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Gender-Inclusive Human Capital and Innovation Performance in Kazakhstan

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Abstract

Technological modernization of the economy depends not only on the volume of investments in research and development, but also on the quality of human capital and the degree of its gender-inclusive use. The purpose of the study is to assess the relationship between gender-inclusive human capital and innovation performance in Kazakhstan. The information base consists of annual data for Kazakhstan for 2015-2024, obtained from the materials of the World Bank, the World Intellectual Property Organization, the Bureau of National Statistics of Kazakhstan, the United Nations and the World Economic Forum. Methods of descriptive statistics, correlation and multiple regression analysis, as well as a panel model with fixed effects are applied. The results of the national regression showed a positive and statistically significant relationship between the Gender Human Capital Index and the Global Innovation Index. The explanatory power of the model was $R2 = 0.986$, adjusted $R2 = 0.980$. The coefficients of the total Human Capital Index and research and development expenditures did not reach statistical significance at the level of 5%. The results of the regional model also confirmed a positive relationship between gender-inclusive human capital and patent activity: the coefficient of the regional index was 2.34 at $p = 0.009$, and the coefficient of the gross regional product per capita was 0.67 at $p = 0.035$. The results show that a more complete inclusion of women's human capital in education, employment, entrepreneurship, and technology industries is associated with an increase in Kazakhstan's innovation performance.

Keywords: Human Capital, Gender, Gender Equality, Gender Inclusion, Technological Modernization, Innovation, Innovation Efficiency

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1. INTRODUCTION

In modern conditions, technological modernisation is one of the key directions of long-term economic development, productivity growth and diversification of national economies. For Kazakhstan, this issue is especially important due to the long-term dependence on the resource sector, regional heterogeneity, sectoral imbalances and the need to move toward an innovation-based development model. Technological modernisation should therefore be understood not only as the renewal of equipment, digital infrastructure or R&D financing, but also as the formation of new competencies, the development of human capital and the inclusive involvement of the population in high-performance economic activities.

Global experience shows that technological renewal cannot be achieved only through capital investment and technology imports. Even when financial resources and state programs are available, innovation development remains limited if the economy lacks qualified, adaptive and effectively used human capital. The classical theory of human capital emphasises that investment in education, health, professional skills and experience increases productivity and supports economic growth (Becker, 1993; Schultz, 1961; Mincer, 1974). In theories of endogenous growth, human capital is also considered a source of technological change, knowledge diffusion and positive externalities (Lucas, 1988; Romer, 1990).

However, in the context of modernisation, not only the total volume of human capital matters, but also the quality of its distribution and the degree of women's and men's involvement in new sectors of the economy. Gender equality, therefore, acquires direct economic significance. International evidence also emphasises that gender equality contributes to inclusive growth, better use of human capital and broader economic opportunities (OECD, 2017). Gender gaps in education, employment, wages, entrepreneurship and career advancement reduce the efficiency of human capital use, limit the supply of qualified personnel and weaken the innovation ecosystem. Previous studies show that gender inequality in education, labour force participation and entrepreneurship leads to macroeconomic losses because the economy does not fully use available talent and competencies (Duflo, 2003; Cuberes & Teignier, 2016).

For Kazakhstan, the relationship between human capital, gender equality and technological modernisation is of particular importance. The country has achieved progress in education, digitalisation, and the development of innovative institutions. However, women’s high educational potential does not always translate into equal access to high-paid, technologically complex and career-promising jobs. This creates a contradiction between the accumulated level of human capital and the actual degree of its use in modernisation processes.

This contradiction is visible in the innovation sphere. Kazakhstan declares a transition to a knowledge-based economy, the development of digital competencies, and the strengthening of science, technology, and innovation. At the same time, international indicators show a gap between innovation inputs and innovation outputs. The country has advantages in institutions, infrastructure and human capital, but still lags in business sophistication, knowledge commercialisation, technological results and innovation efficiency (World Intellectual Property Organisation, 2025). One possible reason is the insufficient use of gender-inclusive human capital.

Despite women’s active participation in education, their representation in STEM fields, IT, engineering, innovative entrepreneurship and technology management remains limited. The gender pay gap, occupational segregation, unequal distribution of family responsibilities and restricted career advancement reduce women’s participation in technological modernisation. In the context of digitalisation and artificial intelligence, these barriers may become even more significant, since access to digital skills, STEM education and technological entrepreneurship determines future labour market opportunities.

In the scientific literature, human capital, gender equality and innovation development in Kazakhstan are often studied separately. Human capital research usually focuses on education, health and qualifications; gender studies examine employment, wages and entrepreneurship; innovation studies analyse R&D, institutions, infrastructure and digitalisation. However, an integrated empirical approach that assesses how gender-inclusive human capital affects innovation efficiency and technological modernisation remain insufficiently developed.

The purpose of the study is to assess the relationship between gender-inclusive human capital and innovation performance in Kazakhstan. To achieve this goal, the article develops a gender human capital index that includes indicators of economic participation, wage equality, women's entrepreneurship, educational achievement and women's labour market position. Based on time series data for 2015–2024, the study assesses the relationship between this index and innovation efficiency, as measured by the Global Innovation Index. Multiple regression analysis, the Granger causality test, the Johansen cointegration test and the VEC model are used to identify the strength, direction and long-term nature of this relationship.

Thus, the article assumes that technological modernisation in Kazakhstan should be viewed in terms of the quality and inclusiveness of human capital. In this context, gender equality is not a secondary social outcome but one of the key conditions for increasing the efficiency of innovation.

