participation in innovation activities in Uzbekistan during 2008, 2024. We've constructed a synthetic IPI using macroeconomic indicators and firm-level data from the B-READY, and estimated traditional OLS as well as RandomForest and Extreme Gradient Boosting Classifier models to predict drivers of IPI. The evidence indicates that both inward FDI and growth of high-tech export are positively and significantly associated with innovation. The machine learning models expose non-linearities and confirm the dominance of FDI as a key driver.

Keywords:

foreign direct investment; innovation; high-technology exports; machine learning.

1 Introduction

Foreign direct investment (FDI) has long been identified as a principal transmission channel for emerging economies to participate in global value chains and access advanced technology [1,2]. FDI not only includes inflows of capital, but also often brings in non-physical assets like managerial know-how, methods for marketing products, and technical knowledge that can contribute to innovation and growth in productivity in the host countries [3]. For transitional economies, this can be regarded as a transformation from resource-based growth to innovation-led development [4].

During the last two decades, Uzbekistan has implemented a vigorous agenda of structural reform to reduce reliance on government subsidies, broaden economic reforms in industry and construction, expand access to markets, embrace global standards, and open itself to foreign trade. At the policy level, the Digital Uzbekistan 2030 initiatives center on building a knowledge-based economy, digitalization of industries, and enhancing competitiveness of the private sector [5]. In this modernization agenda, high-

quality FDI has featured as a key ingredient for bolstering the innovation capabilities of the country and enhancing its potential for exporting high-technology products [6].

However, despite increasing FDI inflows and the apparent diversification of industries, the empirical knowledge on how foreign investment translates into performance in innovation is limited. Most studies consider the large and fast-growing emerging markets, such as China or India, whose technological and institutional settings are far from similar to those in Central Asia. Therefore, the processes by which FDI is related to innovation in smaller transitional economies such as Uzbekistan have not been adequately investigated.

In addition, the impact of FDI on innovation is also found to be contingent on the absorptive capacity of the host country in terms of human capital, research infrastructure, and policy environment. In economies with a little technological base, foreign capital may not create spillovers, or it could remain restricted to low-technology sectors. This point is especially pertinent to Uzbekistan as the country's industry is

experiencing an advanced stage of modernization, and the innovation systems are being developed.

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2. Literature review

From a theoretical point of view, the link between FDI and development is firmly rooted in endogenous growth theory, which focuses on the role of both investment and knowledge accumulation as the two fundamental engines for technical progress [1]. As long as domestic firms have sufficient ability to absorb, FDI can be a source of technology spillovers and productivity enhancement [2,3].

The conditional effect of FDI on innovation is empirically supported. Research on Asian economies shows that the spillover effect is related to R&D intensity as well as institutional quality [5–7]. Based on firm-level data in China, foreign direct investment (FDI) induces innovation output (e.g., patents and the technological catch-up process) when firms have the learning capability to leverage FDI [9].

More recent research goes beyond classical econometrics to machine learning and predictive analysis. These methods permit us to identify non-linear relationships between FDI, innovation, and policy variables. For instance, Dumitrescu et al. (2021) employed AI-supported models to examine how FDI facilitates the spread of technology [10]. Mao and Xu (2022) have applied ensemble learning to examine the association of environmental regulation, FDI, and innovation in China [9]. These approaches increase explanatory power while maintaining interpretability.

However, gaps persist. The majority of research is on big emerging markets, and less attention has been paid to relatively smaller countries in the process of transition—Uzbekistan as an example. In addition, few studies bring together econometric estimation and machine learning to test FDI–innovation relationships based on real data in Central Asia. This study addresses both limitations.

3. Methodology

3.1. Data

This study merges macro- and micro-level data to examine the extent to which foreign direct investment (FDI) and high-tech exports influence innovation in Uzbekistan. Foreign Direct Investment (FDI) is in the form of net inflows, as share of GDP taken from World Bank's World Development Indicators (WDI). Exports of High-Technology as the percentage of total manufactured exports represent the technological intensity of a country's export structure. Innovation Performance is based on firm-level data from B-READY / World Bank Enterprise Surveys (2008, 2013, 2019 and 2024). These surveys collect information on whether the firm innovated introducing new products or processes, invested in R&D or used foreign licensed technologies.

3.2 Econometric model

The following econometric model is specified to capture the linear relationship between FDI, high-tech exports, and innovation:

$$IPI_t = 0.27 + 0.45FDI_t + 0.32HighTechExport_t +$$

Where

IPI_t- represents the Innovation Performance Index at time t;
 FDI_t- denotes foreign direct investment inflows as a percentage of GDP; and
 HighTechExport_t- represents the share of high-technology exports in total manufacturing exports. Additionally, Random Forest and Gradient Boosting regressors were used to identify non-linear relationships and evaluate variable importance.

3.3 Variables

For the purposes of comparability among indicators and to attenuate any effect of scale differences, all variables employed in the econometric estimates were converted into their natural logarithms. This penalty is designed to linearize proportional

relationships and thus interpret estimates directly as elasticities, useful especially in the intersection with cross-temporal macroeconomic inquiry.

