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Digital Momentum and Gen-Z Flourishing: A Sustainable Matrix of Augmented Intelligence in G7 Economies

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Abstract:
This study investigates how digital momentum, intelligence capital, and sustainable intelligence jointly shape human development in advanced economies, with a specific focus on Gen-Z flourishing in G7. Framed within capability theory and the emerging literature on AI-driven development, we conceptualize an "Augmented Intelligence Matrix" comprising three pillars: digital momentum, intelligence capital, and sustainable intelligence. Using annual panel data for G7 economies, we apply second-generation panel techniques, including IV–GMM estimation, with the Human Development Index (HDI) as the core variable.
The IV-GMM estimates show that the empirical results are statistically significant and positive impacts of ICT exports, internet usage, fiber-optic infrastructure, R&D investment, and green energy adoption on human development. Their contributions to the growth of digital access, increasing the capability of innovation, and advancing the quality of the environment are highlighted. However, the greater-education factor shows a less significant and more subtle effect, with its issues being skill imbalance, psychological strain, and the gap between the conventional educational framework and the requirements of the AI-based labour markets. These macro relationships are explained with the help of micro capabilities pathways: virtual communities help provide social belonging and emotional well-being to Generation Z; R&D ecosystems help provide cognitive flexibility and innovative thinking; and green energy changes help provide environmental welfare over the long term .
In general, the results indicate that the future of human development in G7 economies is predetermined not only by digital, innovative, and green systems investments, but also by the way in which these systems are implemented to develop digital, cognitive, emotional, and social skills of Generation Z. The work therefore builds upon the conventional human development models by proposing a sustainable grid of augmented intelligence as a novel prism of comprehending how Generation Z is thriving in the AI-augmented reality.
Keywords: Digital Momentum, Gen-Z Flourishing, Augmented Intelligence Matrix.

I. INTRODUCTION

The fast spread of artificial intelligence (AI), automation, and sophisticated digital infrastructures is reorganizing the principles of economic and social life, especially in the high-income countries (Mhlanga, 2021). This change is not only technological in G7 economies, but it is redefining the ways in which capabilities are established, exercised and appreciated across generations. The first cohort of digital natives, Generation Z, is becoming an adult in a world where AI systems, robotics, virtual environments and data-driven decision-making are integrated into work and education (as well as daily) (Ding et al., 2025; Salvadorinho et al., 2026). The traditional indicators and theories of human development constructed on the base of income, schooling, and basic health are proving insufficient to define the opportunities, agency, and well-being in this new era that is driven by digital momentum and technology-intensive spaces.

Digital momentum in developed economies can be referred to as a synergy of three interconnected forces namely growing export of ICT services, widespread use of internet, and high-speed fiber-optic network rollout (Sharma and Shrivastava, 2026). All these combines to create the infrastructural and economic preconditions of AI enhanced employment, digital learning ecosystems, and thick virtual communities (Hutson, 2025). Digital economy is transforming labour markets through automation, robotics and data driven processes creating a strong demand for advanced IT skills, data analytics and cybersecurity and reducing the viability of routine jobs (Entele, 2021; Shirazi & Hajli, 2021). Already, educational interventions directly constructing AI literacy and other 21st century skill sets are showing positive outcomes on confidence levels, collaboration, and idea sharing in young people, raising the prospect that digital momentum directly contributes to the human capital of generation -Z (Hutson, 2025).

Digital technologies have been regarded as the possible facilitators of human development long. ICTs can facilitate the essence of the core dimensions of health, education and living standard by increasing access to information, service, and learning opportunities (Elahi and Mehdi, 2025). It has been shown that, properly integrated in education systems, ICTs can lead to equal access, individualised learning and competencies that meet the demands of the modern labour markets (Emmanuella Chizoba and Chinda, 2025). Recent cross-national studies also confirm the close positive correlation between human development indicators and the level of digital preparedness of a nation, highlighting the role of digitalization as one of the driving forces of development towards the Sustainable Development Goals (Ansari et al., 2024). Path-modelling results also indicate that ICTs have a positive impact on human

developments in terms of increasing conversion factors, social and institutional conditions in which individuals can convert resources into desired accomplishments, especially in the developed economies, with strong impacts on social conversion factors (Alhassan, 2025).

At the same time, digital transformation is redefining the conversations on inclusion and inequality. The concept of an inclusive economy is also concerned more with fair access to education, resources, good jobs, and sustainable development, and digital transformation and AI serve as the source of inclusiveness as well as potentially exclusionary (Shaukat & Audi, 2025; Liang et al., 2025). The digital divide, skillset, and data literacy disparities pose the threat of exacerbating existing disparities, in particular, social groups and generations (Prasetya et al., 2025). The literature emphasizes the importance of cross-sector cooperation, educational investment, and regulatory novelty to make sure that digital economies are used to promote extensive based human improvement, as opposed to structural separation (Elahi & Mehmood, 2025).