2. LITERATURE REVIEW

Gender economics shows that the distribution of economic resources within households may depend on the gender of the person who controls them. Evidence from South Africa demonstrates that women's pension income had a stronger positive effect on granddaughters' nutritional status, highlighting the importance of women's control over household resources (Duflo, 2003). Cuberes and Teignier quantified the macroeconomic losses caused by gender gaps in labour force participation and entrepreneurship (Cuberes & Teignier, 2016). Duflo also showed that women's empowerment in education, employment and decision-making produces broader social effects, including improvements in household development and children's outcomes (Duflo, 2012).

In post-socialist and transition economies, the gender dimension of human capital has specific features. A high level of formal education among women, inherited from the Soviet system, has not always been accompanied by equal access to high-paying sectors, economic power, and managerial positions. Brainerd showed that gender wage gaps widened in many Eastern European and former Soviet countries during market transformation despite high levels of female education and employment (Brainerd, 2000). Ashwin also emphasised the persistence of institutional and cultural norms that reproduce gender segregation even under formal equality of rights (Ashwin, 2000).

For Kazakhstan, this problem is reflected in the contradiction between women's high educational potential and the limited realisation of this potential in the labour market. National studies show that gender inequality is manifested not so much in formal access to education as in occupational structure, wages, career advancement, entrepreneurship, and representation in technology-intensive sectors. Nyussupova et al. (2023) identify persistent gender differences in the Kazakhstan labour market in the context of sustainable development, while Sarsembayeva (2005) emphasises institutional barriers affecting women's position in society and the economy. A comparative analysis of the global labour market and Kazakhstan also reveals persistent gender differences in employment opportunities, occupational distribution and access to economically advantageous positions, despite the relatively high level of women's participation in the labour force (Alpysbayev et al., 2024).

Recent empirical studies also confirm the importance of the gender pay gap as an indicator of unequal use of human capital. Kireyeva and Satybaldin showed that women in Kazakhstan earn less than men, especially in resource-intensive regions and sectors (Kireyeva & Satybaldin, 2019). Abdulla and Serikbayeva, using labour force survey microdata and the Oaxaca–Blinder decomposition, found that a significant part of the gender wage gap cannot be explained by observable worker characteristics, suggesting discriminatory mechanisms in the labour market (Abdulla & Serikbayeva, 2024). Bekbossinova and Zips also showed that the share of female researchers has a statistically significant effect on reducing the gender wage gap (Bekbossinova & Zips, 2024).

Women's entrepreneurship is another important form of human capital realisation. Kenzheali, analysing structural shifts in Kazakhstan's entrepreneurial ecosystem in 2019–2024, found that after 2022, the share of women managers of small and medium-sized businesses increased, and the gender entrepreneurship index moved from negative to positive values (Kenzheali, 2025). However, it remains important to determine whether women's entrepreneurship is concentrated in innovative and technological sectors or remains mainly in traditional forms of small business.

The role of education and universities in regional innovation is also significant. Olzhebayeva, Abdykadyr, and Rakhimberdinova, using panel data for Kazakhstan's regions for 2000–2023, found that gross regional product and the number of graduate students positively influence innovation activity, whereas the number of university graduates and education expenditures do not have a statistically significant effect (Olzhebayeva et al., 2025). This finding is important because it shows that formal educational indicators are not automatically transformed into innovation results. For modernisation, not only does education itself matter, but so does the inclusion of graduates in research, entrepreneurship, and innovation activities. Nelson and Phelps (1966) argued that human capital contributes to economic growth not only by directly increasing worker productivity, but also by improving the ability of individuals and organisations to understand, adopt and disseminate new technologies. From this perspective, the effectiveness of education depends on whether accumulated knowledge is incorporated into technological diffusion and innovation processes.

The concept of innovation systems complements human capital theory by adding an institutional dimension. Freeman and Lundvall considered innovation to be the result of interaction among the state, business, universities, research organisations, financial institutions, and the labour market (Freeman, 1987; Lundvall, 1992). In this approach, innovation efficiency depends not only on R&D expenditure but also on the quality of links among actors, knowledge diffusion, the commercialisation of research, and the demand for new technologies. The endogenous growth model developed by Aghion and Howitt (1992) further explains technological development as a process of creative destruction, in which new innovations replace outdated technologies and production methods. This process increases productivity but also requires a continuous renewal of knowledge and skills, because workers, researchers and entrepreneurs must adapt to changing technological conditions.

Initially, innovation system studies paid limited attention to gender issues. However, recent research increasingly emphasises that the diversity of human capital, including gender diversity, improves the quality of innovation processes. Diverse research and management teams can expand the range of ideas, better reflect social and market needs, increase creativity, and strengthen organisations' ability to solve complex problems. Therefore, gender equality becomes not only an issue of labour market access, but also an important characteristic of the innovation ecosystem. In the context of creative destruction and technological diffusion, unequal access to education, scientific careers, entrepreneurship and managerial positions may slow the adoption of new technologies by excluding part of the available talent pool from innovation activity (Aghion & Howitt, 1992; Nelson & Phelps, 1966).

For Kazakhstan, the gender dimension of technological modernisation is especially important because women have significant educational potential but face barriers to transitioning into technology sectors. This can be described as "pipeline leakage," in which women are present at the early stages of education but gradually disappear during the transition to STEM employment, scientific careers, innovative entrepreneurship, and leadership. As a result, the economy formally possesses human capital but does not fully use it for technological renewal. The labour market evidence presented by Alpysbayev et al. (2024) supports this conclusion by demonstrating that women's relatively strong educational attainment and labour force participation do not necessarily ensure equal access to higher-paid occupations, leadership positions, and sectors with greater technological intensity.

