The Contribution of Higher Education to Innovation Development: Long-Term and Short-Term Analysis

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Abstract

The relationship between higher education and innovation development is pivotal to advancing Sustainable Development Goals (SDGs), particularly in fostering quality education (SDG 4), decent work and economic growth (SDG 8), and industry, innovation, and infrastructure (SDG 9). Understanding how higher education drives innovation can inform policies to develop human capital, accelerate technological progress, and promote sustainable economic and social development. This paper aims to assess the short-term and long-term impacts of higher education indicators on innovation development in Ukraine. Using data from 2014 to 2022, the study employs a vector error correction model to analyse the relationship between innovation development and higher education indicators. Innovation development was evaluated using the Malmquist productivity index, which incorporates time-series data from the Global Innovation Index to analyse short- and long-term dynamics in resource efficiency and innovation output, with a focus on Ukraine and the Visegrad Four countries for cross-country comparison. Methodological steps include stationarity testing with the ADF test, determining optimal lag length, Johansen cointegration analysis, Granger causality testing, and estimating impulse response functions. The results demonstrate a significant long-term equilibrium relationship between innovation development and higher education indicators. STEM graduates and higher education enrolment exhibit substantial positive long-term impacts, while research capacity and intellectual property payments show significant short-term effects. The findings underscore the transformative role of higher education as a driver of sustainable economic growth and

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technological progress. Theoretically, the study advances understanding of how education-driven human capital fosters innovation in transition economies. Practically, it offers evidence-based recommendations for policymakers to prioritise STEM education, support research initiatives, and enhance the use of intellectual property to build a robust and sustainable innovation system.

Key words

human capital, innovation, intellectual property, higher education, STEM, commercialisation, economic growth.

Introduction

Higher education institutions (HEIs) play a vital role in fostering innovation and driving economic development, with their contributions evident in both short-term and long-term impacts. In the short term, HEIs collaborate with industries through joint research projects, consultancy services, and technology transfer offices, addressing immediate challenges and fostering innovation in processes, products, and services. They also equip graduates with contemporary skills tailored to industry needs, offering training programmes, certifications, and hackathons to address specific workforce gaps. Additionally, universities focus on applied research, developing prototypes and practical solutions in sectors such as healthcare, renewable energy, and digital transformation, while also serving as incubators for startups by providing resources, mentorship, and networking opportunities. Over the long term, HEIs build a knowledge-based workforce, emphasising critical thinking, creativity, and lifelong learning, while advancing foundational research that underpins transformative innovations. They institutionalise a culture of inquiry, influencing societal norms, ethics, and public understanding of science and technology. Moreover, universities act as hubs for regional development by attracting talent, investment, and infrastructure, enhancing regional and national competitiveness, and fostering global collaborations that address pressing challenges such as attaining sustainable development goals (Kwilinski et al., 2023b; 2023c; 2023d; 2024c; Kwilinski, 2024a), climate change (Karpenko et al., 2018), and energy security (Kharazishvili et al., 2021; Ziabina et al., 2023; Mlaabdal et al., 2024; Kwilinski et al., 2024a; 2024f).

However, some scholars argue that the contribution of HEIs to innovation development is not as significant or straightforward as often assumed. Critics point to the misalignment between academic research and market needs, arguing that much of the research conducted within universities lacks practical application and fails to address pressing industrial challenges (Perkmann et al., 2013). Furthermore, concerns about bureaucratic inefficiencies and the slow pace of academic innovation have been raised, with some asserting that HEIs struggle to adapt quickly enough to rapidly changing technological landscapes (Nwogu, 2024). There is also debate over the commercialisation of research, with detractors suggesting that the increasing focus on profit-driven innovation risks undermining the pursuit of fundamental knowledge and the societal mission of universities (Kezar & Bernstein-Sierra, 2024; Andrew et al., 2024). Additionally, critics highlight disparities in innovation contributions across regions, noting that well-funded universities in developed countries often dominate global innovation, while underfunded institutions in developing nations struggle to make comparable impacts (Altbach & Salmi, 2011).

Ayala-Mora et al. (2023) emphasise HEIs' contribution to digital governance by equipping graduates with administrative and technological skills, which improve short-term operational efficiency and support long-term digital transformation. Berg and Spicka (2023) discuss HEIs' role in promoting media literacy to combat misinformation, fostering informed citizens who support democratic innovation in the long term. Boyko et al. (2024) and Dacko-Pikiewicz (2019a, 2019b) underline the importance of educational programmes in strategic and financial management, addressing immediate skills gaps and building sustainable economic frameworks. Some studies (Infante-Moro et al., 2022a; Kharazishvili & Kwilinski, 2022) explore the integration of cybersecurity and artificial intelligence, respectively, showing HEIs' short-term role in skill development and their long-term impact on embedding digital security and AI-driven policies. Kwilinski (2019, 2023b, 2024b) highlights blockchain and digital technologies' environmental applications, demonstrating how HEIs prepare students for immediate innovation while fostering interdisciplinary sustainable practices. Kwilinski & Vysochyna (2024) focus on healthcare financing, with HEIs addressing short-term administrative innovations and influencing long-term financial sustainability policies. Kwilinski et al. (2022, 2023a, 2024d) extend this to digital governance, emphasising HEIs' role in aligning digital business with public services for short-term innovation and long-term systemic governance improvements.