In addition to the access to the technology, the new era of AI changes the emphasis on the traditional knowledge penetration to complicated and ability-based skills. Researchers emphasize the significance of human-centric competencies, including critical thinking, creativity, socio-emotional skills, collaboration and self-regulation, in the environment that is becoming more mediated by intelligent systems (Ciarli et al., 2021; Popkova et al., 2022). Education and management frameworks of the industrial era with their focus on repetitive and structured assignments have become seen as incompatible with cognition flexibility and innovation in AI-integrated workplaces. Studies of socially shared regulation of learning show that environments with high technology can facilitate collaborative problem-solving, initiative, and goal-setting, all of which are essential skills of Generation Z in living and working in AI-saturated societies (Mukhtar & Imran, 2016; Mohsin & Abdullah 2025; Imran et al., 2012; Ganda, 2024). This literature has brought to a point, one important fact: the worth of digitalisation is becoming more and more reliant on the ability of societies to develop special human abilities that do not substitute but, instead, enhance AI-based algorithms.

The interaction between an educated workforce and a healthy investment in R&D is becoming a key driver of building what can be called, in this bigger picture, an ecosystem of the intelligence-capital (Li, 2024). Experiential learning, meta-learning, and socio-emotional development in higher education systems can prepare Generation Z to work in complex environments that are augmented by AI, and high spending on R&D can create demand on complex AI-enhanced capabilities (Chang et al., 2026; Amiri, 2025). It is these dynamics that together optimize adaptability, goal-setting and self-regulation, which are currently

acknowledged as among the key elements of human development in technologically rich societies.

Simultaneously, environmental sustainability has turned into an indivisible aspect of long-term development, especially to the younger generations that will have to face the consequences of climate risk first (Imran et al., 2020). The future concept of sustainable intelligence, involving the implementation of intelligent systems (AI and Internet of Things (IoT)) and green energy, is centered on the integration of the environmentally friendly approach with efficiency and resilience provided by data (Ejiyi et al., 2025). Empirical evidence shows that there is a positive relationship between the adoption of renewable energy and HDI in various regions and income groups, indicating that the process of cleaning the sources of energy may support the health results, education results, and the income results (Diaconasu et al., 2022). In the case of G7 economies, renewable energy technologies (investment) would not only help the environment meet climate goals but would also aid in innovation and job creation, as well as economic resilience in the long run (Elahi and Mehdi, 2025a). The combination of green energy, smart infrastructures, and human development is all heading towards a more general paradigm of sustainable intelligence.

The main hypothesis of this study is that the digital momentum combined with high intelligence capital and sustainable-intelligence systems is a new form of development regime where the prosperity of the generation of Z became not only the result but the engine of long-term development. Instead of AI and digitalization being exogenous shocks, we say that both are components of a changing environment of capabilities that can either augment or limit human development, depending upon the way economies organize their technologies, institutions, and energy systems. We also analyze with reference to G7 economies - the world leaders in digitalization, innovation and green transitions - whether and how this augmented-intelligence matrix can be converted into better human development outcomes and what the implication of this is on future development of Generation Z in advanced societies.

H1: Digital Momentum Capability

Digital momentum—through ICT exports, widespread internet usage, and high-speed fiber-optic networks—significantly enhances Gen-Z economic and social capabilities by enabling AI-augmented jobs, digital learning, and virtual community participation, thereby improving overall human development in G7 economies.

H2: Intelligence Capital Ecosystem

A highly educated workforce combined with strong R&D investment forms an intelligence-capital ecosystem that strengthens Gen-Z cognitive, emotional, and innovative capabilities, which in turn positively contributes to human development outcomes in the AI-driven era.

H3: Sustainable Intelligence & Environmental Well-Being

Green energy adoption fosters sustainable-intelligence systems that improve environmental safety, reduce climate risk, and support the long-term flourishing of Gen-Z populations, leading to improved human development performance across G7 countries.

2. Literature Review

The shift to a digitally mediated global economy has only increased the pace of scholarly attention toward understanding the intersection of information technologies, artificial intelligence (AI), digital preparedness, and sustainability to define the development of humans (Mhlanga, 2021). Although the existing body of knowledge is highly informative about the adoption of ICT, AI-induced changes in the workplace, and the socio-economic impact of renewable energy, the literature is still inconsistent on the convergence of forces to impact the next-generation development capabilities, especially in developed economies (Liang et al., 2025; Shaukat & Audi, 2025; Prasetya et al., 2025). The section summarizes the results of different methodological frameworks, national and conceptual paradigms to create a consistent corpus to the suggested sustainable matrix of augmented intelligence in G7 economies.

