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Gender Equality and Its Role in Determining How Economic Complexity Affects Human Development in Selected Countries

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Abstract

Today, the economic complexity index, which measures the knowledge used in production, is a more appropriate standard than economic growth for measuring human development. In addition, gender equality helps produce higher knowledge by creating equal opportunities for women and men. Therefore, this research aims to examine the developmental effects of gender equality and its role in determining how economic complexity affects the human development index. In this way, first, the convergent countries are classified in technology among 80 countries with the club convergence approach. Next, the model's analysis of how gender equality affects human development in model (1) using the method of moment quantile regression (MMQREG) is investigated. Furthermore, model (2) analyzes the consequences of economic complexity on human development through the lens of gender equality. The results of the model estimation indicated that increasing economic complexity increases human development in all the quantiles. In addition, the gender equality channel strengthens the developmental effects of the knowledge-based economy in all the quantiles. Some things about the novelty of this research are worthy of consideration: First, this study defines the new channel (gender equality) of economic complexity's effects on human development. Second, the use of country convergence criteria to select a panel of countries. Thirdly, using the new panel method of moment quantile regression (MMQREG) helps to provide strong and reliable results. The policy implications of this study are the role of knowledge creation and the promotion of gender equality in the well-being of societies.

Keywords Complex structures · Equal gender opportunities · Knowledge · Human development

Extended author information available on the last page of the article

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Introduction

While economic progress is essential for human development, nations should endeavor to promote the level of living for their citizens. Human development considers three dimensions: the income, education, and health of communities. Nowadays, human development is improving, even in poor nations, and people now live longer, have greater educations, and have easier access to a wider range of products and services than they did in the past. Nonetheless, there are still a lot of issues with the standard level of human growth (Damanik et al., 2023). So, achieving high-quality living and sustainable development requires an understanding of human development and its determinants.

Human development focuses on enhancing an individual's capability in life (Kara, 2022). The human development index measures a country's social and economic performance over time and helps assess the impact of economic policies on the well-being of society (Damanik et al., 2023). In order to improve human growth, a number of elements must be taken into account, including the economic and social elements. Although education and health are among the most crucial elements stimulating development (Awoyemi et al., 2024), however, today, other factors such as knowledge and technology are significant for the development of human capital and subsequently the development of societies (Dao & Khuc, 2023). Technology facilitates the achievement of higher human development (Gao et al., 2024; Kouladoum, 2024). Applying knowledge can improve people's capacity to attain greater well-being (Caous & Huarng, 2021). Economic complexity is a measure that indicates the productive capabilities of a society (Nguyen et al., 2023). The economic complexity shows the differences in production structures (Adebayo et al., 2022). The complex nations are those that manufacture products using more sophisticated technology (Shahzad et al., 2022). Countries improve societal well-being by providing financial incentives for innovation and knowledge (Le-Caous & Huarng, 2021). Therefore, we can conclude that technology and knowledge improve human development.

Technology, knowledge, and human capital can lead to the development of production capacity and subsequently increase productivity. A more complex society can be more innovative (Awoyemi et al., 2024). Achieving higher human development requires more complex and innovative economies (Hartmann et al., 2017). The increase in complex and knowledge-based products enhances human development (Nguea & Noumba, 2024). Since high-tech production requires high knowledge and human capital, ECI affects human welfare capacities in various ways (Hartmann, 2014; Hartmann et al., 2017). Additionally, businesses must adapt to new technologies to gain a competitive advantage (Saviotti & Pyka, 2013). However, economic complexity is not the only component affecting human development.

Today, gender equality is essential for human development (Asongu & Odhiambo, 2023; Kanat et al., 2023). The gender gap shows the most significant gap among low-income countries (Sarkar & Lakshmana, 2022). Gender inequality, in the sense of differences in wages and financial resources and women's limited

access to education and job opportunities, has significant developmental and economic consequences (Mbatha, 2024). Gender equality in the economy, in addition to the full realization of human capacities, causes economic growth and development (Mbatha, 2024). Gender equality increases HDI through improved levels of education, income, and household well-being (Arthur-Jolasinmi, 2024). Several nations, for optimal use of human resourcess, attempted to decrease their discrimination. Because women's active participation in society leads to better health, education, and growth, gender inequality is even decreasing in underdeveloped nations(Gelard & Abdi, 2016). Reducing the gender gap through equal educational opportunities, promoting women's entrepreneurship, and implementing policies to guarantee equal rights will leave significant developmental effects in society that will stimulate innovation and achieve sustainable growth (Mbatha, 2024).

As mentioned above, the development of technology, knowledge, and innovation is essential for improving the well-being of societies. Therefore, economic complexity, which is a measure of knowledge-based production structures, can be an important factor affecting human development. In addition, gender equality can increase knowledge and innovation in society by creating equal economic, educational, and social opportunities for women and men. Increasing the economic and educational capabilities of women in society increases household income and well-being. Therefore, gender equality, in addition to its direct effects, may also strengthen the development consequences of technology and knowledge on improving the well-being of society. So, in addition to examining the direct impact of gender equality and technology on human development, this research also analyzes the role of technology in human development through gender equality. Some studies have focused on the role of economic growth on HDI (Awoyemi et al., 2024; Miar et al., 2024). Anyway, economic growth is not the sole driver of HDI, so some studies have examined other factors affecting human development (Hidayat & Bariyah, 2020; Nakyah et al., 2024). Many of these studies have failed to answer the question of how ECI affects the well-being of societies through the gender equality channel (Le Caous & Huarng, 2021; Lee & Vu, 2020). In addition, no study so far has investigated the developmental consequences of economic complexity via the channel of gender equality. So, this study is innovative in several ways to fill the void of previous studies: First, sample selection. In this study, a panel of 50 convergent economies is selected in technology with the club convergence model. Given the rapid rise of technology, examining a group of countries converging on technology offers important policy implications and strategic outcomes. Second, apart from investigating the immediate impact of economic complexity on human advancement with model (1), the developmental effects of strengthening gender equality on economic complexity are also analyzed with model (2). Third, this study uses a new panel approach. The new advanced panel approach MMQREG is very efficient in heterogeneous and outlier panel data and provides strong results in the face of data with non-normal and non-linear distribution (Qiu et al., 2024). Additionally, Dumitrescu and Hurlin's (D-H) panel causality tests and Driscoll-Kraay standard errors model help strengthen the results (Fig. 1). The scatter diagram shows the economic complexity index in 50 converging economies.

Figure 1 shows trend of the economic complexity index of the studied countries during 1990–2021. Economic complexity (ECI) is a comprehensive measure of

knowledge utilization, measured by the ECI, which ranges from − 3 (worst performance) to 3 (best performance). In Fig. 1, we can observe that the highest value of ECI is related to Japan (2.858) and the lowest value is related to Kuwait (− 2.695). Furthermore, it is observed that in 2021, the highest value of ECI is related to Japan and the lowest value is related to Cameroon.

The structure of this study is as follows: Presented in the following section is the literature review. "Empirical Methodology and Data Description" describes the data and methods. The empirical results and discussion are displayed in the "Empirical Results and Discussion," and "Conclusion and Policy Implications" contains recommendations for policy and the conclusion.