The synergies between short-term successes, such as spin-offs and applied research, and long-term investments in human capital and basic research reinforce the pivotal role of higher education in innovation ecosystems. However, to maximise their impact and address these criticisms, HEIs must overcome challenges such as funding constraints, misalignment with industry needs, and bureaucratic hurdles by strengthening academia–industry–government collaboration, increasing investment in research, promoting interdisciplinary partnerships, and aligning educational outcomes with innovation goals. By addressing these challenges and balancing short-term practical applications with the pursuit of long-term foundational knowledge, HEIs can continue to make significant contributions to innovation development across both short-term and long-term horizons. The relationship between higher education and innovation development has been extensively analysed in recent studies (Southworth et al., 2023; Michel-Villarreal et al., 2023; Wang et al., 2023; Adeel et al., 2023; Akcigit et al., 2024), underscoring the role of higher education institutions in fostering economic growth, technological advancement, and sustainable development. However, the existing body of research often suffers from two critical limitations. The vast range of studies relies on aggregated indices, such as the Global Innovation Index (GII), which, while useful, obscure the nuanced contributions of specific higher education indicators to innovation development. This aggregation often leads to a lack of clarity in understanding the mechanisms through which higher education impacts innovation. Second, the interplay between the short-term and long-term impacts of higher education on innovation remains underexplored. Studies tend to either focus on immediate effects, such as skill development and technology transfer, or emphasize long-term contributions, such as foundational research and human capital accumulation, without providing an integrated analysis of these dynamics. This research addresses these gaps by developing a methodological framework that integrates specific indicators of higher education into the analysis of innovation development. By applying a vector error correction model (VECM), this study captures both the short-term and long-term dynamics of the relationship, providing a robust analytical tool to understand the equilibrium adjustments in innovation development. The contribution of this research is threefold. First, it advances methodological innovation by quantifying the elasticity of innovation development with respect to individual higher education indicators, providing precise estimates that can guide policy formulation. Second, it offers empirical evidence on the differentiated short-term and long-term impacts of higher education on innovation, highlighting the pathways through which specific indicators contribute to sustainable economic growth. Finally, the study situates Ukraine within the broader context of innovation development in the Visegrad countries, offering insights into best practices and policy interventions that can enhance the country's innovation ecosystem.

The paper has the following structure: literature review—exploring the theoretical background on the role of the university in boosting innovation development; methodology—outlining the data resources, methods and instruments to check the research hypotheses; results—describing the empirical results of the investigation; discussion—comparison analysis of the obtained results with those of previous studies; and conclusion—summarising the core findings, outlining the policy implications, limitations and further directions for investigations.

1. Literature review

HEIs have a dual impact on innovation. Short-term contributions include skill development, research applications, and technological adoption, whereas long-term contributions focus on cultivating human capital, embedding innovation into economic structures, and aligning with global sustainability goals. Dementyev et al. (2021) analyse how innovation and information technologies restructure global political and economic systems. Higher education contributes to the short term by advancing research and technology that improve decision-making. Long-term contributions include shaping global innovation ecosystems and fostering sustainable development. Gigauri et al. (2024) examine the market potential for smart packaging, showcasing how higher education impacts innovation through research on consumer behaviour and technology. Short-term effects include equipping graduates with marketing and technical skills, whereas long-term impacts emerge through sustained industry-academic collaborations.

Infante-Moro et al. (2022b) focus on e-proctoring in Spanish universities, highlighting higher education's role in digital transformation. Short-term contributions include operational efficiency in remote learning, whereas long-term effects normalize digital tools and foster a tech-savvy workforce. Kharazishvili et al. (2020) explore social safety indicators aligned with sustainable development goals. Higher education fosters the human capital that drives society (Titko et al., 2021), with short-term contributions evident in research applications and long-term impacts in shaping strategic sustainability policies. Kwilinski and Kardas (2024a) analyse the Pareto principle in Industry 4.0, emphasizing advanced education and research in adapting to technological shifts. Short-term contributions focus on implementing innovative practices, whereas long-term impacts embed quality management principles in workforce and industry standards. Kwilinski et al. (2024b) examine the connection between a country's global image and immigration flows, highlighting higher education's short-term contributions in addressing cultural diversity and long-term benefits in enhancing global collaboration and competitiveness.

Labudova and Fodranova (2024) discuss socioeconomic factors influencing digital skills in the EU, highlighting higher education's role in addressing skill gaps. Short-term contributions include targeted educational programs, whereas long-term impacts develop a digitally proficient workforce that drives regional innovation. Lyulyov et al. (2024) analyse public perceptions of artificial intelligence, showcasing higher education's role in short-term expertise and research and long-term contributions to ethical frameworks and trust-building in AI technologies. Surya et al. (2024) examine green human resources in hospitality innovation, showing higher education's short-term influence through specialized programs for eco-conscious professionals and long-term impacts through industry-wide adoption of sustainable practices. Zimbroff (2023) explored extension programming postpandemic, emphasizing higher education's role in adapting curricula to meet immediate challenges and ensuring resilience for long-term innovation in education systems.

The relationship between higher education and innovation development has been extensively studied, revealing both direct and indirect impacts on economic and technological progress (Li & Liu, 2021; Zhou & Luo, 2018; Kruss et al., 2015; Cai et al., 2020). HEIs are recognized as crucial drivers of the knowledge economy, contributing to the generation, dissemination, and application of knowledge essential for innovation (Macerinskiene & Vaiksnoraite, 2006). However, while investments in higher education yield significant economic benefits, they may also lead to challenges such as diminished quality and diploma devaluation if not carefully managed. Studies (Kwilinski et al., 2024e; Moretti, 2004) highlighted the positive spillover effects of educated workers, demonstrating that higher education enhances not only individual productivity but also the overall performance of peers, even those without higher education.

Kyrylov et al. (2020) analyse international tourism development amidst globalization risks, focusing on Ukraine's integration into the global tourism industry. Higher education institutions

(HEIs) play a vital short-term role by preparing professionals with specialized knowledge in global tourism management. Long-term contributions include fostering research on sustainable tourism practices, enhancing resilience against globalization risks, and integrating academic insights into policymaking. Lyulyov et al. (2020) explored the relationship between economic growth and tourism, emphasizing the impact of COVID-19. HEIs' short-term role includes analysing immediate economic disruptions and preparing students to address tourism sector challenges. In the long term, higher education fosters interdisciplinary research and innovation to align tourism with sustainable development goals, ensuring economic recovery and resilience in the postpandemic era. Payonk et al. (2015) examine the operations of business entities in the context of globalization, highlighting the importance of HEIs in equipping graduates with the skills to navigate globalized markets. In the short term, higher education contributes by providing practical training to adapt to global market dynamics. In the long term, it fosters innovation by integrating globalization studies into curricula and advancing research on global business strategies.