Thus, the literature shows that human capital, gender equality and innovation efficiency are closely connected, although existing studies often examine them separately. Human capital theory explains the role of education and skills in growth; gender economics reveals the economic losses from unequal access to opportunities; and innovation system theory shows the importance of institutions, universities, business and research infrastructure. The theories of technological diffusion and creative destruction additionally demonstrate that the

economic return on human capital depends on its capacity to support the adoption, creation and replacement of technologies (Nelson & Phelps, 1966; Aghion & Howitt, 1992). However, an integrated empirical approach that assesses how gender-inclusive human capital affects innovation efficiency in a transition economy remains insufficiently developed.

This study fills this gap by developing a gender human capital index and linking it with indicators of technological modernisation in Kazakhstan. Unlike approaches focused solely on education, employment, or innovation spending, this article considers the gender distribution of human capital as an independent factor in innovation efficiency. This makes it possible to show that Kazakhstan's technological modernisation depends not only on R&D investment and digital infrastructure but also on the extent to which women's human capital is included in scientific, entrepreneurial and technological sectors.

3. METHODOLOGY

The empirical part of the study aims to assess the relationship between gender-inclusive human capital and the innovation efficiency of Kazakhstan's economy. Kazakhstan was selected as the object of analysis because it combines a relatively high level of accumulated human capital, a developed education system, growing digital infrastructure, and strategic priorities for technological modernisation with persistent gender differences in wages, employment structure, entrepreneurship, and women's participation in STEM fields.

The information base consists of annual time series for Kazakhstan for 2015–2024. This period covers important changes in digitalisation, innovation policy, human capital development, labour market transformation, post-crisis adaptation and the effects of the COVID-19 pandemic. The main data sources are the World Bank Human Capital Index, the Global Innovation Index reports of the World Intellectual Property Organization, data from the Bureau of National Statistics of Kazakhstan, United Nations analytical materials, World Economic Forum reports and Ranking.kz data on women's participation in technology sectors (World Bank, 2023; World Intellectual Property Organization, 2025;

Bureau of National Statistics of Kazakhstan, 2024; United Nations, 2024; World Economic Forum, 2024; Ranking.kz, 2025).

The dependent variable is the Global Innovation Index (GII), which serves as a composite indicator of innovation efficiency and technological modernisation. It reflects the country's ability to transform innovation resources into outcomes in knowledge production, technological outputs, creative activity, institutional quality, infrastructure, human capital, and business sophistication.

The key independent variable is the author's Gender Human Capital Index (GHC). It was developed because traditional human capital indicators typically reflect education, health, and expected productivity, but do not adequately capture the gender distribution of opportunities. The GHC index includes five components: women's economic participation, wage equality, women's entrepreneurship, women's tertiary education and the inverse value of the female NEET rate. The index is calculated using formula (1):

$$GHC_t = 0{,}30ECO_t + 0{,}25WAGE_t + 0{,}20ENT_t + 0{,}15EDU_t + 0{,}10NEET_t \quad (1)$$

where:

GHCt – the gender Human Capital Index per year (t);

ECOt – the indicator of women's economic participation and opportunities;

WAGEt – the indicator of wage equality calculated as the inverse of the gender pay gap.;

ENTt – the share of women in entrepreneurship;

EDUt – the indicator of women's tertiary education;

NEETt – the inverse of the proportion of women who are not involved in employment, education, or vocational training.

The wage equality indicator is calculated as the inverse of the gender pay gap. The general formula is (2):

$$\mathrm{WAGE_t} = 1 - \frac{\mathrm{GPG_t}}{100} \quad (2)$$

where:

WAGEt – indicator of wage equality in the year t;

GPGt – the gender pay gap as a percentage.

The gender pay gap is calculated as the relative difference between the average salary of men and women. This indicator is used in the study as an indicator of structural inequality in the labour market and is determined by the formula (3):

$$GPG_t \left(\frac{\left(W_t^m - W_t^f\right)}{W_t^m}\right) \times 100 \quad (3)$$

where:

GPG_t – the gender pay gap in the year t;

W_t^m – the average salary of men in the year t;

W_t^f – the average salary of women in the year t.

Along with the GHC index, the model includes the World Bank Human Capital Index (HCI), which reflects expected productivity based on education and health. Its inclusion enables comparison of the effects of aggregated and gender-inclusive human capital on innovation efficiency. Research and development expenditures as a percentage of GDP are also included to assess the role of traditional innovation financing. Additional control variables include high-tech exports, women's participation in STEM fields and the gender pay gap.

To test the main hypothesis, multiple regression analysis was used. The basic model is formula (4):

$$GII_t = \beta_0 + \beta_{1HCI_t} + \beta_{2GHC_t} + \beta_{3RD_t} + \varepsilon_t \quad (4)$$

where:

GII_t – the value of the Global Innovation Index in the year t;

HCI_t – the Human Capital Index;

GHC_t – the Gender Human Capital Index;

RD_t – the research and development expenditures as a percentage of GDP;

β_0 – the free member of the model;

$\beta_1, \beta_2, \beta_3$ – the estimated coefficients;

ε_t – accidental error.

Special attention is paid to the GHC coefficient, since its significance indicates the role of gender-inclusive human capital in technological modernisation.

The Granger causality test was applied to assess the direction of the relationship between gender human capital and innovation efficiency. The test determines whether past values of GHC help explain future values of GII beyond the information contained in past values of GII itself. Reverse causality was also tested by using GHC as the dependent variable.