Literature Review

Economic Complexity's Impact on Human Development

Only two elements—the labor force and physical capital—were highlighted as the primary determinants of a nation's economic growth in the early theories of

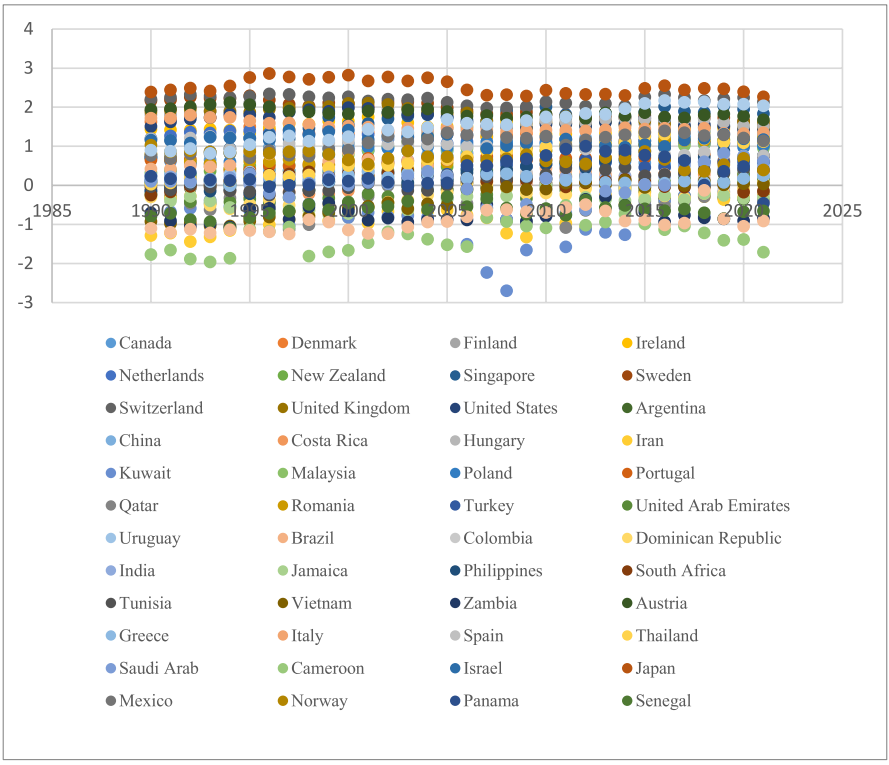

Fig. 1 Scatter diagram of the economic complexity index of the studied countries during 1990–2021. Source: authors' compilations

economic growth. Nonetheless, knowledge is presented as one of the fundamental elements influencing a nation's economic development in modern theories of economic growth (Romer, 2012). The economic complexity index (ECI), by measuring the amount of knowledge and innovation ideas in a country's economic structure, can be a suitable criterion for evaluating the knowledge of countries (Nguyen et al., 2023). A nation's productive structure is altered by economic development, which transforms its resources from simple to complex industries. The workforce becomes more capable due to human capital, resulting in the production of high-tech items (Hidalgo & Hausmann, 2009). Increasing human capital strengthens the effects of innovation on economic development (Gao et al., 2024). Consequently, since the production of products depends on preexisting knowledge, economic growth alone cannot adequately describe human development (Hartmann, 2014).

An endogenous growth model with capital accumulation can be used to illustrate the relationships between economic complexity and human development (Khan et al., 2024). Investing in educational infrastructure can increase welfare by increasing labor productivity (Kouladoum, 2024). Ferrarini and Scaramozzino (2016) argue that a more complex structure improves the quality of life by enhancing infrastructure such as education, health, social services, etc., all of which increase the welfare of the country's people. Increasing investment in technology infrastructures help increase the level of human development (Boumahdi & Zaoujal, 2024; Gariba & Prokop, 2024; Kouladoum, 2024). More options translate into greater capacities and a higher quality of life (Ali et al., 2024). Societies with high-tech production require more knowledge, innovation, and technology than countries with simple production (Nguea, 2024). Since more complex societies have more human capital and technology, economic complexity increases human development (Le Caous & Huarng, 2021). In addition, countries with a higher economic complexity index have better financial capabilities and infrastructure to deal with crises (Nguea & Noumba, 2024). Higher prosperity requires more sophisticated technologies because knowledge improves society's education, health, etc. (Hartmann, 2014). Increasing technology and knowledge accelerates the improvement of social issues in society (Nguea & Noumba, 2024). Countries that score higher on the economic complexity index produce more complex and diverse products. So, they can benefit from competitive advantages in international communities, which increases the income and welfare of the countries (Nguea, 2024). Awoyemi et al. (2024) concluded that the development of knowledge leads to economic development and the welfare of society because knowledge increases the productivity of the workforce. However, some studies have found that ECI does not improve HDI because technology is not a basic necessity for improving human development like access to food, healthcare, education, etc. (Lapatinas, 2016). The idea is that human development is not always correlated with people's freedom, choice, and technology (Schwartz, 2020). By contrast, the diversity of a country's products and behaviors may change over time which influences the direction of ECI's impact on human development (Le-Caous & Huarng, 2021). Few studies have focused on examining the impact of economic complexity on human development. Therefore, examining the developmental effects of economic complexity will provide important policy implications for increasing the welfare of societies.

Economic Complexity's Impact on Human Development via the New Channel of Gender Equality

Today, many countries still face the problem of gender inequality. Multiple factors influence discrimination against women (Arthur-Jolasinmi, 2024). The gender gap deprives women of equal economic, educational, and social opportunities with men (Sarkar & Lakshmana, 2022). Reducing the gender gap is a vital component of the well-being and sustainability of societies. Although the gender gap is declining in many countries, in some societies, women still face gender discrimination (Le-Caous & Huarng, 2021). So, creating equal opportunities for women and men in society is an important step towards achieving sustainable development (Awoyemi et al., 2024). Higher human development levels are associated with greater gender equality than lower human development levels (Stoet & Geary, 2019). Education plays an important role in reducing gender inequality (Khan et al., 2024). Educating women through the channel of socio-economic stability leads to sustainable human capital (Pasha, 2024). In societies where women have more of an impact on household income, household spending on high-tech goods is increasing.

Equal educational opportunities for women and men improve human development by increasing human capital (Kara, 2022). Equal social opportunities increase women's ability to make important decisions in the family and society (Pantelopoulos, 2024). Women's economic and political empowerment increase the well-being of society (Arthur-Jolasinmi, 2024). Innovation and knowledge are the prerequisites for successful entrepreneurship, and women's entrepreneurship contributes significantly to the social and economic development of societies (Kamberidou, 2020). Reducing the gender gap increases various dimensions of human development (including income, life expectancy, and literacy levels) (Yavorska et al., 2024). So, gender equality plays an important role in improving the human development index (Sarkar & Lakshmana, 2022). Gender equality increases the education of women and the education of the whole society (Mbatha, 2024). The development of education also contributes to the development of human capital through increasing productivity (Awoyemi et al., 2024). Therefore, reducing the gender gap can lead to the development of knowledge and technology, thereby strengthening economic complexity's effects on human development.