Alqararah (2023) explored the robustness of global innovation rankings such as the GII, revealing discrepancies in methodology that affect middle-ranking countries, thus emphasizing the need for comprehensive and localized approaches.

Critiques of traditional innovation metrics, such as the GII and the European Innovation Scoreboard, highlight their limitations, including aggregation biases and subjective weightings (Grupp & Mogee, 2004). To address these issues, alternative methods such as the VECM offer a more objective analysis of higher education's influence on innovation by integrating human capital and intellectual property dimensions into the assessment.

The formation of human capital through higher education is pivotal for fostering innovative outputs, as shown by studies focusing on regional specificity and stakeholder engagement (Shkarlet et al., 2019). Furthermore, aligning university education with national strategies, such as Saudi Arabia's "Vision 2030," enhances long-term innovation and economic diversification (Thomran & Alshammari, 2023). Mayboroda et al. (2024) proposed a model integrating talent management principles with knowledge economy frameworks, underscoring the importance of cooperation between universities, businesses, and science in creating both short-term innovations and long-term human capital development.

Additional studies emphasize practical aspects of the role of higher education in innovation. Abbas (2019) linked university branding to attracting and retaining talented students and faculty, whereas Migala-Warchol & Pasternak-Malicka (2018) underscored the centrality of HEIs in research and workforce preparation for innovative economies. Dual education systems also strengthen the connection between education and labour market needs, equipping students with practical skills critical for innovation-driven industries (Davlikanova & Hofstetter, 2020).

These papers (Bartha et al., 2019; Danova et al., 2022; Oturakci, 2021) provide valuable insights into how HEIs contribute to innovation development in both short-term and long-term contexts. Bartha et al. (2019) focus on the management of innovations within Hungarian HEIs, particularly through the Erasmus mobility program, highlighting short-term benefits such as knowledge transfer, cultural diversity, and skill development, as well as long-term impacts such as enduring international collaborations and alumni networks that strengthen global innovation ecosystems. Danova et al. (2022) explore the role of innovations in human resource management within HEIs, emphasizing the short-term effects of improved employee performance and organizational efficiency, alongside long-term benefits such as cultivating a highly skilled workforce capable of driving sustained economic and technological advancements. Oturakci (2021) provides a comprehensive analysis of the GII, critiquing its limitations and advocating for region-specific metrics that better capture HEIs' contributions to innovation.

On the basis of the abovementioned results of analysis, this study checks the following research questions:

How do different higher education indicators contribute to the elasticity of innovation development in transition economies?

How do the dynamics between higher education and innovation development evolve over time, and what are the key drivers of these changes in transition economies?

2. Methodology

To investigate the intricate relationship between higher education and innovation development in the country, the following functional form was employed:

$$ID = f(X_i) \tag{1}$$

where ID represents the innovation development of Ukraine and X represents higher education.

To analyse this relationship, the variables were transformed into their natural logarithmic form. This transformation facilitates the interpretation of the coefficients as elasticities, quantifying the percentage change in innovation development resulting from a one-percent variation in higher education indicators. The log-linear model is specified as follows:

$$lnID_t = a_0 + a_1 lnX_{it} + \mu_i \tag{2}$$

where ln represents the natural logarithm; ID_t denotes the innovation development of the country at time t; X_{it} is the i-th higher education indicator at time t; a_0 is the intercept, capturing the baseline level of innovation development; a_1 represents the elasticity of innovation development with respect to the higher education indicator, indicating how sensitive innovation development is to changes in higher education inputs; and μ_i is the error term, accounting for unobserved factors that may influence innovation development.

To evaluate innovation development, the Malmquist productivity index was applied. Compared with existing approaches (Peters, et al., 2017; Schwab, 2018; Hollanders, et al., 2019; Dutta, et al., 2022), this methodology allows for the simultaneous assessment of changes in resource utilization efficiency and innovation output over time. Unlike static methods, the Malmquist productivity index incorporates the time factor, enabling the analysis of both short-term and long-term dynamics (Bansal et al., 2022; Lou et al., 2024). Additionally, the approach allows for the comparison of innovation development levels between countries with varying degrees of economic development, economic structures, and resource capacities. By incorporating time series data, this method enables tracking the dynamics of innovation development over the analysed period, identifying trends and critical influencing factors. The analytical basis for calculating innovation development relies on Global Innovation Index reports prepared by experts from the World Intellectual Property Organization (Dutta et al., 2022). The study focused on data from Ukraine and the Visegrad Four countries (Hungary, Poland, Slovakia, and the Czech Republic). The selection of these countries was justified by shared economic and historical conditions, enabling a valid comparison of their innovation strategies, the similarity of challenges in innovation policy development and investment attraction, and the availability of a comparable statistical database.

To measure the level of higher education development in this study, the following indicators were used: X1 – percentage of graduates from science, technology, engineering and mathematics programmes in tertiary education. both sexes (%); X2 – School enrolment. tertiary (% gross); X3 – Total researchers by higher education sector – full-time equivalent; X4 – Charges for the use of intellectual property payments (BoP. current US$). These specific indicators are not included in the Global Innovation Index (GII), whose components were used to compute the ID – Innovation Development of Ukraine. The GII is a widely used tool to measure innovation development across countries, but it does not fully capture the specific contributions of higher education systems or detailed aspects of intellectual property engagement in its composite structure. First, X1 and X2 represent the human capital pipelines—STEM graduates and tertiary school enrolment—which are foundational to a country's innovation capacity (Lenhart et al., 2022; Ng & Park, 2021). A well-educated workforce, particularly in the science and technology fields, is essential for developing cutting-edge technologies and innovations. These variables provide a clearer picture of the supply of skilled professionals who can contribute to research, entrepreneurship, and technological advancements in Ukraine. Second, X3 reflects the research and development capacity of the country, which is critical for generating new knowledge and fostering innovation (Kwiek, 2021; Benito & Romera, 2020). While the GII considers broader research and development expenditures, the number of researchers directly demonstrates the capacity to perform innovative research and thus deserves attention in measuring innovation development. Finally, X4 reflects the country's engagement with the global intellectual property system, indicating how well the country is commercializing and protecting innovations (Llewelyn, 2024; Ploman & Hamilton, 2024). This aspect is essential for understanding how innovations are transferred, protected, and monetized, which is a key driver of sustainable innovation but is not explicitly included as a separate component in the GII. The data on X1, X2, X3, and X4 were collected from the World Data Bank (2024) and Eurostat (2024).