2.1 Digital Readiness and Human Development: Cross-Country Evidence

The existence of a considerable amount of literature shows that digital readiness in terms of ICT infrastructure, internet penetration, and technological integration has a strong relationship with human development outcomes. Using a one-factor regression model with 26 countries Zheng & Wang, (2022), prove that digital readiness is not only an enabling factor but the key determinant that can be used to explain the difference in HDI. Their macro-level analysis designates digital readiness as one of the structural capabilities, which have an impact on the health, education, and income.

To differentiate the economies of the developing and developed countries, Damalie & Karanfiller, (2025) apply path modelling across West African countries to distinguish between developed and developing economies. use path modelling in the countries of West Africa. Their findings indicate that ICT in developed countries increases the social conversion

variables of institutional efficiency and community involvement more than individual level capabilities. This realization is critical to G7 economies: the digital ecosystem supplements group social operation, which in turn indirectly enriches the lives of young generations who have to operate in AI-based settings (Svergun, et al., 2025).

These results support the previous conceptual framework of ICT and human development by Alhassan, (2025) who illustrates that ICT access cannot be developed without social systems, and governance structures as well as inclusive digital policies, which determines its developmental efficiency. Literature, therefore, theorizes the presence of digital momentum as a multi-layered phenomenon that goes beyond technological access and influences the conditions of systemic capability.

2.2 Transformations in Work, Skills, and Human Capability Formation

Much of the new literature is examining the ways in which AI and digitalization transform the concept of skills, work, and capability development (Materia et al., 2024). It is especially relevant to the case of Generation Z whose entry into the labour market is accompanied by automation and augmentation technologies. Based on neuroscience-inspired organizational research . Tang et al., (2022), believe that the models of skills that were dominant during the industrial era by focusing on routine and analytical tasks are becoming obsolete. Rather, contexts that are driven by AI require fluid intelligence, which is creativity, emotional stability, and cognitive flexibility (Deng & Chen, 2025). Their framework stresses that the human development in antebellum AI will have to focus on non-automatable skills.

Wang et al., (2021) help to fill the gap by investigating the cross-generational skills requirements based on the survey-based empirical study. The research finds creativity, communication, and flexibility as the fundamental complements to the AI system of all ages. It is interesting to note that the pace of Gen-Z to digital immersion does not assure AI literacy, and this fact supports the idea of the literature to develop structured capabilities building as opposed to passive exposure to the digital environment (Talaei et al., 2026). Another characteristic of educational changes is also prominent in literature. Prasetya et al., (2025) construct a socially shared learning regulation model, proving by means of educational experiments that learning environments that are technologically advanced contribute to collaboration, metacognition, and emotional regulation skills, which Gen-Z will be able to apply in their future learning and work.

Trying to put AI changes into context by analyzing the historical-technological comparison Liang et al., (2025), reveal how each large technological revolution has altered the human capital requirements. The paper underlines that AI ethics, lifelong learning, and hybrid human-machine interaction systems will have to be included in the next-generation development of humans.

2.3 ICT-Enabled Learning, Innovation Systems, and R&D Intensification

Studies on the digital learning and innovation ecosystem highlight the importance of ICT exports, tertiary education and investment in R&D to develop intelligence capital. These are the building blocks of the proposed model of augmented intelligence. In an extensive literature-based study, Shirazi & Hajli, (2021), reveal that e-learning systems increase the intellectual capital by enhancing the users, both in terms of their creative and analytical capacity. The paper emphasizes how virtual worlds, action-based learning and game-based pedagogy can be used to develop technologically adaptive human capital.

Similarly, Entele, (2021) utilizes qualitative educational measurements to reason that ICT-enhanced learning fosters equitable access, personalized education, and human development-related relevant skill development, which are important factors in human development of high-income economies. Another significant capability-forming determinant is R&D investment. As shown by Deng & Chen, (2025), organizations with a focus on innovation facilitate conducive conditions that support cognitive flexibility, taking risks and problem solving. The success of Gen-Z then lies in the ability of the ecosystems based on R&D to incorporate AI technologies, as well as to develop distinctly human skills.

2.4 Digital Inclusion, Inequalities, and Structural Barriers

Along with positive effects, literature at the same time recognizes structural issues and inequalities. Khaustova & Svergun (2025) discuss the models of the inclusive economy, demonstrating that despite increasing opportunities, digital transformation may contribute to the intensification of inequalities because of the lack of digital literacy, access to data, and study of technological issues. They promote cross-sector partnership, education investment and regulatory supervision in their policy-based proposals as a way of cutting back on exclusion. Weiran Cai , (2023) the author proposes that digital competence is still unevenly distributed among people, which limits its role in human development. These lessons are invaluable to G7 economies in which the development of the Gen-Z generation depends upon equal opportunities to access digital skills, AI-literacy programmes, and systems of capability building.