Research Gap

Despite the importance of ECI on human development (HDI), the developmental effects of economic complexity are still unknown, and few studies have analyzed it. Therefore, this paper investigates how economic complexity affects human development both directly and indirectly from the new channel of gender equality. To estimate the parameters, a new panel MMQREG approach has been used in this study. The new technique addresses the limitations of traditional quantitative regression approaches by effectively addressing concerns about heterogeneity, endogeneity, and sample selection bias. The mentioned approach provides strong and reliable results, especially for outlier and heterogeneous data, using an integrated framework characterized by flexibility, robustness,

and computational efficiency (Awan et al., 2022; Banday & Erdem, 2024). In addition, in this study, the approaches of the Driscoll-Kraay standard errors model are used to ensure the accuracy of the estimation. In addition, the outcomes of Dumitrescu and Horlin (D-H) causality tests are also presented to provide reliable results and policy suggestions. These approaches can help unify the analytical framework of study results and solve some statistical and econometric problems. Another different contribution of this study focuses on the fact that the studied panel is selected based on the club convergence approach in the economic complexity variable, which has been neglected in the previous literature. The policy implications of this study can provide policymakers with valuable insights into human development strategies. In addition, the emphasis on converging economies in the ECI index offers fresh perspectives on the difficulties and possibilities these economies confront in their search for poverty reduction, increased welfare, and community development solutions. Since human development is based on the principle of humanity and its freedoms, equal opportunities help to discover people's talents. In addition, reducing the gender gap increases the education of women and the education of the whole society (Mbatha, 2024). The development of education also contributes to the development of human capital through increasing productivity (Awoyemi et al., 2024). Therefore, reducing the gender gap can lead to the development of knowledge and technology, thereby strengthening the effects of economic complexity on human development.

Empirical Methodology and Data Description

This study aims to explore the variables influencing the human development index in 50 converging countries using annual data from 1990 to 2021. According to previous studies (Nakyah et al., 2024; Pham et al., 2024; Ryu & Nam, 2024), some potential factors affecting the human development index, including economic growth, energy consumption, unemployment rate, and gender equality, have been confirmed. In this study, human development is modeled as a function of economic complexity, energy consumption, unemployment rate, and gender equality. To eliminate possible heterogeneity phenomena, the econometric theory emphasizes that variables enter the model logarithmically (Sadiq et al., 2023). Therefore, it was logarithmized, and our model follows as in Eq. 1 below:

$$LHDI_{it} = L\alpha + \beta_1 LECI_{it} + \beta_2 LGI_{it} + \beta_3 LE_{it} + \beta_4 LU_{it} + \varepsilon_{it.} \quad (1)$$

In Eq. 1, *HDI* is the human development index, *ECI* is the economic complexity index, *GI* is the gender equality, *E* is the energy consumption, and *U* is the unemployment. In addition, given that the logarithm of the variables is considered, the coefficients therefore represent the elasticities (Khezri et al., 2022). It is assumed that increasing economic complexity helps to increase human development (Nguea & Noumba, 2024). It is also assumed that there is a positive relationship between gender equality in society and HDI. In addition, existing research assumes that the increase of gender equality through the creation of equal opportunities will increase the number of women with higher knowledge and education, which can help increase the ECI and

subsequently increase the HDI in society. To investigate economic complexity's effects on human development from the channel of gender equality, Eq. 2 is considered:

$$LHDI_{it} = L\alpha + \beta_1 LECI_{it} + \beta_2 (GI * LECI)_{it} + \beta_3 LE_{it} + \beta_4 LU_{IT} + \varepsilon_{it.} \quad (2)$$

The coefficients of the interaction term (GI*LECI) show the interaction between ECI and GI. To investigate economic complexity's marginal impact on human development, we have:

$$\frac{d(LHDI)}{d(LECI)} = \beta_1 + \beta_2 GI$$

In addition to examining economic complexity's effects on human development, this study helps to understand the new channel of economic complexity's effects on human development through gender equality.

The Model of Club Convergence for Panel Selection

In the research, Phillips and Sul's (2007) nonlinear time-varying factor convergence club model is applied. This approach looks at the historical convergence of nations (Payne & Apergis, 2020). About the Phillips and Sul (2007) method, specifically, the following time-varying shared element is used in Eq. 3:

$$X_{it} = \delta_{it} \mu_t \quad (3)$$

In Eq. 3, X is the shared element in nation i at time t, μ_t is the enduring element, and δ_{it} is the eccentric element. The difference between X_{it} and the common component μ_t is measured by the δ_{it} component measure. Due to over-parameterization, δ_{it} cannot be calculated directly from Eq. 3. Therefore, Phillips and Sul (2009) employ h_{it}, the relative transfer parameter, in the following way:

$$h_{it} = \frac{X_{it}}{\frac{1}{M}\sum_{i=1}^{M} X_{it}} = \frac{\delta_{it}}{\frac{1}{M}\sum_{i=1}^{M} \delta_{it}} \quad (4)$$

h_{it} in Eq. 4 takes into account the path of the relative transition based on the mean of the panel, and it is measured by δ_{it}. The country's relative transition path, h_{it} converges to 1 ($t \to \infty$). when δ_{it} converges to the constant δ. Thus, refer to Eq. 5:

$$H_t = \frac{1}{M}\sum_{i=1}^{M} (h_{it} - 1)^2 \to 0 \quad (5)$$

If the following conditions is satisfied, shape of H_t is finite (see Eq. 6):

$$\begin{cases} \delta_{it} \to \delta \\ t \to \infty \\ h_{it} \to 1 \\ H_t \to 0 \end{cases}$$

$$H_t \sim \frac{A}{L(t)^2 t^{2\rho}} \tag{6}$$

A is the positive element, $L(t)$ is a feature that gradually changes, and ρ is the speed of convergence; the convergence hypothesis tests are as Eq. 7:

$$H_0 : \delta_i = \delta \& \propto \geq 0 H_1 : \delta_i \neq \delta \& \propto < 0 \tag{7}$$

According to Phillips and Sul (2007), convergence can be tested using ln t regression, and convergence clubs can be found using the clustering algorithm as follows Eq. 8:

$$\ln\left(\frac{H_1}{H_2}\right) - 2\ln L(t) = \widehat{\alpha} + \widehat{b}\ln t + \varepsilon_t \tag{8}$$

If $t=rT$, $rT+1\ldots$, T, the range (0.2, 0.3) is set for $r>0$. The one-way test's null hypothesis for $\widehat{b} = 2a$, takes into account $\widehat{b} \geq 0$ versus $\widehat{b} < 0$. The t-test statistic is built utilizing a standard error that is compatible with heteroscedasticity and autocorrelation, and it asymptotically follows the standard normal distribution. The unimodal t-test predicated on t_b is referred to in Eq. 8 as the "ln t-test" by Phillips and Sul (2007).

Data

In this study, the developmental effects of gender equality and its role in determining how economic complexity affects the human development index are examined in a panel of 50 countries that converge in the ECI. The introduction of variables and their source are shown in Table 1.

Considering that some values of economic complexity are negative. A value of 3 has been added to all observations before transforming the variables into logarithms. Also, Table 2 displays the statistical properties of the research variables.