In the first step, the augmented Dickey–Fuller (ADF) test was employed to check for stationarity in the time series data (Singh et al., 2024). Stationarity is a crucial condition for time series analysis, as nonstationary data can lead to misleading results. The null hypothesis of the ADF test posits that the series contains a unit root (nonstationary). If the null hypothesis is rejected, the series is considered stationary. This test was applied to each variable to ensure that it was stationary either in levels or after differencing. After establishing stationarity, the optimal number of lags for the variables was determined. Various criteria, such as the Akaike information criterion (AIC), Hannan-Quinn information criterion (HQIC), and Schwarz Bayesian information criterion (SBIC), were used to select the lag length (Utouh & Tile, 2023). The correct lag selection ensures that the model captures the dynamic relationships between the variables without overfitting. The Johansen cointegration test was applied to examine the presence of long-term equilibrium relationships between the variables (Ivascu et al., 2021). This test determines whether nonstationary variables are cointegrated, indicating that despite short-term deviations, the variables move together in the long run. The trace and maximum eigenvalue statistics were used to assess the number of cointegrating relationships. To identify the direction of causality between the variables, the Granger causality test was performed (Shojaie & Fox, 2022). This test examines whether past values of one variable can predict the current values of another. The test results help to establish whether the independent variables have predictive power over innovation development in Ukraine. On the basis of the results of the cointegration test, either a vector autoregression (VAR) or a vector error correction model (VECM) was estimated. The VAR model is used for noncointegrated series, capturing the interdependencies and dynamic relationships between variables. In the case of cointegrated variables, the VECM model was employed to account for both short-term deviations and long-term equilibrium relationships between the variables (Morshed & Hossain, 2022):

$$\Delta lnID_t = b_0 + \lambda_1 ec_{t-1} + b_1 \Delta lnID_{t-1} + b_2 \Delta lnX_{i,t-1} + \varepsilon_t \tag{3}$$

where $\Delta lnID_t$ represents the first difference of the natural logarithm of innovation development at time t; b_0 represents the intercept term, which captures any constant factors affecting innovation development in the short term; λ_1 represents the speed of the adjustment coefficient; ec_{t-1} represents the error correction term from the previous period; b_1 represents how the past period's changes in innovation development affect the current period's changes; $\Delta lnID_{t-1}$ represents the short-term lagged effects of changes in innovation development on itself; b_2 represents how past changes in higher education inputs influence current innovation development in the short term; $\Delta lnX_{i,t-1}$

represents the short-term effects of changes in the higher education indicators; and ε_t represents the error term accounting for random shocks or factors that are not explained by the model at time t.

The error correction term reflects the deviation from the long-run equilibrium. If the system is out of equilibrium, this term helps adjust the variables back toward their long-run relationship. A significant and negative λ_1 suggests that if innovation development deviates from its long-run path, the system will correct itself over time, with the magnitude of λ_1 indicating the speed of this adjustment. The IRF was used to trace the response of one variable to a shock in another over time. This provides insight into the dynamic interactions and how the variables influence each other following an exogenous shock. The Jarque-Bera test was applied to assess whether the residuals of the model followed a normal distribution. This is important for ensuring the validity of the model's inference. The stability of the VECM model was evaluated via the eigenvalue stability condition. A model is considered stable if all the eigenvalues lie within the unit circle, indicating that the system is dynamically stable.

3. Research results

The ADF test results indicate that the variable ID is stationary in level (Table 1). This suggests that the ID is integrated of order 0, or I(0), meaning that it does not contain a unit root and is stable over time.

Table 1. ADF test results.

Variable	Test statistic	MacKinnon approximate p value	Conclusion
ID	-3.903	0.002	Stable
D.ID	-4.141	0.001	Stable
X1	-1.025	0.744	Unstable
D.X1	-3.952	0.002	Stable
X2	-2.653	0.256	Unstable
D.X2	-3.511	0.038	Stable
X3	-1.069	0.727	Unstable
D.X3	-3.723	0.004	Stable
X4	-2.208	0.203	Unstable
D.X4	-3.671	0.004	Stable

Source: created by the authors.

The variables X1, X2, X3, and X4 are nonstationary in their original form (levels). The ADF test statistics for these variables are greater than the critical values at the 1%, 5%, and 10% significance levels, and their p values are not significant. This implies the presence of a unit root, meaning that the variables are integrated of order 1, or I(1). However, after applying first differencing, these variables become stationary, as their test statistics surpass the critical values, and the p values become statistically significant.

The results in Table 2 present the optimal number of lags for the variables in the analysis, which are determined via multiple criteria such as the likelihood ratio (LR), the Akaike information criterion (AIC), the Hannan-Quinn information criterion (HQIC), and the Schwarz Bayesian information criterion (SBIC).

Table 2. Optimal number of lags.

Lag	LL	LR	FPE	AIC	HQIC	SBIC
			X1			
0	13.539		0.000*	-4.615	-5.035	-4.772
1	16.896	6.713	0.000	-4.358	-5.616	-4.827
2	327.505	621.22*	.	-127.002*	-129.099*	-127.783*
			X2			

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	9.457		0.000*	-2.982	-3.402	-3.139
1	13.433	7.953	0.093	0.000	-2.973	-4.231
3	323.822			-125.529*	-127.625*	-126.31*
			X3			
0	10.065		0.000	-3.226	-3.645	-3.382
1	21.434	22.736*	0.000*	-6.173*	-7.431*	-6.642
			X4			
0	2.433		0.002	-0.17336	-0.592	-.3295
1	10.675	16.485*	0.001*	-1.870	-3.128	-2.339
3	328.301			-127.321*	-129.417*	-128.102*

Source: created by the authors.