Since the variables may exhibit long-term relationships, the Johansen cointegration test was used to identify a stable equilibrium relationship among GII, GHC, and HCI. The long-term relationship was estimated using a logarithmic model (5):

$$\ln(GII_t) = \alpha_0 + \alpha_{1\ln}(GHC_t) + \alpha_{2\ln}(HCI_t) + u_t \quad (5)$$

where:

α_1 and α_2 – long-term elasticity coefficients.

If cointegration is detected, a vector error correction model (VECM) is estimated to combine short-term dynamics with the mechanism of return to long-term equilibrium (6):

$$\Delta \ln(GII_t) = \lambda ECT_{t-1} + \Sigma_{i=1}^{k-1} \gamma_{i\Delta\ln}(GII_{t-i}) + \Sigma_{i=1}^{k-1} \delta_{i\Delta\ln}(GHC_{t-i}) + \Sigma_{i=1}^{k-1} \theta_{i\Delta\ln}(HCI_{t-i}) + \varepsilon_t \quad (6)$$

where:

Δ – the operator of the first difference;

λ – the coefficient of the rate of correction of deviations from long-term equilibrium;

ECT_{t-1} – the lagged term of the correction error;

$\gamma_i, \delta_i, \theta_i$ – the short-term coefficients;

k – the number of lags;

ε_t – accidental error.

The error correction term is calculated as in formula (7):

$$ECT_{t-1} = \ln(GII_{t-1}) - \alpha_0 - \alpha_{1\ln}(GHC_{t-1}) - \alpha_{2\ln}(HCI_{t-1}) \quad (7)$$

A negative and statistically significant λ indicates that deviations from long-term equilibrium are corrected over time.

To verify the robustness of the results, a regional panel analysis was also conducted. The panel includes 17 regions of Kazakhstan for 2019–2023, forming 85 observations. Regional innovation activity, measured by the number of patent applications per 10,000 employees, is used as the dependent variable.

The key independent variable is the regional GHC index, which includes women's participation in IT employment, the gender wage gap and the share of female executives. The model also includes the regional HCI, R&D expenditures, GRP per capita and urbanisation.

The fixed-effects panel model is specified as formula (8):

$$Innovation_{it} = \mu_i + \beta_{1GHC_{it}} + \beta_{2HCI_{it}} + \beta_{3RD_{it}} + \beta_{4ln(GRPpc_{it})} + \beta_{5URB_{it}} + \varepsilon_{it} \quad (8)$$

where:

$Innovation_{it}$ – the innovation activity of region I in year t;
GHC_{it} – the Regional Gender Human Capital Index;
HCI_{it} – the Regional Human Capital Index;
RD_{it} – the regional expenditure on research and development;
$\ln(GRPpc_{it})$ – the natural logarithm of the gross regional product per capita;
URB_{it} – the level of urbanization of the region;
μ_i – the regional fixed effects;
e_{it} – accidental error.

The analysis was carried out in several stages. First, descriptive statistics were calculated for the main variables. Second, the GHC index was constructed and validated by comparing it with gender equality, employment, and innovation indicators. Third, correlation analysis was conducted. Fourth, multiple regression was used to estimate the contribution of HCI, GHC and R&D to innovation efficiency. Fifth, the Granger test, the Johansen test, and the VECM were applied to assess the direction, long-term equilibrium, and adjustment speed. Sixth, regional panel analysis was used to test the robustness of the results at the subnational level.

The study has several limitations. The national time series includes only ten annual observations, which limits the degrees of freedom and requires careful interpretation. The GHC index is based on theoretically defined weights because the limited data does not permit factor analysis or other more complex weighting methods. In addition, observational data does not fully rule out potential endogeneity between human capital and innovation efficiency. Nevertheless, the use of complementary methods - regression, Granger causality, cointegration analysis, VECM and panel estimates - increases the reliability of the conclusions.

Thus, the methodology is designed to test the hypothesis that gender-inclusive human capital is a significant factor in Kazakhstan's technological modernisation. The combination of national time series and regional panel data allows the relationship to be analysed in both temporal and spatial dimensions.

4. ANALYSIS AND RESULTS

The empirical analysis revealed both positive dynamics and internal contradictions in the relationship between human capital, gender equality and technological modernisation in Kazakhstan. In 2015–2024, innovation efficiency, general human capital and several gender indicators improved. However, persistent wage differences, occupational segregation, declining representation of women in STEM, and limited participation in technological entrepreneurship show that accumulated human capital is not fully utilised in modernisation processes.

During the study period, the GII increased from 36.2 to 44.5 points, while the HCI rose from 0.63 to 0.82. The GHC index also increased from 0.580 to 0.661, but at a slower pace. This shows that Kazakhstan has accumulated human capital, but the gender-inclusive use of it remains insufficient. The gender pay gap decreased from 34% in 2015 to 21% in 2021, but then increased to 24.5% in 2024, indicating unstable progress. In addition, women's representation in STEM declined from 31.7% in 2019 to 26.0% in 2024, which shows that the expansion of technology sectors does not automatically ensure gender balance.

Descriptive statistics confirm the heterogeneous dynamics of the indicators studied. The Global Innovation Index averaged 40.80 points, the Human Capital Index averaged 0.756, while the Gender Human Capital Index averaged 0.626. The lower GHC value relative to HCI indicates that total human capital is developing faster than its gender-inclusive component. The results are presented in Table 1.