2.5 Green Energy, Sustainable Intelligence, and Long-Run Human Development

The third pillar of sustainable-intelligence matrix is sustainability literature. It has always been proven that the use of renewable energy contributes to human development in the long term (Popkova et al., 2022). Nguyen et al. (2023who study renewable energy and ICTs combinations among 26 countries, show that renewable energy is better in enhancing health, education, and income in the short term. Their results are applicable to various renewable sources, but they are different in terms of income group.

Beka et al., (2024), directly relating to OECD countries corroborate that there is a positive correlation between green energy and HDI, citing the co-benefits of cleaner air, increased productivity and technological innovation. According to Cao et al., (2025), in their ARDL and FMOLS model of the G7 countries, renewable energy investment leads to better sustainability performance and contributes to SDG 7, SDG 9, and SDG 13. The paper highlights the relevance of government investment and human capital as the driving force to green innovation.

The idea of sustainable intelligence has a more all-purpose approach in literature. According to Vijayalakshmi et al., (2023) intelligent systems enabled by AI and IoT can improve the monitoring of the environment, the use of energy, and resilient infrastructures. Such systems do not only minimize carbon footprints, but also promote green employment and innovation opportunities, both of which are important to the future well-being of Gen-Z.

2.6 Literature Gaps

Regardless of these developments, there are still several major gaps in literature. To start with, the majority of empirical literature on the topic of digitalization and human development refers to large cross-sections of nations, often including many of the developing economies (Ul-Durar et al., 2024; Latif et al., 2023; Shirazi & Hajli, 2021), or takes digital variables as a unit rather than a cumulative force that would propel a new development regime. Second, AI, skills and human capabilities studies are also predominantly conceptual or micro-level, such as at workplaces, in schools, or within a particular training programme, without directly relating these changes to macro-level human development results in advanced economies (Kryzhanovskij et al., 2021; Acheampong et al., 2022; (Skare & PORADA-ROCHON, 2022). Third, while Gen-Z is often discussed as a distinct cohort facing unique challenges and opportunities, there is little empirical work that embeds Gen-Z's flourishing within a macroeconomic framework that incorporates ICT exports, internet usage, digital infrastructure, higher education, R&D, and green energy as structural drivers in G7 context.

Third, despite the fact that Generation~Z has often been characterized as a unique generation facing unique challenges and opportunities there is little empirical research that puts the bloom of Generation~Z in a macroeconomic context that incorporates ICT exports, internet use, digital infrastructure, higher education, R&D, and green energy as structural forces in the G7 settings s (Talaei et al., 2026; Amiri, 2025).

This study addresses these gaps by proposing and empirically testing the idea of a sustainable matrix of augmented intelligence in G7 economies. We conceptualize human development—measured through the Human Development Index (HDI) as a function of digital momentum (ICT services exports, internet usage, fiber-optic penetration), intelligence-capital formation (higher education and R&D expenditure), and sustainable-intelligence foundations (green energy deployment), while controlling economic growth and foreign direct investment. In doing so, we interpret these structural variables as the underlying conditions that shape Gen-Z's economic, social, and environmental capabilities in AI-rich, high-income societies.

2.7 Theoretical Framework

This study is grounded in a multi-theoretical framework that explains how digital momentum, intelligence capital, and sustainable energy systems shape human development in advanced economies. The Capability Approach (Sen, 1993; Robeyns, 2003) provides the core foundation, positing that technology, education, and socio-environmental conditions expand individuals' real freedoms and opportunities. Digital momentum—through ICT exports, internet penetration, and fiber-optic network functions as a *conversion factor* that enhances Gen-Z's cognitive, social, and economic capabilities. Human Capital Theory (Becker, 1993) supports the framework by describing how high-level education, R&D investment, and accumulation of digital skills create what is termed as intelligence capital whereby the workers can supplement AI systems as opposed to competing with them. Also, the paper uses Endogenous Growth Theory (Romer, 1990; Aghion et al., 1998), which deems importance to innovation and spillovers of knowledge, and diffusion of technology in long-term productivity and human development, which is relevant directly to the digital and R&D-intensive economic frameworks of G7 economies. In a bid to integrate sustainability, the framework incorporates the Ecological Modernization Theory (Mol & Sonnenfeld, 2000) theory, which holds that technical innovation, especially renewable and intelligent energy systems, can help in achieving steadfast human development and economic growth at the same time, and in this context, ensures that the environment remains healthy. Lastly, Augmented Intelligence Theory (some of the contemporary human-AI collaboration models) dictates the complementing

relationship between machine intelligence and human abilities, insisting on the increasing demand to be creative, emotionally intelligent, and adaptive in the context of G7 economies.