The Johansen cointegration test results indicate the presence of long-term equilibrium relationships. For X1, the trace statistic at rank 0 is 28.768, exceeding the critical value of 15.41, and the max statistic of 27.0280 is also greater than its critical value of 14.07. This suggests that the null hypothesis of no cointegration is rejected at rank 0, indicating the existence of at least one cointegrating relationship. However, at rank 1, the trace statistic (1.740) is smaller than the critical value (3.76), leading to the conclusion that X1 has one cointegrating relationship.

Table 3. The Johansen cointegration test.

Maximum rank	Eigenvalue	Trace statistic	Critical value	Max-Statistic	Eigen critical value
			For X1		
0		28.768	15.41	27.028	14.07
1	0.978	1.740*	3.76	1.740	3.76
2	0.220				
			For X2		
0		41.565	15.41	35.835	14.07
1	0.994	5.730	3.76	5.730	3.76
2	0.558				
			For X3		
0		22.073	18.17	18.255	16.87
1	0.897	3.818	3.74	3.818	3.74
2	0.379				
			For X4		
0		16.336*	18.17	11.751	16.87
1	0.769	4.584	3.74	4.584	3.74
2	0.436				

Source: created by the authors.

In the case of X2, which represents school enrolment in tertiary education, both the trace statistic (41.565) and the max statistic (35.835) are significantly larger than their respective critical values at rank 0, and even at rank 1, the statistic (5.730) remains above the critical value, suggesting strong evidence of multiple cointegration relationships. For X3, the trace statistic at rank 0 is 22.073, exceeding the critical value of 18.17, and the max statistic (18.255) surpasses the critical value (16.87). This indicates the rejection of the null hypothesis at rank 0, suggesting that X3 has one cointegrating relationship. Finally, for X4, the trace statistic at rank 0 (16.336) falls below the critical value, suggesting no cointegration at this rank, whereas the statistic at rank 1 (4.584) exceeds the critical value, indicating a cointegration relationship. Overall, the Johansen test shows that X1 and X3 each have one cointegrating relationship, X2 has two cointegrating relationships, and X4 does not exhibit clear cointegration in the initial rank but shows weak cointegration at rank 1.

Table 4 presents the results of the Wald tests for Granger causality, which determine whether one variable can predict (Granger-cause) another in a time series context. The null hypothesis for the Granger causality test states that the excluded variable does not Granger-cause the dependent variable. A significant chi-square statistic (p value < 0.05) indicates the rejection of the null hypothesis, suggesting the presence of Granger causality.

Table 4. Granger causality Wald tests (Dependent variable: ID).

Equation	Excluded	chi2	Prob > chi2
ID	X1	43.876	0.000
X1	ID	2.0717	0.355
ID	X2	22.369	0.000
X2	ID	3.1434	0.208
ID	X3	8.8194	0.012
X3	ID	29.295	0.000
ID	X4	7.9676	0.019
X4	ID	8.428	0.015

Source: created by the authors.

The test shows that X1 Granger-causes ID with a chi-square value of 43.876 and a p value of 0.000, meaning that changes in X1 significantly predict changes in ID. Conversely, ID does not Granger-cause X1, as the chi-square value (2.071) and p value (0.355) indicate that the null hypothesis cannot be rejected. Similarly, X2 Granger-causes ID, but there is no reverse causality from ID to X2. In contrast, there is a significant bidirectional Granger causality between ID and X3. The chi-square value for X3 Granger-causes ID is 8.8194 (p value = 0.012), and for ID Granger-causes X3, the chi-square value is 29.295 (p value = 0.000). This finding indicates that both variables can predict each other. X4 has a bidirectional relationship with ID. The test shows that X4 Granger-causes ID, with a chi-square value of 7.967 and a p value of 0.019, indicating a predictive relationship from X4 to ID. Similarly, ID Granger causes X4, as reflected by a chi-square value of 8.428 and a p value of 0.015, confirming the presence of bidirectional causality between ID and X4.

Table 5 presents the results of the cointegration equation, which outlines the long-term relationship between the dependent variable ID and the explanatory variables X1, X3, and X4, all lagged by one period.

Table 5. Results of the cointegration equation.

Cointegrating equation	Coefficient			
ID(-1)	1	1	1	1
X1(-1)	0.995 [0.000] (0.144)			
X2(-1)		2.093 [0.000] (0.037)		
X3(-1)			0.024 [0.000] (0.005)	
X4(-1)				0.4686 [0.000] (0.067)
const	3.253	-9.161	-0.186	-9.382

Note: Standard errors in () and P values in [ ].

Source: Developed by the authors.

X1 has a coefficient of 0.9949919, with a p value of 0.000 and a standard error of 0.144, suggesting that an increase in X1 leads to greater innovation development. Similarly, X2 shows a strong positive relationship with a coefficient of 2.093, with a p value of 0.000, implying that greater school enrollment in tertiary education increases innovation development. X3 also has a positive effect on ID, with a coefficient of 0.024, a p value of 0.000, and a standard error of 0.005. Finally, X4 has a positive long-term relationship with ID, with a coefficient of 0.468 and a p value of 0.000.

The VECM estimates are presented in Table 6. It demonstrates the short-term dynamics and the speed of adjustment toward long-term equilibrium among the variables. The significant error correction terms indicate that innovation development tends to revert to its long-term equilibrium when deviations occur, showing that the innovation system is stable and adjusts over time to changes in key economic variables. This suggests that any shocks or disruptions in innovation are temporary and that the system self-corrects, reinforcing the resilience of innovation efforts in Ukraine.

Table 6. VECM (1) Estimates.