The Econometrics Methods

In this research, the new panel technique method moments quantile regression (MMQREQ) is used to estimate Eqs. 1 and 2. In addition, the Driscoll-Kraay

Table 1 Data sources and description of the variables

Abbreviation	Definitions	Sources
HDI	Index of human development	World Bank Data (WBD)
ECI	Index of economic complexity	Observatory of Economic Complexity (OEC)
GI	Gender equality index	World Bank Data (WBD)
E	Primary energy consumption (TWh)	World Bank Data (WBD)
U	Unemployment rate	World Bank Data (WBD)

Note: authors' compilations

Table 2 Characteristic statistics

Variables		Characteristic statistics				
	Observations	Median	Mean	Standard deviation	Minimum	Maximum
HDI	1600	0.7895	0.7647	0.1355	0.369	0.962
ECI	1600	0.5323	0.5776	0.9264	−2.6958	2.8588
GI	1600	3.4423	6.0577	7.5208	1.4064	76.9230
E	1600	443.5429	2053.426	5082.917	9.8235	43873.1
U	1600	5.93	7.3891	5.3144	0.1	33.559

Note: authors' compilations

standard error regression is also used for the robustness of the results. Regression DK reports coefficients that face strong and heterogeneous cross-sectional dependence (Driscoll & Kraay, 1998). The Hausman test results showed that the DK model with fixed effects is the most suitable method. The model DK only considers average of the dependent variable, and since the DK regression provides limited policy implications in countries with high and low development, therefore, to provide policy recommendations according to the degree of each nation's human development, in this study, the MMQREG approach created by Machado and Silva (2019) was used. This regression provides distributional and heterogeneous impacts in different positions of the human development index. In Eq. 9, the conditional quantile for the location-scale model is presented:

$$\mathbb{Q}_Y\left(\tau|X_{it}\right) = \alpha_i + \delta_i q_i(\tau) + X_{it}^{/}\gamma + Z_{it}^{/}\varphi q(\tau) \tag{9}$$

In Eq. 9, $X^{/}$ represents the vector of regressors and $\alpha_i + \delta_i q_i(\tau)$ expresses the parameters is permitted to be heterogeneous and to differ among the quantiles of Y, as measured by the scalar coefficient of the (τ) quantile. Equation 9 is able to be redefined according to Eq. 1, and Eq. 2 with Eq. 10, and Eq. 11, respectively:

$$\mathbb{Q}_{LHDI_{i,t}}\left[\tau|\alpha_i, \varepsilon_{it}, X_{i,t}\right] = \alpha_{it} + \gamma_{1a\tau}LECI_{i,t} + \gamma_{2a\tau}LGI_{i,t} + \gamma_{3a\tau}LE_{i,t} + \gamma_{4a\tau}LU_{i,t} + \varepsilon_{i,t} \tag{10}$$

$$\mathbb{Q}_{LHDI_{i,t}}\left[\tau|\alpha_i, \varepsilon_{it}, X_{i,t}\right] = \alpha_{it} + \gamma_{1a\tau}LECI_{i,t} + \gamma_{2a\tau}(GI * LECI)_{i,t} + \gamma_{3a\tau}LE_{i,t} + \gamma_{4a\tau}LU_{i,t} + \varepsilon_{i,t} \tag{11}$$

In the above equations, $\mathbb{Q}_{LHDI_{i,t}}\left[\tau|\alpha_i, \varepsilon_{it}, X_{i,t}\right]$ represents HDI conditional quantile that for the distributional effect at τ, has the scalar coefficient $(\alpha_i(\tau))$. For example, to investigate the variable impact of economic complexity on the HDI, τ is set between zero and one, which creates the effect of the independent variable at the chosen point in the dependent variable's conditional distribution. For example, if $\tau = 0.25$ is equivalent to the quantile 25th of the distribution of the dependent variable. The new MMQREG approach, which accounts for unexpected factors such as financial crises, natural disasters, and political conflicts, often leads to heterogeneity in economic data. Traditional estimation techniques

may yield invalid and misleading results under such conditions. In contrast, quantile regression serves as a robust approach for testing potential heterogeneity and asymmetry of explanatory variables at different positions within the conditional distribution of the explained variables (Kuziboev et al., 2024). This method not only provides reliable and efficient results but also reinforces the robustness of our findings. Furthermore, the results of the normality test in Table 4 provide a strong argument for using the aforementioned approach. The methodology strategy of this study is presented in Fig. 2.

Empirical Results and Discussion

Here, we include several subsections. First, the results of the club convergence model are applied to present the analysis of convergence between nations. Following the selection of convergent countries, pre-tests are examined, and while examining

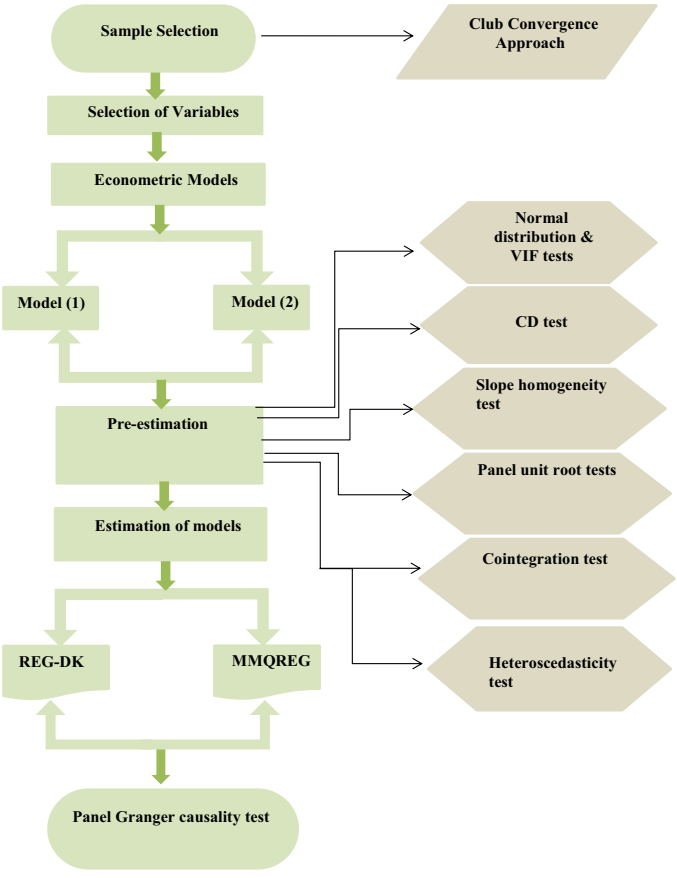

Fig. 2 Methodology strategy

the developmental effects of economic complexity, the role of gender equality on how complexity affects human development is analyzed by MMQREG regression. In addition, the results of the Driscoll-Kraay standard error regression are presented for the robustness check, and finally, the D-H causality test results are also looked at.

Results of Club Convergence

Here, using the club convergence method, the convergence of technology between 80 nations is checked. Table 3 displays the final outcomes of the convergence test.

The findings of Table 3 show that there is one non-convergent subgroup and four convergent subgroups. Each of the 4 subgroups converges. In this research, Club 1, which includes 50 countries, has been examined.

Pre-test Results

Here, before estimating the models first, the preliminary tests are checked.

Normal Distribution Test and VIF Test

Given that, the fundamental requirement for quantile regression estimation is that the data have a non-normal distribution. First, a normality test is run in this study. In this research, two tests are used: the Shapiro–Wilk and the Shapiro-France. The results are presented in Table 4.