Table 1. Descriptive statistics of key variables for 2015-2024

Variable	Average	St. dev.	Min.	Max.
GII index	40,80	2,86	36,20	44,50
HCI Index	0,756	0,065	0,630	0,820
GHC Index	0,626	0,029	0,580	0,661
R&D, % OF GDP	0,138	0,013	0,120	0,160
High-tech exports, billion US dollars	3,35	1,01	2,10	5,18
Percentage of women in STEM, %	29,45	1,82	26,00	31,70
Gender pay gap, %	27,57	4,21	21,00	34,00
Women in IT, thousand people	73,96	3,92	68,00	80,00
Female Business Owners, %	29,55	2,17	25,00	32,00

Note: compiled by the authors

Correlation analysis confirmed a close relationship between innovation efficiency and gender-inclusive human capital. The strongest positive correlation was found between GII and GHC, with a coefficient of 0.989. High-tech exports also showed a strong positive relationship with GII, whereas the general HCI showed a weaker positive relationship. The gender pay gap had a strong negative correlation with innovation efficiency, meaning that wage inequality reduces the effective use of human capital in modernisation.

To further illustrate the gender dimension of Kazakhstan's technological modernisation, Figure 1 presents the dynamics of women's participation in STEM, the gender pay gap, women's employment in IT, and women's business ownership during 2015–2024. These indicators show that progress in women's involvement in IT and entrepreneurship has not been fully matched by equal representation in STEM fields or a sustained reduction in wage inequality. Figure 1 shows the contradictory nature of gender changes.

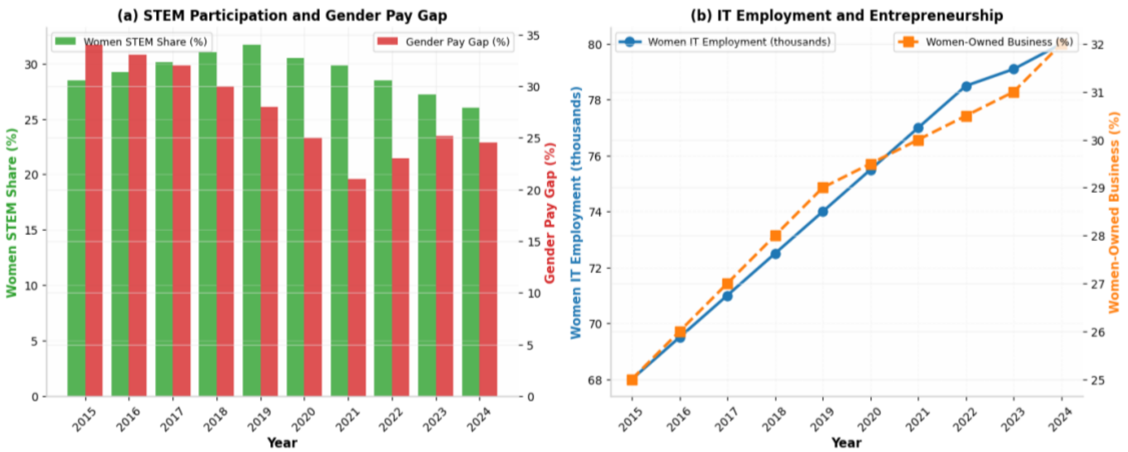

Figure 1. Gender dimensions of technological modernisation of Kazakhstan's economy for 2015-2024

Women's employment in IT and the share of female business owners increased, but the gender pay gap remained significant, and women's participation in STEM decreased after 2019. This confirms that technological development requires targeted gender-sensitive measures.

The dynamics of GII, HCI and GHC can be divided into three phases. In 2015–2017, innovation efficiency and human capital improved rapidly. In 2018–2021, all indices continued to grow, but GHC lagged behind HCI. In 2022–2024, the gap between innovation efficiency and gender indicators widened: GII continued to grow, while GHC became less stable. This indicates that modernisation can proceed faster than the institutional mechanisms of gender inclusion.

To clarify the broader relationship between innovation performance and human capital, Figure 2 presents the dynamics of the Global Innovation Index, the Human Capital Index, and the Gender Human Capital Index for 2015–2024.

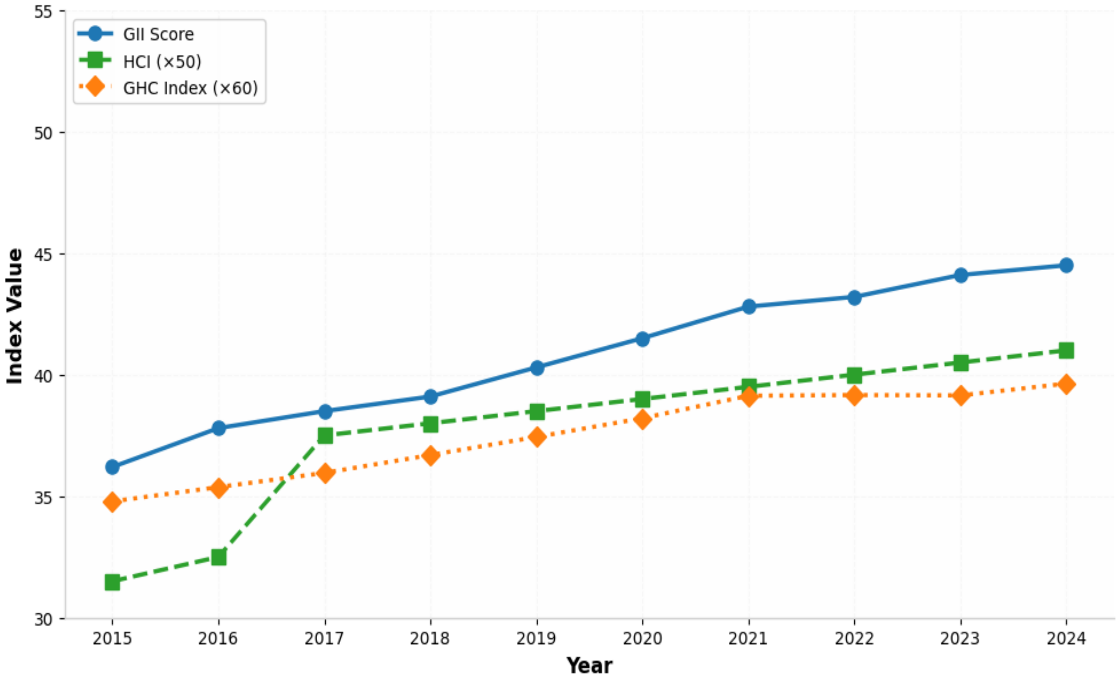

Figure 2. Dynamics of innovation and human capital indices in Kazakhstan for 2015-2024