Error correction	ID			
COINT	-2.782 [0.000] (0.438)	-6.38 [0.004] (2.212)	-2.946 [0.000] (0.562)	-1.109 [0.213] (0.8907)
ΔID	1.272 [0.000] (0.359)	2.155 [0.064] (1.164)	1.123 [0.004] (0.394)	-0.0694 [0.910] (0.6145)
ΔX1	4.250 [0.000] (0.969)			
ΔX2		4.521 [0.070] (2.499)		
ΔX3			0.069 [0.077] (0.039)	
ΔX4				0.463 [0.070] (0.25)
C	-0.0004 [0.990] (0.030)	0.0003 [0.995] (0.049)	0.184 [0.000] (0.039)	-0.019 [0.790] (-0.019)
R-squared	0.9594	0.868	0.945	0.718
AIC	-6.020	-7.063	-0.081	-1.003
HQIC	-6.879	-7.923	-0.941	-1.862
SBIC	-6.089	-7.133	-0.151	-1.072
Log likelihood	30.070	33.722	9.286	12.510

Note: Standard errors in () and P value in [ ], where Δ is the first difference.
Source: Developed by the authors.

The coefficient for the short-term impact of X1 on ID is 4.250, with a p value of 0.000, indicating a strong and significant positive short-term effect. The highly significant positive impact of X1 (the percentage of STEM graduates) on innovation development underscores the critical role of human capital in fostering innovation. A larger pool of STEM-educated individuals contributes to a more skilled workforce capable of driving technological advancements and innovation. This suggests that policies aimed at increasing STEM education can have a strong, direct effect on enhancing innovation capacity in Ukraine. The coefficient for X2 is 4.52, with a p value of 0.070, indicating a marginally significant positive short-term effect on ID. The short-term effect of X3 is 0.069, with a p value of 0.077, which suggests a weakly significant positive relationship between the first difference of X3 and ID. The coefficient for X4 is 0.463, with a p value of 0.070, indicating a marginally significant positive impact of the first difference of X4 on ID in the short run. The positive, though weaker, impact of X2 (school enrolment in tertiary education), X3 (total researchers), and X4 (intellectual property payments) highlights several important economic implications. An increase in X2 reflects the expanding base of educated individuals who will contribute to the country's innovation capacity in the long term. Higher education plays a key role in equipping students with the skills and knowledge necessary for participating in innovation-driven sectors, laying the groundwork for a more innovative and competitive economy. Thus, even a modest short-term effect of X2 is significant because it reflects investments in human capital, which are crucial for sustained innovation. Similarly, X3 (total researchers) represents the country's research and development capacity. While the short-term effect of X3 is only marginally significant, its role in generating new knowledge and fostering technological advancements is vital. Researchers are at the heart of innovation, driving scientific discoveries and technological innovations that fuel economic growth. Over time, an increase in the number of researchers enhances a country's ability to produce breakthrough innovations, contributing to sustained improvements in productivity and competitiveness. Finally, X4 (intellectual property payments) reflects the country's ability to engage with global markets and protect its innovations. A positive impact of X4 suggests that the country is increasingly involved in the commercialization of its innovations, as well as the acquisition and licensing of intellectual property from abroad. This integration into the global innovation system not only helps protect domestic innovations but also facilitates knowledge transfer and collaboration, which are essential for building a robust innovation ecosystem. By ensuring that intellectual property is properly managed and commercialized, the country can support the development of new products, services, and technologies, further strengthening its innovation capacity and economic growth trajectory.

Figure 1 shows the dynamic relationships between innovation development and the explanatory variables.

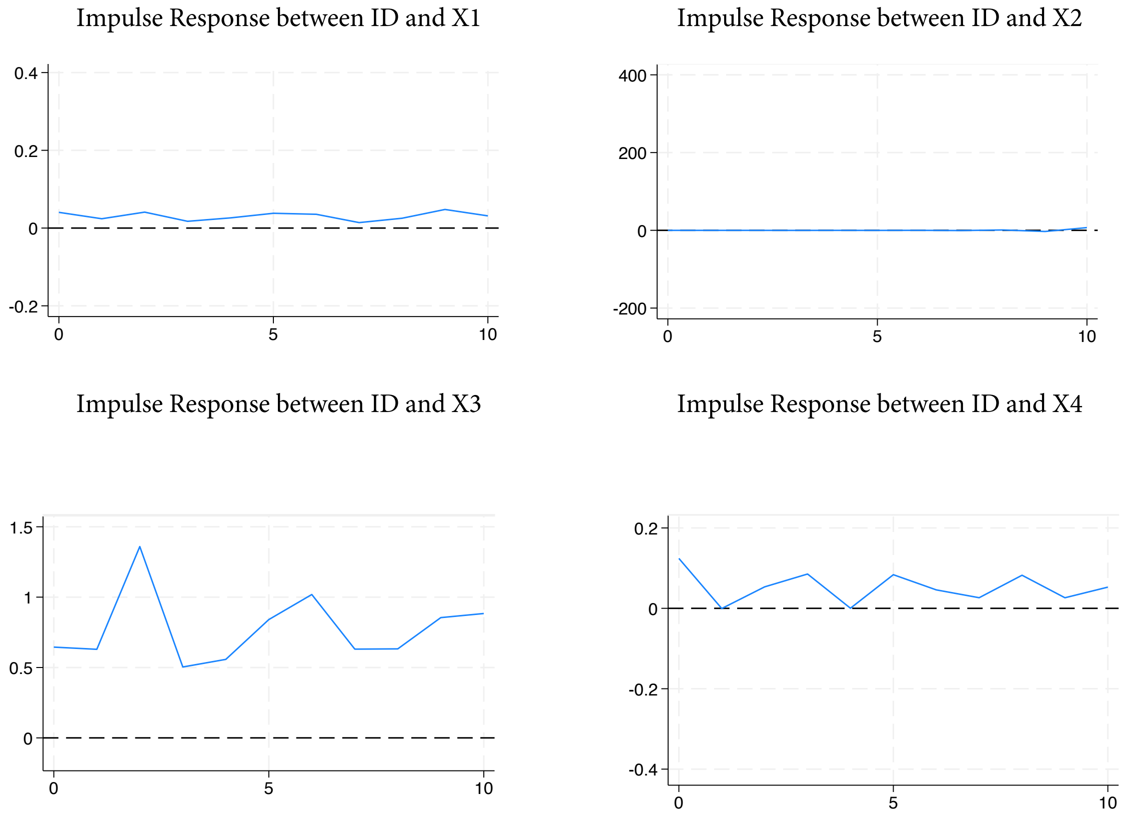

Figure 1. The impulse response graphs between the ID and the variables X1, X2, X3, and X4.
Source: Developed by the authors.