Table 3 Final club classifications of club convergence (80 economics)

Club	Results	Countries	Coefficient	*t*-statistics
1	Convergent group	Argentina, Austria, Brazil, Cameroon, Canada, China, Colombia, Costa Rica, Denmark, Dominican Republic, Finland, Greece, Hungary, India, Iran, Ireland, Israel, Italy, Jamaica, Japan, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Norway, Panama, Philippines, Poland, Portugal, Qatar, Romania, Saudi Arab, Senegal, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Tanzania, Thailand, Tunisia, Turkey, United Arab Emirates, United Kingdom, United States, Uruguay, Vietnam, Zambia	− 0.048	− 0.982
2	Convergent group	Australia, Chile, Cote d'Ivoire, Egypt, Indonesia, Jordan	0.003	0.055
3	Convergent group	Albania, Algeria, Bangladesh, Ecuador, El Salvador, Ghana, Guatemala, Honduras, Kenya, Morocco, Pakistan, Paraguay, Peru, Sri Lanka	0.085	3.805
4	Convergent group	Bolivia, Cambodia, Mongolia, Nicaragua	0.583	2.778
5	Not convergent group	France, Germany, Guinea, Mozambique, Sudan, Zimbabwe	− 1.388	− 29.258***

Notes: the critical value at level 5% is − 1.651 in all cases. The null hypothesis is $b \geq 0$

Table 4 Test of normal distribution & VIF

Variables	Shapiro–Wilk test	Shapiro-France test	VIF
LHDI	0.87017 (0.00000)	0.87053 (0.00001)	-
LECI	0.94643 (0.00000)	0.94543 (0.00001)	**2.16**
LGI	0.92627 (0.00000)	0.92671 (0.00001)	**1.74**
LE	0.98761 (0.00000)	0.98819 (0.00001)	**1.34**
LU	0.95410 (0.00000)	0.95384 (0.00001)	**1.01**

Note: suthors' compilations

The findings of Table 4 indicate that all the variables of this study have a non-normal distribution, which is the concept of having a significant deviation from the symmetrical pattern. In addition, the result of the variance inflation factor (VIF) test is listed in Table 4. Since all of the variables' VIF values are less than 10 and the mean is 1.56, there is no multicollinearity issue.

Test of Cross-Sectional Dependence

Today, due to the development of globalization and expansion of trade, common global shocks, technological development, and cross-sectional dependence exist in panel data analysis (Yadav & Mahalik, 2024). CD shows the contagion effects of a shock from one country to another, and ignoring it leads to biased estimates (Pesaran, 2015). To check cross-sectional dependence (CST), we use the developed CD test (Pesaran, 2015). Table 5 presents the findings. The absence of CD is the null hypothesis.

Findings of Table 5 show that the null hypothesis was disproved. In the sense that there is a connection between these nations. This finding implies that the interdependence of these economies is what causes the spillover effect.

Table 5 Test of cross-sectional dependence

Variables	CD-test	*p*-value	Average joint *T*
LHDI	189.502	0.000	32.00
LECI	3.632	0.000	32.00
LGI	178.646	0.000	32.00
LE	78.122	0.000	32.00
LU	8.155	0.000	32.00

Note: authors, compilations

Test of Slope Homogeneity

When analyzing panel data, it is crucial to look into the slope homogeneity test to identify the unit root and suitable cointegration estimator (Saygin & Iskenderoglu, 2022). In this study, the test of Pesaran and Yamagata (2008) is accustomed to checking the homogeneity of the slope. In this test, the null hypothesis is homogeneous slopes, which means that all slope coefficients are the same throughout the cross-sectional units. The outcomes of this test are presented in Table 6.

Findings of Table 6 demonstrate that there is slope heterogeneity and reject the null hypothesis. The selected panel has different rates of development. The finding of the test of slope homogeneity helps to improve the results by determining the unit root tests and other appropriate methods despite dependency on cross sections and heterogeneity in slope.

Tests of Unit Root

Because of dependence on CS and to avoid biased estimates, to obtain the properties of the variables' stationarity, the unit root tests of second-generation (CIPS), created by Pesaran (2007), and the Pescadf test, evolved by Pesaran (2007), are used in this investigation. The aforementioned approaches provide accurate estimates despite cross-sectional correlation and heterogeneity, in contrast to the first-generation unit root tests (Saygin & Iskenderoglu, 2022). Table 7 displays the results of the CIPS and CADF tests.

Findings of Table 7 demonstrate that LHDI, LECI, LE, and LU are level stationary variables. On the other hand, order I (1) integrates the variable of LGI. However, all variables became stationary in lags 0 or 1.

Test of Co-integration

Since cross-sectional correlation is ignored by the cointegration analysis suggested by previous studies, in this study, we use Westerlund's (2007) cointegration test to address this issue. Nevertheless, during this stage of the study, we also considered the heterogeneity and cross-sectional dependence of co-accumulated variables, and as a result, the cointegration test created by Westerlund (2007) is employed. These results are displayed in Table 8.

In this test, Gt and Ga examine the existence of a long-term connection in at least one country, and Pt and Pa also test the existence of a long-term connection

Table 6 Test of slope heterogeneous

Pesaran and Yamagata's test	
Delta	57.094***
Delta adj	62.156***

Notes: ***Statistical significance at 1%

Table 7 Tests of unit root

Variables	CIPS test		CADF test	
	I (0)	I (1)	I (0)	I (1)
	(Zt-bar)	(Zt-bar)	Z[t-bar]	Z[t-bar]
LHDI	−2.182**	−4.236***	−2.480***	−9.830***
LECI	−2.483***	−5.644***	−2.387***	−17.803***
LGI	−1.611	−4.962***	−1.740	−13.117***
LE	−2.111**	−5.169***	−2.134**	−15.042***
LU	−2.126**	−4.220***	−2.459***	−9.297***

Notes: *Statistical significance at 1% levels

**Statistical significance at 5% level

***Statistical significance at 10% level

Also, critical values −2.23, −2.11, and −2.05.

in the complete panel under study. The results of Table 8 showed that three of the four factors verify whether a long-term relationship exists.

Test of Heteroscedasticity

In this step, the heteroscedasticity test is checked. In this test, the null hypothesis indicates the homogeneity of the data. However, the opposite hypothesis indicates that the data are heterogeneous. The results are reported in Table 9.

Findings of Table 9 demonstrate the rejection of the null hypothesis. Therefore, the existence of heterogeneity in the data confirms the use of the MMQREG approach due to the heterogeneity of the data (Qiu et al., 2024).

Results of Estimation of Model Parameters

In this study, two models 1 and 2 are analyzed by the MMQREG method. The MMQREG provides distribution and heterogeneous effects in different locations of HDI (Nwani, 2022). Equation 1 examines the direct effects of economic complexity on human development in the 50 countries converging on the ECI. The estimation results of Eq. 1 are reported in Table 10.

Table 8 Test of Westerlund panel cointegration

Statistics	Value	*Z*-value	Robust *p*-value
Gt	−3.121	−4.763	0.040
Ga	−23.717	−8.884	0.000
Pt	−15.954	−6.278	0.020
Pa	−15.302	−5.314	0.100

Note: authors' compilations

Table 9 Test of heteroscedasticity

Test of heteroscedasticity	
Ho: homoscedasticity	chi2(14) = 655.100
H1: unrestricted heteroscedasticity	Prob > chi2 = 0.0000

Note: authors' compilations

The results of estimating coefficients with MMQREG regression in Table 8 show that the increase of each percentage unit of economic complexity, irrespective of a nation's quantile position within the distribution, causes an increase of 0.131 to 0.721 percent HDI in the level of quantiles. The impact is stronger at low quantile levels, so the highest coefficient belongs to quantile 10th and about 0.7214. The findings show that the effect of ECI on human development is significantly reduced in high quantiles (see Table 10). Some studies have shown that increasing ECI helps increase social welfare through knowledge creation and dissemination (Boumahdi & Zaoujal, 2024; Nguea & Noumba, 2024). Gao et al. (2024) found that technology and innovation lead to increased levels of human development. Le-Caous & Huarng (2021) concluded that increasing ECI increases HDI. Anyway, Schwartz, (2020) reported conflicting results. The results are defensible because complex production requires skilled labor and specialized skills, which, through the learning-on-the-job effect, expands education in society. In addition, individuals in advanced societies are forced to learn higher skills and knowledge in order to obtain jobs. With higher knowledge, the capacity and infrastructure of the country to deal with various problems increase. The coefficients of the DK model also support our results.