Figure 2 confirms that Kazakhstan improved both innovation efficiency and human capital indicators. However, the less stable dynamics of GHC show a gap between the accumulation of human capital and its gender-inclusive use.

Multiple regression results confirm the study's key hypothesis. The model with GII as the dependent variable has high explanatory power: $R^2 = 0.986$ and adjusted $R^2 = 0.980$. The F-statistics are 144.653, indicating that the model is significant. The most important result is the high and statistically significant coefficient of the GHC index. Its value is 84.555, with $p = 0.001$, meaning that gender-inclusive human capital is strongly associated with innovation efficiency. The HCI coefficient is positive but not statistically significant, suggesting that aggregated human capital indicators may mask internal gender inequalities.

Table 2 presents the regression results, with the Global Innovation Index as the dependent variable.

Table 2. Results of multiple regression: determinants of innovation efficiency

Variable	Coefficient	St. error	t-statistics	p-value	Significance
The constant	-13.400	8.512	-1.575	0.167	-
HCI Index	6.302	6.258	1.007	0.350	-
GHC Index	84.555	13.091	6.459	0.001	***
R&D, % OF GDP	-25.261	12.702	-1.988	0.094	*
Model characteristics: R2 = 0.986; adjusted R2 = 0.980; F-statistics = 144.653; number of observations = 10. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$					

R&D expenditures have a negative and marginally significant coefficient, reflecting the gap between innovation inputs and outputs in Kazakhstan. This means that R&D spending alone does not guarantee innovation efficiency without effective commercialisation, institutional links and inclusive human capital. Figure 3 visualises this relationship by showing how changes in gender-inclusive human capital are associated with the Global Innovation Index during 2015–2024.

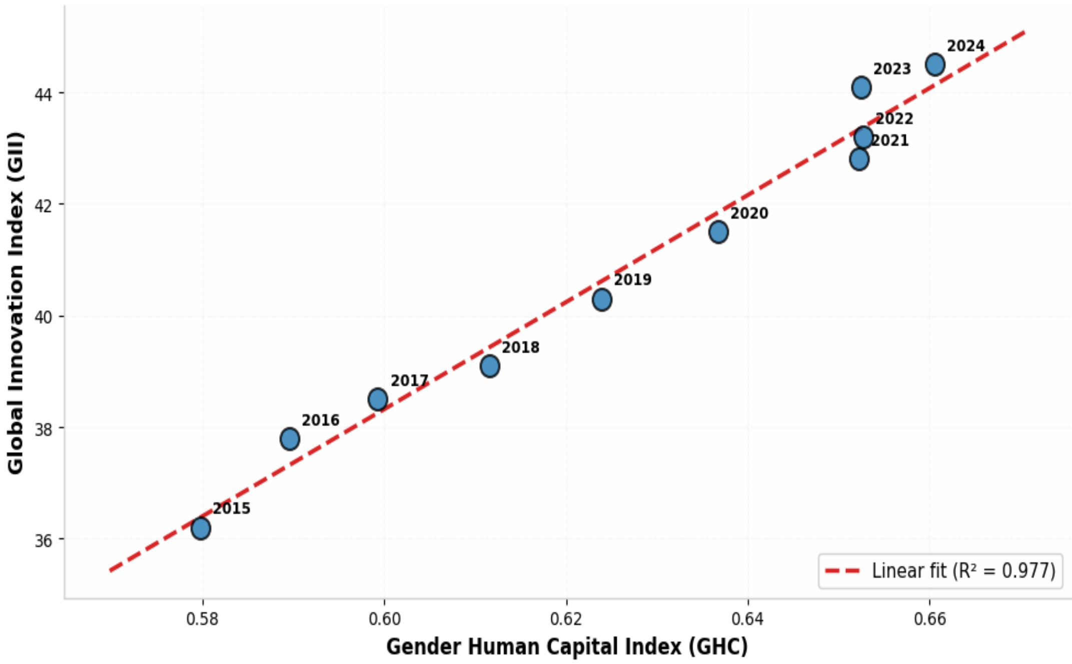

Figure 3. Relationship between the Gender Human Capital Index and the Global Innovation Index in Kazakhstan for 2015-2024

Figure 3 demonstrates a strong positive relationship between GHC and GII. The observations are located along an upward regression line, confirming that improved gender-inclusive use of human capital is associated with higher innovation efficiency.

The Granger causality test was used to determine the direction of the relationship between GHC and GII. The results show unidirectional causality from GHC to GII. This means that past values of gender human capital help predict future innovation efficiency. The reverse effect from GII to GHC is not confirmed. Therefore, technological modernisation does not automatically improve gender inclusiveness; rather, gender-inclusive human capital precedes and supports innovation.

Table 3 presents the results of this test and shows the direction of the relationship between the Gender Human Capital Index and the Global Innovation Index.