The upper-left graph shows the impulse response function (IRF) of a shock in X1 on ID. This finding indicates that a positive shock to X1 causes an initial increase in ID, suggesting that an increase in the number of STEM graduates leads to greater innovation development. This positive effect diminishes over time but does not entirely die out, indicating a sustained impact on innovation development from improvements in STEM education. The upper-right graph displays the IRF of a shock in X2 on ID. A positive shock to X2 results in a gradual increase in ID, highlighting that higher tertiary school enrollment contributes positively to innovation development. The effect starts strong but begins to diminish after a few periods, eventually stabilizing, although it does not completely die out, indicating a long-term contribution of higher education to innovation. The bottom-left graph illustrates the IRF of a shock in X3 on ID. A positive shock to X3 leads to an immediate increase in ID, suggesting that an increase in the number of researchers enhances innovation development. The effect peaks shortly after the shock and gradually fades over time, showing that research capacity has a significant, albeit diminishing, effect on innovation. The bottom-right graph shows the IRF of a shock in X4 on ID. A positive shock to X4 results in a delayed but sustained increase in ID, implying that increased intellectual property engagement boosts innovation development over time. The effect tapers off slowly but remains positive, reflecting the long-lasting impact of intellectual property on innovation.

4. Discussion

The findings of this study highlight the significant contributions of HEIs to innovation development in Ukraine, with a focus on both short-term and long-term impacts. These results are consistent with those of previous studies that emphasized the pivotal role of higher education institutions (HEIs) in fostering human capital and technological advancement. For example, the strong positive effect of STEM graduates and tertiary enrolment aligns with findings by Li & Liu (2021), who showed that higher education inputs directly enhance technological innovation and economic growth. Similarly, this study's evidence of higher education's impact on long-term equilibrium relationships corroborates Kruss et al. (2015), who emphasized that HEIs build technological capabilities that drive sustainable innovation ecosystems. The short-term impacts observed in this study, such as the influence of research capacity and intellectual property payments on innovation, are supported by prior research emphasizing HEIs' immediate contributions to technological adoption and applied research. Thus, Dementyev et al. (2021) reported that HEIs advance research and technology to address current economic and political challenges, fostering short-term decision-making capabilities. Similarly, Infante-Moro et al. (2022) highlighted the role of higher education in facilitating digital transformation through operational efficiency, which parallels this study's findings on intellectual property engagement.

This study also identifies challenges related to the short-term effects of tertiary education enrolment and research capacity, which are statistically significant but less impactful than STEM education is. Grupp & Mogee (2004) criticized traditional metrics of GII for underestimating the contributions of human capital development. Furthermore, the results align with those of Zhou and Luo (2018), who demonstrated that investment in higher education yields substantial long-term benefits, even if short-term gains appear modest. Comparative analysis with studies from other regions reveals additional insights. For example, Kyrylov et al. (2020) emphasized HEIs' role in preparing professionals for globalized industries, similar to this study's findings on the role of HEIs in fostering innovation capacity through international collaboration and intellectual property integration. Similarly, Payonk et al. (2015) highlighted the importance of HEIs in adapting business practices to globalization, aligning with the study's focus on long-term innovation capacity.

While this study validates the transformative potential of higher education, it also underscores the importance of targeted policies to increase its impact. Previous studies by Macerinskiene & Vaiksnoraite (2006) advocate aligning educational outputs with industry demands to maximize innovation outcomes. This study's findings strengthen the argument for prioritizing STEM education, supporting research initiatives, and leveraging intellectual property frameworks to address immediate and future innovation challenges.

This study contributes to the understanding of the dual role of HEIs in fostering innovation by bridging short-term applied research and long-term human capital development. The results reinforce the theoretical frameworks proposed by earlier studies while offering evidence-based recommendations for policymakers to increase higher education’s role in sustainable economic growth and technological progress.

Conclusions

The VECM results highlight that changes in STEM graduates have both immediate and lasting effects on innovation development. The coefficient for X1 is 0.994, with a p value of 0.000, which indicates a strong positive long-term relationship between STEM graduates and innovation development. Thus, a 1% increase in the number of STEM graduates is associated with an approximately 0.99% increase in innovation development. Policymakers can use this elasticity to set realistic targets. For example, if the goal is to increase innovation by 20%, efforts should focus on increasing the STEM graduate rate by a similar magnitude, considering the near one-to-one relationship. The VECM estimates show the short-term effect of changes in the number of STEM graduates on innovation development, with a coefficient of 4.250 and a p value of 0.000. This finding indicates that in the short run, changes in the number of STEM graduates have a substantial immediate effect on innovation. A 1% increase in the number of STEM graduates results in a 4.25% increase in innovation in the short term. Short-term policy measures, such as scholarships, curriculum updates, and incentives for STEM enrolment, could produce immediate boosts in innovation capacity. The sustained impact seen in the IRF suggests that investments in STEM education yield long-lasting benefits.

The coefficient for X2 is 2.093, with a p value of 0.000, indicating a strong positive long-term relationship between tertiary education enrolment and innovation development. This suggests that a 1% increase in tertiary enrolment is associated with an approximately 2.09% increase in innovation development. Policymakers can use this elasticity to set realistic targets. For example, if the goal is to increase innovation by 10%, efforts should focus on increasing the tertiary school enrollment rate by a proportional amount, considering the greater-than-proportional relationship. The VECM estimates also show the short-term effect of changes in tertiary enrolment on innovation development, with a coefficient of 4.521 and a p value of 0.070. This finding indicates that in the short run, changes in tertiary enrolment have a substantial immediate effect on innovation. A 1% increase in tertiary enrolment results in a 4.52% increase in innovation in the short term. Short-term policy measures, such as expanding access to tertiary education, reducing barriers to enrolment, and improving the quality of higher education, could produce immediate increases in innovation capacity. The sustained impact seen in the IRF suggests that investments in expanding tertiary education enrollment yield long-lasting benefits.