Finding of Table 10 shows that the effect of gender equality on human development is positive and significant in all parameters. The results also indicate that in countries with lower levels of human development (i.e., lower quantiles), the coefficient of influence of gender equality on human development is higher. The highest coefficient is related to quantile 10th and around 0.4692. The finding can be justified since lowering gender disparity improves women's status in society, which in turn improves women's and their children's health and culture. Numerous studies have shown that increasing gender equality improves societal well-being (Agu et al., 2024; Arthur-Jolasinmi, 2024; Awoyemi et al., 2024; Mbatha, 2024; Wani & Khanday, 2024; Yavorska et al., 2024). Pasha (2024) found that gender equality leads to higher economic performance in Pakistan. However, Gariba and Prokop (2024) found that women in politics did not have a significant impact on human development in OECD countries.

Table 10's finding demonstrate that the impact of energy consumption on HDI in the 10th quantile is not significant and the 50th, 75th, and 90th quantiles are positive and significant. Ouedraogo (2013) found a positive relationship between electricity consumption and HDI. Pham et al. (2024) concluded a positive connection between energy and HDI. Economic growth is an important aspect of HDI, and countries need energy consumption for economic development. From this perspective, increasing energy consumption improve HDI.

Table 10 Results of FE-DK & MMQREG from Eq. 1

Variables	DK regression with fixed effects	MMQREG regression						
		Location	Scale	Qtile 10th	Qtile 25th	Qtile 50th	Qtile 75th	Qtile 90th
LECI	0.0547 (0.0222) [2.46]**	0.4177 (0.0286) [14.61]***	−0.1904 (0.0185) [−10.25]***	0.7214 (0.0488) [14.76]***	0.5705 (0.0373) [15.26]***	0.3773 (0.0280) [13.46]***	0.2362 (0.0269) [8.78]***	0.1317 (0.0304) [4.32]***
LGI	0.0557 (0.0283) [1.97]*	0.41.96 (0.0715) [5.87]***	−0.0311 (0.0464) [−0.67]	0.4692 (0.1224) [3.83]***	0.4446 (0.0933) [4.76]***	0.4130 (0.0680) [6.07]***	0.3900 (0.0667) [5.84]***	0.3729 (0.0764) [4.88]***
LE	0.1833 (0.0043) [42.11]***	0.0137 (0.0031) [4.34]***	0.0081 (0.0020) [3.98]***	0.0006 (0.0054) [0.13]	0.0071 (0.0041) [1.74]*	0.0154 (0.0030) [5.11]***	0.0215 (0.0029) [7.28]***	0.0259 (0.0033) [7.69]***
LU	−0.0064 (0.0105) [−0.62]	−0.0145 (0.0065) [−2.24]**	−0.0167 (0.0042) [−3.96]***	0.0121 (0.0111) [1.09]	−0.0011 (0.0084) [−0.14]	−0.0181 (0.0062) [−2.91]***	−0.0304 (0.0060) [−5.02]***	−0.0369 (0.0069) [−5.71]***
CONS	−1.4847 (0.0273) [−54.23]***	−0.8722 (0.0337) [−25.83]***	0.3217 (0.0219) [14.67]***	−1.3852 (0.0579) [−23.90]***	−1.1303 (0.0443) [−25.48]***	−0.8041 (0.03396) [−23.67]***	−0.5657 (0.0320) [−17.64]***	−0.3891 (0.0361) [−10.71]***

Note: Dependent variable, LHDI

() indicate standard errors

[] indicate *t*-statistics

*Statistical significance at 1% levels

**Statistical significance at 5% level

***Statistical significance at 10% level

The results of Table 10 show that the unemployment rate in different quantiles has different effects on HDI. The effect of unemployment on the index of human development in the quantiles 10th and 25th is not significant. However, the unemployment rate in the quantiles 50th, 75th, and 90th has a negative and significant impact on human development. The results of this study emphasize that increasing employment in countries with higher economic complexity (i.e., high quantiles) significantly contributes to increasing human development. According to the Philips curve, there is a direct relationship between employment and income. As a result, a decrease in unemployment causes an increase in HDI. Hidayat and Bariyah (2020) concluded that there is a direct relationship between unemployment and poverty. Some studies have found similar results (Mardiko & Rospida, 2023; Saputra et al., 2024). The graphical behavior of the coefficients of the independent variables of the model (1) is presented in Fig. 3.

Figure 3 shows the heterogeneous exchange of independent variables along the unconditional distribution of human development. The areas enclosed by the two dashed lines represent the confidence intervals, and the horizontal lines between the dot and the two lines represent the OLS estimates, which are, as one might expect constants. On each graph, however, the effects and matching confidence intervals produced by quantile regression are indicated by a blue line and a shaded region. The results of Table 10 provide important policy implications about the role of ECI on human development, but it does not say anything about the role of gender

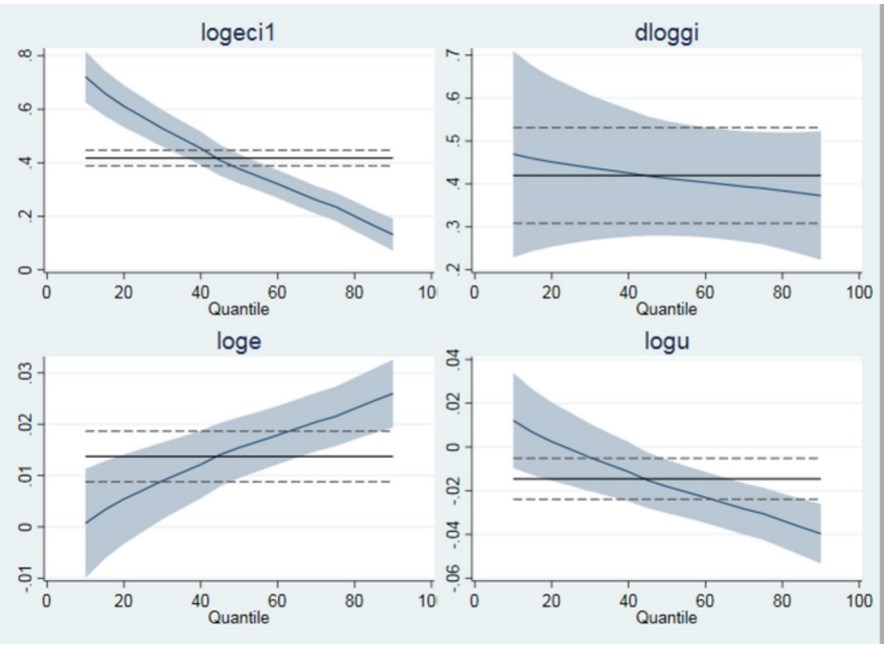

Fig. 3 Graphical representation of coefficient of independent variables from OLS regression and MMQREG. Source: Authors' compilations

equality in how economic complexity affects the index of human development. Therefore, the effect of economic complexity on HDI is investigated through the channel of gender equality in Eq. 2. The estimation results of Eq. 2 parameters are presented in Table 11.