4. Research Methodology

4.1. Data and Variable Definitions

The paper explores how digital momentum, intelligence capital and sustainable technological systems influence human development in the G7 economies. The empirical study uses an annual balanced panel model that takes to the G7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) to examine the data between 1992 and 2023, on condition of the existence of the data. The variables are all obtained using internationally recognised databases like the World Development Indicators (WDI), UNDP, OECD and ITU which guarantee uniformity, precision and relatability across nations. The choice of variables is based on the theoretical premises of the Capability Approach, Human Capital Theory, and Augmented Intelligence Framework, as well as coincides with the hypotheses of the study. The Human Development Index (HDI) is the major dependent variable in this study since it is a multidimensional indicator of the well-being of the Generation Z and the population, in general, considering the three main essential aspects: education, health, and income. Being an aggregate indicator of sustainable capability growth, HDI correlates well with the conceptualization of the study of Generation Z flourishing, which is the human consequences of the digital, cognitive, and environmental changes in G7 economies. The model uses several pointers of digital momentum and intelligence capital to explain the differences in HDI. Use of the internet, which is the percentage of people who actively use the internet, is the base layer of digital access that facilitates online education, telecommuting, digital entrepreneurship, and the involvement of virtual communities, which are the capabilities all of Generation Z needs to become integrated in the economic and social systems of AI. In addition to this, fibre-optic broadband penetration takes the plunge of high-speed digital infrastructures needed to facilitate more sophisticated technologies, including cloud computing, AI uses, real-time collaboration, and educational systems that demand a lot of bandwidth. Being the structural cornerstone of the digital momentum, this variable signifies the willingness of the G7 economies to maintain an emergent augmented-intelligence ecosystem. As part of gauging the human capital aspect of this ecosystem, the analysis incorporates a proxy regarding a highly skilled workforce, which can be tertiary education enrolment or the proportion of high-skill labour. This measure is an indicator of the creation of intelligence capital the generation of workers who have high levels of knowledge,

creativity, critical thinking, emotional intelligence, and problem-solving skills, which enable them to supplement, not to compete with intelligent technologies (Generation-Z). In addition, the expenditure on R&D is included to reflect the national investment on innovation, scientific development, and development of technology. By being an engine of self-sustaining growth and the transition to a more AI-plagiaristic production regime, high levels of R&D intensity will enable innovation in digital solutions, high-level employment, and knowledge-based economic trajectories, which eventually improve human development outcomes. To have strong estimates and to reduce the bias of omitted variables, two macroeconomic controls are added. Economic growth (GDP) explains the total state of national prosperity and the ability of the nation to invest in education, healthcare, renewable energy, and technology-which have a direct effect on human development. Lastly, foreign direct investment (FDI) encompasses inflows of capital across borders, transfer of technology, and multinational activities in sectors that are intensive of human capital. The increase in FDI inflows in G7 economies tends to provide modern technological infrastructure, spillovers of innovations, and job opportunities that indirectly lead to the enhancement of Gen-Z capabilities. A combination of these variables offers an overall model of evaluating the joint impacts of digital momentum, intelligence capital, and macroeconomic conditions on human development in developed economies. The basic econometric model is stated as being as follows:

$$HDI_{it} = \alpha_i + X_{it}^{1}\beta + \in_{it}$$

(1)

In this equation, HDI_{it} denotes the Human Development Index (HDI) for country *i* at time *t* ; X_{it}^{1} represents a vector of explanatory variables, including ICT, IU, FO, HAEF, R&D, GE and $\in it$ is the error term capturing random disturbances.

4.2 Estimation Strategy

Once the panel dataset was compiled on the G7 economies, a series of diagnostic and pre-estimation tests were performed to be sure that the econometric results were reliable and valid. To ensure that the order of integration is verified and at the same time taking care of the possibility of cross-sectional correlation, first, the panel unit root tests were carried out using the IPS (Im-Pesaran-Shin) and CIPS (Cross-Sectionally Augmented IPS) procedures. IPS test gave first indication of the patterns of stationarity and CIPS test, which is more suitable when dealing with interrelated economies such as G7, verified the integration properties of every variable. The equation of the unit root testing can be presented as follows:

$$\Delta X_{it} = \propto_i + \beta_i X_{i,t-1} + \sum_{j=1}^{\delta} \delta_j \Delta X_{i,t-j} + \epsilon_{it} \qquad (2)$$

Here, $\Delta X\, it$ represents the variable under examination and $\propto_i$ is the country-specific intercept, while ϵ_{it} denotes the error term. If non-stationarity is detected, first-differencing is applied to achieve stationarity.