The analysis reveals that an increase in the number of researchers in Ukraine's higher education sector (X3) is crucial for innovation development. The long-term coefficient of 0.024 (p value = 0.000) implies that while the direct impact may seem modest, each 1% increase in research personnel is associated with a 0.024% increase in innovation. This suggests that building research capacity is an essential, albeit gradual, process for boosting innovation. In the short term, the coefficient of 0.069 (p value = 0.077) suggests that an increase in researchers has an immediate, albeit weaker, positive effect on innovation development.

The influence of intellectual property engagement (X4) on innovation in Ukraine is evident from the long-term coefficient of 0.468 (p value = 0.000). This strong relationship indicates that a 1% increase in intellectual property payments corresponds to a nearly 0.47% increase in innovation development. These findings underscore the importance of intellectual property as a driver of innovation, suggesting that policies should encourage both the use and commercialization of intellectual property assets. In the short term, the coefficient of 0.463 (p value = 0.070) highlights a meaningful and almost immediate positive impact of intellectual property payments on innovation.

On the basis of the major findings of this study, several policy recommendations are proposed to align with Ukraine's strategic goals of building a more innovation-driven economy:

1. To support the country's "National Economic Strategy until 2030," policymakers should target a 20–30% increase in STEM graduation rates. This increase is critical for driving innovation development, as evidenced by the positive impact of STEM education on innovation. To achieve this target, investments in scholarships, grants, and other incentives for STEM education in Ukrainian universities and technical institutions are essential. Moreover, collaboration with educational institutions to enhance STEM curricula and facilities will further strengthen Ukraine's transition to a knowledge-based, technologically advanced

economy. The experiences of countries such as Estonia and Poland demonstrate the importance of STEM-focused reforms. Estonia, for example, achieved significant progress in its innovation ecosystem by prioritizing STEM education in its university system, resulting in a pool of skilled professionals capable of driving technological advancements. Similarly, Poland's efforts to expand STEM programs through government-funded initiatives have led to a marked increase in the number of graduates entering high-tech industries. Additionally, integrating practical experience with industry partnerships, as seen in successful programs in South Korea, can provide students with the skills necessary to meet market demands.

2. In line with the strategy for higher education in Ukraine from 2021--2031, a focus on improving access to quality higher education is paramount. Policymakers should aim for a 25–30% increase in tertiary enrolment over the next decade. This strategy not only builds a solid foundation for a knowledge-based economy but also helps develop a skilled workforce that drives innovation. To achieve this goal, strengthening the capacity of Ukrainian universities, enhancing the quality of education, and aligning educational programs with labor market demands are necessary steps. Germany's dual education system provides a relevant model, offering academic knowledge alongside practical, workplace-focused training. Furthermore, Poland's educational reforms over the past decade have successfully increased tertiary enrolment through measures such as expanding student financial aid programmes and enhancing the quality of university infrastructure. By implementing reforms to improve the quality of university programs and aligning education with labor market needs, Lithuania significantly increased its number of tertiary-educated professionals. Similarly, Latvia implemented programs to make higher education more accessible and affordable, which in turn improved its innovation ecosystem.
3. The study's results highlight the importance of research ecosystems within universities. In alignment with the Global Innovation Vision of Ukraine 2030, Ukraine should aim for a 15–20% increase in the research workforce in higher education by 2030. This target can be achieved through enhanced funding for research grants, support for early-career researchers, and initiatives fostering industry–academia partnerships. Investing in research facilities and encouraging the hiring of researchers will strengthen short-term innovation capacity and lay a solid foundation for long-term growth. The government of Estonia invested heavily in building research infrastructure within universities and offered funding opportunities for early-career researchers. These initiatives not only increased Estonia's research output but also fostered stronger industry-academia collaboration, a key driver of technological innovation. Likewise, Czechia has strengthened its research sector through strategic investment in R&D and encouraging partnerships between universities and the private sector.
4. The National Intellectual Property Development Strategy emphasizes the importance of intellectual property rights and the commercialization of innovations. To leverage this effect, policymakers should target a 20–25% increase in intellectual property payments by 2030. Achieving this goal requires establishing a robust intellectual property infrastructure, including legal frameworks and support systems for innovators. Immediate actions include simplifying patenting procedures, providing support to universities and research institutions for intellectual property management, and creating incentives for businesses to protect and commercialize their innovations. Countries such as Poland and Hungary have taken steps to strengthen their intellectual property frameworks to promote innovation. For example, Poland simplified its patenting process and established support systems for universities and research institutions to manage intellectual property effectively. Hungary implemented policies to incentivize businesses to protect and commercialize their innovations, creating an environment conducive to technology transfer and the commercialization of research.

The use of the vector error correction model (VECM) enables the identification of long-term relationships and short-term dynamics between higher education indicators and innovation. However, it does not establish definitive causal relationships. Other unobserved variables or external shocks (e.g., economic crises, policy changes) could also influence innovation development, making it challenging to attribute changes in innovation solely to changes in higher education. The study uses time series data from 2014--2022. This relatively short period might limit the ability to capture longer-term trends and structural changes in Ukraine's innovation ecosystem. The study period also coincides with significant political and economic events in Ukraine, which could have affected the higher education sector and innovation development, potentially confounding the results. Further research could involve in-depth comparative analyses between Ukraine and other countries with similar transitional economies (e.g., Georgia, Moldova, Romania). This comparison helps identify best practices and lessons learned that are most relevant to Ukraine's context. Analysing the success factors and challenges of different innovation strategies across countries can guide more targeted policy development.

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