In a more detailed study, model (2) isolates the developmental spillover effects of gender equality. The following equations report the final effects of ECI on HDI in model 2:

$$\frac{\text{dLHDI}}{\text{DLECI}} = 0.6671 + 0.0035(\text{GI})\text{Qtile\_10} \tag{12}$$

$$\frac{\text{dLHDI}}{\text{DLECI}} = 0.4851 + 0.0042(\text{GI})\text{Qtile\_25} \tag{13}$$

$$\frac{\text{dLHDI}}{\text{DLECI}} = 0.2905 + 0.0050(\text{GI})\text{Qtile\_50} \tag{14}$$

$$\frac{\text{dLHDI}}{\text{DLECI}} = 0.1391 + 0.0056(\text{GI})\text{Qtile\_75} \tag{15}$$

$$\frac{\text{dLHDI}}{\text{DLECI}} = 0.0422 + 0.0060(\text{GI})\text{Qtile\_90} \tag{16}$$

$$\frac{\text{dLHDI}}{\text{DLECI}} = 0.0600 + 0.0023(\text{GI})\text{DK} \tag{17}$$

The above relationships show that the reduction of the gender gap increases the strengthening effects of ECI on HDI, which means the efficiency of technology and knowledge. In addition, the value of the interaction term in countries with less ECI is significant. The results of Eqs. 12, 13, 14, 15, 16, and 17 show the effects of the gender equality scale and indicate that although economic complexity leads to an increase in human development, the reduction of gender inequality strengthens the impacts of ECI on HDI. Gender equality helps to develop innovation, and innovation causes the production of more complex products and production efficiency and can thus expand human development in society. In addition, the positive values of the interaction term imply that in countries with higher gender equality, the effect of ECI on HDI is greater. Ryu and Nam (2024) also found that gender equality helps to increase innovation. In addition, gender equality through the development of women's skills can help the development of knowledge and knowledge-based productions, which will strengthen the developmental effects of economic complexity. Thouars and Pablo (2024) also found that reducing the gender gap increases women's social, economic, and cultural competencies. In Fig. 4, the graphical behavior of the explanatory variable coefficients of model (2) is presented.

Table 11 MMQREG and FE-DK models results from Eq. 2

Variables	DK regression with fixed effects	MMQREG regression						
		Location	Scale	Qtile 10th	Qtile 25th	Qtile 50th	Qtile 75th	Qtile 90th
LECI	0.0600 (0.0256) [2.34]**	0.3298 (0.0337) [9.77]***	−0.2078 (0.0218) [−9.52]***	0.6671 (0.0600) [11.11]***	0.4851 (0.0432) [11.21]***	0.2905 (0.0341) [8.51]***	0.1391 (0.0301) [4.62]***	0.0422 (0.0333) [1.27]
GI*LECI	0.0023 (0.0005) [4.19]***	0.0048 (0.0004) [10.89]***	0.0008 (0.0002) [2.85]***	0.0035 (0.0007) [4.51]***	0.0042 (0.0005) [7.37]***	0.0050 (0.0004) [11.74]***	0.0056 (0.0004) [13.96]***	0.0060 (0.0004) [13.52]***
LE	0.1780 (0.0048) [36.90]***	0.0185 (0.0031) [5.83]***	0.0057 (0.0020) [2.79]***	0.0092 (0.0055) [1.66]*	0.0142 (0.0041) [3.47]***	0.0196 (0.0030) [6.45]***	0.0237 (0.0028) [8.30]***	0.0264 (0.0031) [8.37]***
LU	−0.0074 (0.0085) [−0.87]	−0.0146 (0.0060) [−2.42]**	−0.0136 (0.0039) [−3.50]***	0.0075 (0.0106) [0.71]	−0.0044 (0.0078) [−0.57]	−0.0172 (0.0058) [−2.97]***	−0.0272 (0.0054) [−4.99]***	−0.0336 (0.0060) [−5.58]***
CONS	−1.4762 (0.0227) [−64.91]***	−0.8252 (0.0354) [−23.29]***	0.3409 (0.0229) [14.88]	−1.3786 (0.0644) [−21.40]***	−1.0800 (0.0451) [−23.92]***	−0.7606 (0.0381) [−19.94]***	−0.5123 (0.0313) [−16.35]***	−0.3534 (0.0350) [−10.09]***

Note: dependent variable, LHDI

() indicate standard errors

[] indicate *t*-statistics

*Statistical significance at 1% levels

**Statistical significance at 5% level

***Statistical significance at 10% level

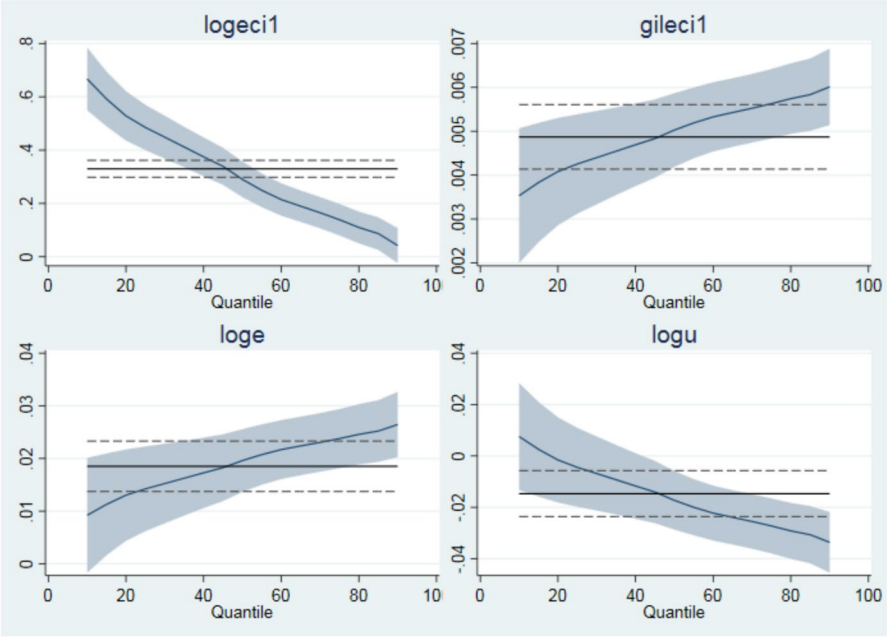

Fig. 4 Graphical representation of coefficient of independent variables from OLS regression and MMQREG. Source: authors' compilations

Panel Causality Test

The MMQREG and DK estimators show the relationship between model variables well. However, they do not explain the causal link. To strengthen the outcomes of model estimations, the causal relationship between the panel variables is investigated. The panel causality test by Dumitrescu and Hurlin (2012) is employed in this investigation, which is usually suitable for investigating the connection of causation between two variables. Table 12 highlights the results of D-H.

In this test, the null hypothesis means that there is no cause for the dependent variable in the independent variable. Hypothesis H1 is that the independent variable is the cause of the dependent variable at least in one panel. Figure 5 is drawn according to the results of the DH test.