Table 3. Results of the Granger Causality Test

The null hypothesis	F-statistics	p-value	Decision
GHC is Not a Granger Reason for GII	8,73	0,042	The hypothesis is rejected
GII is Not a Granger Reason for GHC	1,15	0,412	The hypothesis is not rejected
HCI is not a Granger Reason for GII	2,34	0,198	The hypothesis is not rejected
GII is not a Granger Reason for HCI	0,87	0,523	The hypothesis is not rejected

Note: compiled by the authors

Therefore, technological modernisation does not automatically improve gender inclusiveness; rather, gender-inclusive human capital precedes and supports innovation.

The Johansen cointegration test confirmed a long-term equilibrium relationship between GII, GHC and HCI. Table 4 presents the results of this test and shows whether the variables form a long-term equilibrium relationship, which is important for understanding the sustainable effect of gender-inclusive human capital on technological modernisation in Kazakhstan.

Table 4. Results of the Johansen cointegration Test

Null hypothesis	Eigenvalue	Trace statistic	5% critical value	Decision
(r=0)	0.847	18.42	29.80	Not rejected
(r\leq1)	0.312	4.18	15.49	Not rejected
(r\leq2)	0.089	0.67	3.84	Not rejected
* (r) denotes the cointegration rank. The VAR system includes (\ln(GII)), (\ln(GHC)), and (\ln(HCI)). The test was estimated using two lags and a specification with a constant but without a deterministic trend. Critical values may differ depending on the specification of deterministic components.				

Note: compiled by the authors

The long-term equation is:

$$\ln(GII_t) = 1{,}24\ln(GHC_t) + 0{,}31\ln(HCI_t) - 0{,}08$$

This equation shows that a 1% increase in GHC is associated with a 1.24% increase in innovation efficiency, while the elasticity of HCI is only 0.31%. Thus, gender-inclusive human capital has a stronger long-term effect on innovation efficiency than aggregated human capital.

The VEC model confirms the mechanism of return to long-term equilibrium. Table 5 presents the VEC model results and shows whether changes in innovation efficiency return to the long-term path determined by gender-inclusive human capital and total human capital.

Table 5. Results of the VEC model

The equation	Correction rate α	t-statistics	p-value	Significance
Δln(GII)	-0,34	-2,87	0,031	**
Δln(GHC)	0,12	1,45	0,198	-
Δln(HCI)	0,08	0,92	0,401	-

Note: compiled by the authors

The correction coefficient in the GII equation is negative and statistically significant: -0.34. This means that about 34% of deviations from long-term equilibrium are corrected within one year. In the short term, changes in GHC also positively affect GII, whereas HCI and R&D do not show significant effects. This confirms that gender-inclusive human capital is a more sensitive indicator of innovation dynamics than aggregated human capital or R&D spending.

To test the robustness of the results, a fixed-effects panel regression was conducted for 17 regions of Kazakhstan for 2019–2023. The dependent variable was regional innovation activity measured by patent applications per 10,000 employees. Table 6 presents the results of this robustness check, where regional innovation activity is explained by the regional Gender Human Capital Index, human capital, R&D expenditures, GRP per capita, and urbanisation.

Table 6. Results of panel regression with fixed effects for 2019-2023

Variable	Ratio	St. Error	t-statistics	p-value	Significance
GHC Regional Index	2.34	0.87	2.69	0.009	***
Regional HCI	0.45	0.52	0.87	0.389	-
Regional R&D, % of GDP	-0.18	0.23	-0.78	0.438	-
GRP per capita, ln	0.67	0.31	2.16	0.035	**
Urbanization, %	0.12	0.08	1.50	0.140	-

Note: compiled by the authors

The panel's results confirm the national-level findings. The regional GHC index has a positive and statistically significant effect on innovation activity. Its coefficient is 2.34 ($p = 0.009$), indicating that regions with higher gender inclusiveness in human capital exhibit higher patent activity. Regional HCI and R&D expenditures are not statistically significant, while GRP per capita has a positive effect. This shows that gender inclusiveness is an independent factor of regional innovation activity, not only a reflection of regional wealth.

Overall, the econometric results show that gender-inclusive human capital has strong explanatory, predictive and long-term significance for Kazakhstan's innovation efficiency. The GHC index is significant in regression analysis, predicts GII in the Granger test, forms a long-term cointegration relationship with innovation efficiency and remains significant in regional panel analysis.

The structural interpretation of these results shows that gender-inclusive human capital affects technological modernisation through several channels: reduction of the gender pay gap, women's participation in STEM and IT employment, women's entrepreneurship and access to leadership positions. The gender pays gap remains one of the main constraints. Its decline from 34% in 2015 to 21% in 2021 was not stable, as it increased again to 24.5% in 2024. This indicates that modernisation does not automatically reduce inequality without institutional mechanisms for pay transparency, career advancement and support for women in high-income sectors.

Women's participation in STEM is another key factor. Although technological education and digital employment are expanding, women's share in STEM declined from 31.7% in 2019 to 26.0% in 2024. This reflects the phenomenon of "quantity without representation": the absolute number of women in technological fields may grow, but their relative share decreases as male participation grows faster. Such dynamics can weaken the long-term inclusiveness of technological modernisation.

Women's employment in IT increased from 68,000 to 80,000, but these opportunities remain geographically concentrated mainly in Almaty and Astana. This creates a double barrier: gender inequality in access to technological careers and regional inequality in access to digital infrastructure, education and innovation networks. Women's entrepreneurship also expanded, with the share of female business owners increasing from 25% to 32%, but access to capital, markets, digital tools and innovation programs remains uneven.