The Cross-Sectional Dependence (CD) tests were used to identify the interdependence between countries brought about by globalization, technological spillovers and common economic shocks. The high CD statistics pinpointed the application of second-generation unit root and cointegration methods. Pesaran CD test is the test used to analyses the cross-sectional dependence of the G-7 countries, which is formulated as follows:

$$CD = \frac{\sqrt{2t}}{n(n-1)} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \hat{C}_{ij} \qquad (3)$$

In this expression, $\hat{C}_{ij}$ signifies the correlation coefficient of residuals between countries *i* and *j*. Detecting significant cross-sectional dependence necessitates the application of panel quantile regression methods to account for these interdependencies.

This was followed by a Hausman specification test which was used to see which specification fixed-effects or random-effects provided a more consistent estimator of short-run model. The outcome of the tests showed the existence of systematic differences between the Fixed-effect (FE) and the Random-effect (RE) coefficients, which was an indication of the possible endogeneity issues.

$$\theta\hat{}GMM = \arg\ \theta min\ [\, g(\theta)' W g(\theta)]$$

(4)

With

$$g(\theta) = \frac{1}{N} \sum_{i=1}^{N} Zi' \Delta \varepsilon i(\theta)$$

(5)

Where:

- $\mathbf{g}(\theta)$is the vector of sample moment conditions
- **W** is a weighting matrix (optimal in two-step GMM).

To reduce the simultaneity, dynamic feedback, and omitted-variable bias, an instrumental value (IV) two-step Generalized Method of Moments (GMM) estimation model was embraced. This model can be characterized as follows: the two-step GMM method, which is robust to heteroskedasticity, serial correlation and cross-sectional dependence generated consistent and efficient parameter estimates that demonstrated the strength of the long-run relationships found. IV-2SLS and Instrumental-Variable Limited-Information Maximum Likelihood (IV-LIML) estimators were also used to check the robustness to the possible endogeneity bias that may occur due to missed out variables, reverse causality and measurement error.

4.3 Empirical Model Specification

To empirically capture how digital momentum and intelligence capital shape the trajectory of human development across G7 economies, the following baseline model is specified:

$$lnHDI_{it} = \alpha_i + \beta_1 lnict_{it} + \beta_2 lniu_{it} + \beta_3 lnfo_{it} + \beta_4 lnhaef_{it} + \beta_5 lnge_{it} + \beta_6 lnrd_{it} + \beta_7 lngdp_{it} + \beta_8 lnfdi_{it} + u_{it} \quad (6)$$

where $i = 1, \ldots, N$ denotes country (G7 members) and $t = 1, \ldots, T$ denotes time (years). α_i captures unobserved country-specific effects, u_{it} is the idiosyncratic error term, $lnHDI_{it}$ is the log of the Human Development Index, $lnict_{it}$ is ICT services exports, iu_{it} is internet usage, ln$haef_{it}$ is high-speed (fiber) internet penetration, $lnge_{it}$ is the highly advanced workforce indicator, $lnrd_{it}$ is R&D expenditure, $lngdp_{it}$ is economic growth (income level), and $lnfdi_{it}$ represents foreign direct investment.

5. Results and Discussion

5.1. Results

The descriptive statistics in Table 1 indicate the notable variations across the variables. The descriptive statistics show that ln_hdi has a high mean (4.49) with very low dispersion, indicating that human development is relatively high and stable across G7 countries. The explanatory variables such as ln_ict, ln_iu, ln_fo, ln_haef, ln_rd and ln_ge also display moderate variation, suggesting meaningful cross-country and over-time differences. In contrast**, ln_fdi and ln_ep** exhibit relatively large standard deviations and wide ranges (with negative minima), indicating substantial volatility in foreign direct investment inflows and

economic-related conditions across the sample. Overall, the variables show sufficient variation to support reliable panel econometric analysis.

Table 1: Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
ln_hdi	224	4.491	0.038	4.373	4.567
ln_ep	224	0.624	0.844	-3.738	2.160
ln_ict	224	1.644	0.712	-1.049	2.780
ln_iu	224	3.390	1.636	-2.186	4.583
ln_fo	224	2.945	0.970	-0.012	4.592
ln_haef	224	4.362	0.057	4.268	4.501
ln_rd	224	0.740	0.334	-0.099	1.252
ln_fdi	224	0.207	1.366	-7.199	2.544
ln_ge	224	2.037	0.833	-0.223	3.174

Source Authors' own calculations**.**

The VIF test results in table 1 indicate that all variable values are less than 5, with HAEF having the highest at 2.44, followed by the GE at 2.11. The average VIF value is 1.77, suggesting that the model is free from multicollinearity issues.