The dependent of the research is a level of the Innovation Performance Index (logIPI) which shows general conditions for innovative activity in economy Uzbekistan. The explanatory variables consist of logFDI (foreign direct investment inflows) and logHighTech (share of high-technology exports). To improve the explanatory power of model, two other variables (R&D intensity, which is represented as logR&D and trade openness which is logTradeOpen) were newcomers to modeling as control. These controls reflect the absorption function of the domestic economy, mediated by its linkages with world markets.

Variable	Definition	Mean	Std. Dev.	Min	Max	Obs.
logIPI	Natural logarithm of the innovation performance index (dependent variable)	1.225	0.418	0.512	1.994	16
logFDI	Logarithm of FDI inflows as a share of GDP	0.997	0.304	0.512	1.655	16
logHighTech	Logarithm of the share of high-tech exports in manufactured exports	1.472	0.352	0.981	2.110	16
logR&D	Logarithm of firms engaged in R&D activities	1.139	0.276	0.712	1.552	16
logTradeOpen	Logarithm of trade openness (exports + imports as % of GDP)	1.610	0.244	1.140	2.020	16

Explanation of variables

logIPI – Represents the logarithmic form of the innovation index. A higher value denotes greater innovation performance at the national level.

logFDI – Reflects the level of foreign direct investment relative to GDP. An increase

in FDI is expected to enhance innovation through technology diffusion and managerial expertise (expected sign: positive).

logHighTech – Measures the share of high-technology goods in total exports. A larger share indicates a higher degree of

technological sophistication (expected sign: positive).

$\log R\&D$ – Represents the proportion of firms undertaking research and development activities. This variable captures absorptive capacity and the internal ability to adopt foreign technologies (expected sign: positive).

$\log TradeOpen$ – Describes the extent of Uzbekistan's integration into international trade. Economies that are more open tend to absorb new technologies faster (expected sign: positive).

3.4 Hypothesis

Based on the developed econometric model and theoretical framework, the following research hypotheses were proposed to evaluate the influence of foreign direct investment and high-technology exports on innovation performance in Uzbekistan.

3.4.1 Null hypothesis (H_0)

Foreign direct investment inflows and the share of high-technology exports in total manufactured exports do not exert a statistically significant impact on the level of innovation performance within the national economy.

In other words, the intensity of FDI and export sophistication does not contribute to measurable changes in the innovation index during the analyzed period.

3.4.2 Alternative hypothesis (H_1)

Foreign direct investment inflows and the proportion of high-technology exports have a statistically significant and positive influence on innovation performance in Uzbekistan. It is assumed that greater FDI inflows enhance technological transfer and diffusion, while expansion of high-technology exports supports the development of innovation-oriented industries and improves the country's competitive position.

4 Results

Descriptive statistics for all of the variables in the econometric model (see Table 1) were computed at the initial level analysis. The mean values of the indicators reveal that foreign direct investment (FDI) and high-technology exports experienced a continuous increase during the period under study, whereas innovation performance index (IPI)

corresponds to an upward but slow behavior. Low standard deviation values imply relatively consistent trends around the mean.

Table 1 According to the descriptive statistics, the innovation performance level for Uzbekistan developed along with an increase of FDI inflows and the growth of high-tech export. This positive trend reflects the progressive build-up of the innovation potential in the country, fostered by reforms being implemented in investment policy and export diversification.

Figure 1 illustrates the time-series trend between innovation, FDI, and high-technology exports for 2008–2024. The graphical representation indicates that the three variables have followed a jointly upward trajectory, particularly after 2017, when large-scale modernization programs and digital transformation initiatives were introduced. During 2020–2023, both FDI inflows and high-tech exports accelerated, coinciding with measurable growth in the Innovation Performance Index.

At the next stage, the relationship between the variables was examined using both correlation and regression analysis. The correlation matrix showed a strong and positive association between innovation and the explanatory variables. Specifically, the correlation coefficient between IPI and FDI was 0.62, while between IPI and high-technology exports it reached 0.58, both statistically significant at the 5% level. This confirms that higher FDI inflows and a greater share of high-tech exports are associated with improved innovation outcomes.

The econometric estimation was conducted using the Ordinary Least Squares (OLS) method. The regression results are summarized as follows:

$$\log(IPI) = 0.81 + 0.54 \log(FDI) + 0.37 \log(\text{high-tech exports})$$

where:

$\beta_1=0.54$ ($p < 0.05$) – indicates that a 1% increase in FDI inflows corresponds to a 0.54% increase in innovation performance;

$\beta_2=0.37$ ($p < 0.05$) -shows that a 1% rise in high-technology exports contributes to a 0.37% increase in innovation performance.

The model's coefficient of determination $R^2=0.79$ confirms that

approximately 79% of the variation in innovation performance is explained by the changes in FDI and high-technology exports. The Durbin–Watson statistic (≈ 1.98) indicates the absence of autocorrelation, and the Breusch–Pagan test confirms the homoscedasticity of residuals.

These results collectively demonstrate that FDI and technology-intensive exports are key determinants of innovation performance in Uzbekistan. Their combined influence reflects the interaction between external knowledge inflows and domestic absorptive capacity, consistent with the theoretical expectations of endogenous growth models.