Thus, the results show that the gap between innovation inputs and innovation outputs in Kazakhstan has not only financial or institutional causes, but also a gender dimension. If a significant part of the highly educated female population is excluded from technological, research, entrepreneurial, and managerial processes, the innovation system cannot fully leverage the available human capital. Therefore, gender equality should be considered not as an external social addition to innovation policy, but as an internal condition for its effectiveness.

5. DISCUSSION

The discussion of the results allows us to formulate three key conclusions. First, gender-inclusive human capital is a significant factor in the technological modernisation of Kazakhstan's economy. This is confirmed by regression analysis, the Granger causality test, cointegration analysis, the VEC model and regional panel assessment. The consistency of the results across several methods shows that the Gender Human Capital Index is not a random correlate, but an important indicator of innovation efficiency.

Second, total human capital alone does not guarantee innovation outcomes. Kazakhstan has considerable educational potential, including among women, but its transformation into technological modernisation depends on the quality of institutional inclusion. If women remain concentrated in lower-paid and less technologically advanced sectors, their share in STEM declines, and entrepreneurial and career opportunities are unevenly distributed, then the overall level of education does not automatically translate into innovation efficiency.

Third, technological modernisation can unfold in either an inclusive or a non-inclusive scenario. In an inclusive scenario, digitalisation, IT, artificial intelligence, engineering and innovative entrepreneurship create new opportunities for both women and men, expanding the human resource base of modernisation. In a non-inclusive scenario, new technological opportunities are concentrated among already privileged groups, sectors and regions, reinforcing gender and territorial inequalities. The decline in women's share in STEM and the persistence of the wage gap show that Kazakhstan needs a targeted, inclusive model of technological modernisation.

The practical implications of the study underscore the need to rethink human capital and innovation policy. Gender indicators should be integrated into the monitoring system of technological modernisation. Innovation policy assessment should include not only startups, R&D expenditures, digital services and patents, but also women's participation in STEM, IT employment, research projects, innovative entrepreneurship, leadership positions and high-paying sectors.

Targeted programs are also needed to support women in STEM and digital professions. Such support should begin before employment, at the stages of school career guidance, additional education, university choice and professional mentoring. Female role models in science, engineering, IT and technology business are especially important for reducing professional stereotypes and expanding girls' career expectations.

Another priority is the development of transparent remuneration and promotion mechanisms. The gender pay gap cannot be eliminated by economic growth alone. Regular analysis of wages by gender, sector, region, and position is needed, along with corporate practices for equal pay for work of equal value, internal salary audits, and transparent career advancement systems.

Innovation policy should also consider regional differences. Support for women in technology sectors should not be limited to Almaty and Astana. Regions need digital learning programs, remote employment opportunities, support for technological entrepreneurship, regional STEM centres, and cooperation among colleges, universities, and businesses. This can reduce both gender and territorial barriers to modernisation.

Women's entrepreneurship should be linked not only to traditional small businesses but also to innovative sectors. Support for women entrepreneurs in digital services, educational technologies, creative industries, green technologies, agrotechnology, fintech and the platform economy can become an important channel for expanding innovation activity. This requires access to financing, acceleration programs, mentoring, markets and digital tools.

Thus, the results show that technological modernisation in Kazakhstan requires a shift from a narrow technological approach to a comprehensive model that treats human capital and gender equality as interrelated drivers of innovation. Human capital provides the basis for modernisation, while gender equality ensures that this basis is used to its full potential. Therefore, technological development policy should be educational, innovative, labour-oriented, regional and gender-sensitive at the same time.

6. CONCLUSION

The study substantiates that human capital and gender equality are interrelated drivers of technological modernisation in Kazakhstan. Unlike approaches that explain modernisation primarily through R&D investment, digital infrastructure, and institutional reforms, this article shows that the quality and inclusiveness of the use of human capital are also crucial. Technological renewal depends not only on the availability of qualified personnel but also on the equal inclusion of women and men in education, employment, entrepreneurship, STEM fields, and innovation processes.

The Gender Human Capital Index developed in the study enabled empirical assessment of the role of gender-inclusive development in Kazakhstan's innovation efficiency. Multiple regression results showed that GHC is the most significant predictor of the Global Innovation Index, while the general Human Capital Index and R&D expenditure did not demonstrate comparable statistical significance. This means that human capital growth alone does not guarantee technological results if women's educational and professional potential is not fully included in high-performance and innovative sectors.

The Granger test confirmed a unidirectional causal relationship from gender human capital to innovation efficiency. The Johansen cointegration test and the VEC model revealed a long-term equilibrium relationship among GHC, total human capital, and innovation efficiency. Regional panel analysis also showed that regions with higher levels of gender-inclusive human capital exhibit higher levels of innovation activity.

At the same time, the study revealed structural barriers that limit the full realisation of women's human capital in Kazakhstan's modernisation. These include the gender pay gap, the decline in women's participation in STEM, occupational segregation, limited involvement in technological entrepreneurship, and the concentration of innovation opportunities in large cities. Therefore, women's high educational potential does not automatically transform into innovative activity.

The practical significance of the study lies in the need to include gender indicators in technological policy assessment. Alongside R&D spending, patents, digitalisation, and infrastructure, it is necessary to monitor women's participation in STEM, IT employment, research projects, entrepreneurship, and leadership positions. Priority measures should include support for women in digital and engineering professions, the reduction of the gender pay gap, the development of women's technological entrepreneurship, and regional programs that expand access to innovation opportunities.

Thus, Kazakhstan's technological modernisation requires not only financial and infrastructural resources but also the inclusive use of human capital. Gender equality is not a secondary social result, but an independent factor of innovation efficiency. Sustainable technological development is possible only when women and men are fully and equally involved in creating, disseminating and applying new knowledge, competencies and technologies.

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