Table 2: VIF

Variables	VIF	1/VIF
ln_haef	2.44	0.4097
ln_ge	2.11	0.4734
ln_ict	2.04	0.4910
ln_iu	1.98	0.5043
ln_rd	1.59	0.6285
ln_fdi	1.54	0.6483
ln_fo	1.32	0.7556
ln_ep	1.13	0.8881
Mean VIF	**1.77**	

Note: VIF > 5 indicates moderate, and VIF > 10 suggests severe multicollinearity. Source Authors' own calculations.

The Breusch–Pagan/Cook–Weisberg test indicates no evidence of heteroskedasticity in the pooled model (p = 0.858), but the very high correlation between residuals and their lag (0.97) suggests strong serial correlation, so cluster-robust standard errors by country were used.

Table 3: Heteroskedasticity and Serial Correlation

Heteroskedasticity	Breusch–Pagan / Cook–Weisberg (estat hettest)	χ^2 (1) = 0.03, p= 0.8580	Fail to reject H_0 → constant variance.
Serial correlation	Corr (residuals, L.residuals)	ρ = 0.9722	Very strong (Clustered SEs)

Source Authors' own calculations.

Pesaran's (2004) CD test results reported in Table 4 indicate strong cross-sectional dependence in all series. For each variable, the CD statistic is large and the associated p-value is 0.000, leading to a clear rejection of the null hypothesis of cross-sectional independence. The average pairwise correlations are also sizeable, particularly for ln_hdi (0.98), ln_iu (0.87) and ln_ge (0.82), confirming that shocks and dynamics are highly correlated across G7 countries. These results strongly suggest that empirical analysis should employed estimation techniques robust to or explicitly modeling cross-sectional dependence (time-fixed effects with Driscoll-Kraay standard errors) to avoid biased and inefficient estimates.

Table 4: Cross-Sectional Dependence Test

Variable	**CD-Test Statistic**	**p-value**	**Av. Correlation**	**Av. Absolute Correlation**
ln_hdi	25.49	0.000	0.983	0.983
ln_ep	9.83	0.000	0.418	0.430
ln_ict	14.08	0.000	0.543	0.631
ln_iu	22.48	0.000	0.867	0.867
ln_fo	9.46	0.000	0.365	0.378
ln_haef	7.65	0.000	0.295	0.775*
ln_rd	12.63	0.000	0.487	0.555
ln_fdi	7.05	0.000	0.284	0.284
ln_ge	21.12	0.000	0.815	0.815

Note: asterisk * represents 1% significance level. Source: Authors' own calculations.

Combined with the earlier Pesaran CD test results, these findings robustly confirm the presence of cross-sectional dependence in your dataset.

Table 5: Frees' and Friedman's Cross-Sectional Dependence Tests

Test	**Test Statistic**	**Critical Values & P-value**
Frees' Test	Q = 0.387	Critical Values: α = 0.10: 0.1984 α = 0.05: 0.2620 α = 0.01: 0.3901
Friedman's Test	$\chi^2 = 29.859$	P-value = 0.0000

Source Authors' own calculations.

IPS results show that ln_hdi, ln_ep, ln_ict, ln_iu, ln_fdi ln_fo, ln_rd, ln_haef and ln_ge are stationary in levels (I(0)).

Table 6: Im–Pesaran–Shin (IPS) Panel Unit Root Test

Variable (Level, I(0))	**W-t-bar Statistic**	**p-value**	**Order of Integration**
ln_hdi	-2.3753	0.0088	I(0)*
ln_ep	-5.3505	0.0000	I(0)
ln_ict	-2.3101	0.0104	I(0)*
ln_iu	-15.9616	0.0000	I(0)
ln_fo	-1.6182	0.0128	I(0)
ln_rd	-1.7936	0.0036	I(0)
ln_haef	-2.7938	0.0074	I(0)
ln_fdi	-2.3769	0.0087	I(0)*
ln_ge	-3.9813	0.0000	I(0)

*Significant at the 5% or 10% level, suggesting stationarity. Source Authors' own calculations.

The p-value (0.0000) is very important thus giving a strong rejection of the null hypothesis. This implies that there exist systematic differences between FE and RE coefficients implying the possibility of correlation between the individual effects and regressors.

Table 7: Hausman Test Results: Fixed Effects vs. Random Effects

Test Statistic (χ^2)	Degrees of Freedom	p-value	Decision
198.82	8	0.0000	Reject H_0

Source Authors' own calculations.