Conclusion and Policy Implications

Major Conclusions of the Present Study

Nowadays, due to the rapid advancement of technology, economic growth no longer reflects human development, but the ECI shows how economic expansion has specific effects on well-being. Complex structures, by creating high-quality jobs, require a workforce with high knowledge and specialized abilities. Higher

Table 12 Test of panel causality

Dumitrescu and Hurlin causality test				
	W-Bar	Z-Bar	Z-Bar Tilde	Decision
LECI	2.6720	8.3598*** (0.0000)	6.9820*** (0.0000)	Bi-directional
LGI	3.4062	12.0310*** (0.0000)	10.1960*** (0.0000)	Bi-directional
GILECI1	3.1480	10.7401*** (0.0000)	9.0654*** (0.0000)	Bi-directional
LE	1.9387	4.6935*** (0.0000)	3.7723*** (0.0002)	Bi-directional
LU	2.5191	6.9773*** (0.0000)	4.0170*** (0.0001)	Bi-directional

Note: *** represents 1% level of significance

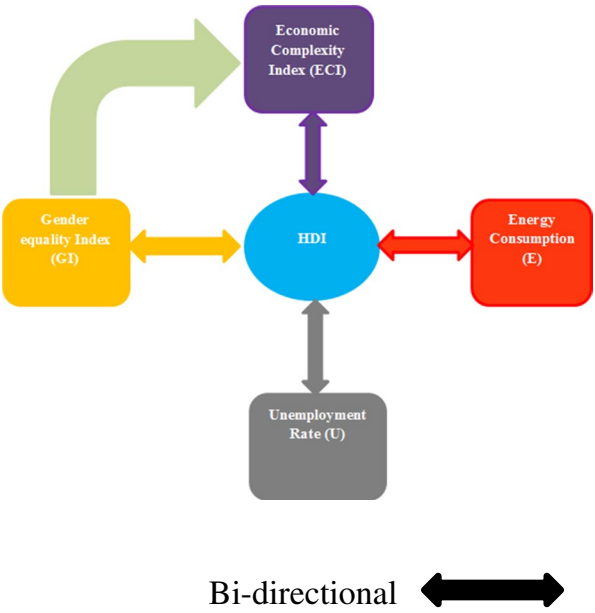

Fig. 5 Causality relationship diagram

levels of knowledge also contribute significantly to the well-being of society through innovation products. In addition, the economic, educational, and social empowerment of women by reducing the gender gap leads to the creation of higher knowledge and the development of complex goods using modern technologies. Therefore, this research has analyzed the effect of gender equality on HDI in the panel of converging countries in technology from 1990 to 2021. In addition, it also analyzes the reinforcing effects of gender equality on the developmental outcomes of economic complexity. First, the panel of economies was selected with a club convergence approach. Then the impact of gender equality and ECI on the

human development index has been investigated with a complex and new panel, MMQREG. In addition, economic complexity's impact on human development has also been investigated through the channel of gender equality. In this study, the Dumitrescu and Hurlin panel causality test (D-H) and DK model were also used for the analysis of robustness.

The results of parameters estimation demonstrated that although the growing complexity of the economy contributes to the growth of human development, the increase in gender equality strengthens the developmental effects of economic complexity. Furthermore, the outcomes demonstrated that the spillover effects of gender equality are more significant in economies with a lower economic complexity rating. In addition, the results indicate that with the reduction of gender inequality, the human development index increases. The unemployment rate implies different results in different quantiles, and as energy consumption increase welfare. In addition, there is a reciprocal causal connection between ECI and HDI, E and HDI, U and HDI, and GI and HDI, according to the causality outcomes.

Comparison with Other Studies

The empirical findings of this study showed that increasing knowledge used in production leads to higher human development. Some studies showed that there is a positive relationship between ECI and HDI (Le-Caous & Huarng, 2021; Nguea & Noumba, 2024; Boumahdi & Zaoujal, 2024; Gao et al., 2024). Some studies reported conflicting results (Schwartz, 2020). The regression results showed that there is a positive relationship between gender equality and human development. Most studies in other countries have reached similar conclusions (Agu et al., 2024; Arthur-Jolasinmi, 2024; Awoyemi et al., 2024; Mbatha, 2024; Pasha, 2024; Wani & Khanday, 2024; Yavorska et al., 2024). But some studies did not find a significant relationship between gender equality and human development (Gariba & Prokop, 2024). The empirical findings also show that although economic complexity leads to increased human development, reducing the gender gap strengthens the effects of ECI on HDI. Some studies have shown that gender equality increases innovation and creativity in society (Thouars & Pablo, 2024).

Implications and Explanation of Findings

Our empirical findings showed that increasing knowledge used in production leads to higher human development. There are several reasons for this. First, a higher ranking in the economic complexity index means that more complex and exclusive products are produced, which helps to increase the income of societies. Higher income is the main key for higher social and economic development. Second, more complex products require a more specialized workforce, which receives higher income for their specialized work. Third, knowledge-based economies create new sectors and high-quality jobs, which increase the well-being and development of

societies. In addition to increasing household income, increasing gender equality increases the health, culture, and morale of women and their children, all of which contribute to raising the level of well-being of the entire society. The most important finding of this study is that, for the first time, it was shown that reducing the gender gap increases the reinforcing effects of ECI on HDI through the channel of technological and knowledge efficiency. Gender equality, by creating equal opportunities for women and men, increases innovation, creativity, knowledge production, and its application in society, which leads to the welfare and development of society.

Strengths and Limitations

Among the most important limitations of the study was the availability of data for all countries; the authors of this study only had access to the data of 80 countries in the first step.

Conclusion, Recommendations, and Direction for Future Research

Based on the findings of this investigation, one of the best strategies for human development is the use of knowledge in the production of products that leads to innovation and creativity. The current study recommends that authorities in technologically convergent countries develop the application of knowledge and innovation in production to achieve higher HDI levels by proving financial facilities to advanced industries. In addition, considering that the reduction of the gender gap strengthens how economic complexity affects human development, the authorities of the studied economies should provide equal economic and social opportunities for women in society to contribute to the development of well-being by developing knowledge and education and creating a more innovative society. For this purpose, governments should implement policies and macro-initiatives in the field of reducing the gender gap. The special suggestion of this study is that the authorities of the mentioned countries, especially economies with less complexity, should pay special attention to the reinforcing effects of reducing the gender gap to improve the effects of complex structures on human development. Other results are also interesting. This study also suggests that considering that energy consumption helps human development, the authorities should not limit people's energy consumption. Although it should have sufficient supervision on the optimal use of resources and energy. The development of clean energy, environmentally friendly technologies, and improving the efficiency of energy consumption can also help to achieve this goal by focusing on sustainable development. Also, according to the findings of the article, reducing the unemployment rate in complex economies can have a significant impact on the development and well-being of people in these societies. For this purpose, government authorities should take various measures to reduce the unemployment rate in countries with a high economic complexity index. Future studies can study the effects of women's employment through the impact of technology on HDI. At the same time, examining how a nation's economic complexity affects its citizens' ability to develop with

different levels of development will also provide interesting results. Future researchers can enlarge the scope of this study by looking at the results of economic innovation and the complexity of other fundamental variables such as poverty and female employment. By considering the different resources of each country, a country-by-country analysis will provide interesting results.

Author Contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Fariba Osmani and Mohammad Ali Falahi. The first draft of the manuscript was written by Fariba Osmani, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

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