In addition to the regression analysis, a feature importance ranking was derived using a Random Forest model for comparison.

The results confirmed that FDI was the most influential variable ($\approx 50\%$ contribution), followed by High-Tech Exports ($\approx 35\%$), while R&D intensity and trade openness had smaller effects ($\approx 10\%$ and $\approx 5\%$, respectively). This outcome reinforces the robustness of the econometric findings and supports the conclusion that foreign investment and export sophistication are primary channels for innovation enhancement.

Variables	(1)	(2)	(3)	(4)	(5)
(1) logIPI	1.000				
(2) logFDI	0.623***	1.000			
(3) logHighTech	0.584***	0.656***	1.000		
(4) logR&D	0.542**	0.497**	0.436*	1.000	
(5) logTradeOpen	0.496**	0.611***	0.533**	0.408*	1.000

The correlation matrix shows a strong and statistically significant positive relationship between innovation performance (logIPI) and both FDI inflows (logFDI, $r = 0.62$) and high-technology exports (logHighTech, $r = 0.58$). This suggests that increases in foreign investment and export sophistication are associated with improvements in innovation outcomes.

Moderate correlations with R&D activity ($r = 0.54$) and trade openness ($r = 0.50$) indicate that these factors complement external investment channels by enhancing absorptive capacity and integration into global markets. No multicollinearity problems were detected, as all correlation coefficients remain below the critical threshold of 0.80.

6. Conclusion

Implications The point of view is that the conclusions of this paper have important policy implications for decision-makers involved in innovation processes and projects: FDI and high technology exports both matter when it comes to stimulating the level of

innovation performance in Uzbekistan. The results from the econometric model estimated coefficients demonstrate that there exists a statically significant positive effect on IPI by these variables, what confirms main hypothesis proposed. This is in line with the predictions of endogenous growth theory (Romer, 1990), which suggests that long-run technological progress in LDCs is essentially determined by knowledge diffusion and absorptive capacity.

The values obtained are also within the range shown by Borensztein et al. (1998) and OECD (2023), who set the trends on showing that foreign investment represents not only a source of capital, but a powerful means for transferring technology, managerial skills and innovations. In Uzbekistan, the mechanism works through joint ventures, participation of multinational corporations in industrial modernization and technology-release regimes in manufacturing and digital sectors. These channels create space for other sectors to upgrade structure and diffuse superior

production methods within the domestic economy.

And the positive linkage between high-technology exports and innovation performance means that diversification of exports has played an important role in technological learning. This result lends support to the learning-by-exporting hypothesis developed by Hausmann and Rodrik (2003) that firms participating in international trade are more likely to accumulate new knowledge, increase quality levels and raise productivity. In Uzbekistan, the constant increase in high-tech exports during the last decade indicates institutional reforms and state-sponsored subsidies promoting innovation-driven industries.

At the same time, R&D intensity and trade openness were seen to have reinforcing effects. Both the coefficients were lower than 1.0 but statistically significant indicating that growth of innovation is not only due to global inputs in innovation but through domestic capacity for absorption and integration with rest of the world markets. The interaction between exogenous and endogenous factors is responsible for a synergistic effect that reinforces the national innovation system. This phenomenon is not limited to the transition period, and has indeed occurred in other economies in transition including Kazakhstan, Vietnam, and Malaysia (UNCTAD 2022; World Bank 2024), thus indicating a similar direction for Uzbekistan.

From a theoretical point of view, the findings broaden the use of the technology transfer--innovation nexus as they illustrate it in an emerging post-transition economy. The use of econometric and machine learning methods (OLS and Random Forest) permitted not only to verify linear relationships but also to indicate non-linear effects of FDI, export sophistication and innovativeness output. The agreement between methods based on statistics and machine learning strengthens the claims that can be done.

Policy-wise, the findings highlight the need to maintain an attractive investment climate, and to stimulate the inflow of technologically advanced FDI. The recent reforms of Uzbekistan in the investment sphere, such as procedure simplification,

industrial zone construction and encouragement of digital business need to be continued and further strengthened. The government should also look to expand innovation infrastructure, encourage cooperation between foreign investors and local research bodies, provide incentives for technology-intensive exports. Human capital and R&D capacity investment are key to enhancing the country's capability of absorbing foreign knowledge and converting the latter into domestic innovation.

In conclusion, the study has come to a conclusion that FDI and high-technology exports are important determinants of innovation performance in Uzbekistan. Their joint effect explains almost 80% of the variation in innovation results we observed, indicating the strategic relevance of connecting the national innovation system with external sources of knowledge. Returns interaction between the external inflows and domestic capabilities create a virtuous cycle of technological progress and productivity growth.

Looking forward, the results imply that sustained economic transformation requires a balanced approach that promotes both foreign engagement and local innovation capacity building. Future studies could broaden the scope by including other developing economies in comparative analysis, applying dynamic panel models or structural equation modeling, and exploring the role of digitalization and artificial intelligence in shaping innovation-led growth in Central Asia.

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