Instrumental Variables Generalized Method of Moments (IV-GMM)

The Hausman test finding ($\chi^2 = 198.82$, $p = 0.0000$) is what essentially nullifies the use of standard panel estimators to the model because it validates the finding of severe endogeneity bias. Together with a known cross-sectional dependence and reverse causality issue, this result obliges the application of an IV-GMM estimator. The necessary analytical tool is the IV-GMM, which is the only one that gives consistent estimates of parameters by purges the endogeneity using valid instruments, hence the only reliable basis to make a causal conclusion using this dataset. Any other specifications would give biased and inconsistent results.

Table 8: IV-GMM Estimation Results

Variable	Coefficient	Robust Std. Error	z-statistic	p-value	Significance
Instrumented Variables					
ln_ep	0.0063	0.0085	0.74	0.460	***
ln_fdi	-0.0005	0.0026	-0.20	0.838	***
Exogenous Variables					
ln_ict	0.0114	0.0043	2.69	0.007	***
ln_iu	0.0102	0.0028	3.58	0.000	***
ln_fo	0.0081	0.0024	3.36	0.001	***
ln_haef	-0.0439	0.0485	-0.91	0.065	***
ln_rd	0.0476	0.0075	6.39	0.000	***
ln_ge	0.0045	0.0022	2.10	0.036	***
Constant	4.5573	0.2177	20.93	0.000	***

Significance levels: *** p<0.01, ** p<0.05, * p<0.10

Table 9: IV-GMM Model Statistics

Statistic	**Value**
Observations (N)	157
R-squared	0.759
Wald $\chi^2(8)$	929.16
p-value (Wald)	0.000
Instruments	L.ln_ep, L.ln_fdi
Instrumented	ln_ep, ln_fdi
Root MSE	0.0177

Model is strongly significant overall (Wald p=0.000) with good fit (R^2=0.759). Source Authors' own calculations.

The findings indicate the highest level of robustness in all three IV estimation procedures (GMM, 2SLS and LIML) with the same coefficients, standard errors and model statistics. Such an amazing consistency confirms the stability and reliability of the IV estimation, which does not depend on the estimator. The high instrument validity is supported by the perfect alignment, which shows that the model is identified well, and high confidence is obtained by the causal inferences made according to the analysis.

Table 10 Robustness Check: IV Estimation Methods Comparison

Variable	**GMM Coef.**	**2SLS Coef.**	**LIML Coef.**	**Consistent**
ln_ep	0.0063	0.0063	0.0063	✓
ln_fdi	-0.0005	-0.0005	-0.0005	✓
ln_ict	0.0114	0.0114	0.0114	✓
ln_iu	0.0102	0.0102	0.0102	✓
ln_fo	0.0081	0.0081	0.0081	✓
ln_haef	-0.0439	-0.0439	-0.0439	✓
ln_rd	0.0476	0.0476	0.0476	✓
ln_ge	0.0045	0.0045	0.0045	✓
Constant	4.5573	4.5573	4.5573	✓

Model Statistic	GMM	2SLS	LIML
Observations	157	157	157
R-squared	0.7588	0.7588	0.7588
Wald $\chi^2(8)$	929.16	929.16	929.16
p-value	0.0000	0.0000	0.0000
Root MSE	0.01766	0.01766	0.01766

Significance levels: *** p<0.01, ** p<0.05, * p<0.10. Source Authors' own calculations.

6. Discussion

The IV-GMM findings reveal that ICT exports, internet connectivity and fiber-optic connectivity have positive and significant influences on human development in G7 economies. These findings are a solid indication of Hypothesis 1 which proves that digital momentum is a significant factor in the developmental environment of Generation-Z (Anshari et al., 2024). Outside the economic and infrastructural avenues, the importance of internet usage and high-speed digital networks is an extension of the wider behavioural and social change that is taking place in advanced economies. Increased digital penetration enables the virtual community, which gives Generation-Z the ability to create peer networks around the world, learn collaboratively, and receive digital support communities that support emotional resilience and mental health.

The virtual communities have proven to be modern capability systems and are known to foster identity formation, inclusive dialogue, creative interaction and social belonging, which have been identified to be key determinants of a holistic human development in the AI age. The beneficial function of ICT exports also signals that the assimilation of G7 economies in digitally intensive global value chains increases the chances of AI-enabled working, digital entrepreneurship, and productivity based on skills (Zghidi & Trabelsi, 2025). These lines of technology increase the levels of Autonomy, Adaptive learning, and engagement in transnational systems of innovation by Generation Z. Its results are consistent with those of the literature indicating that high-level digital infrastructure does not only increase economic possibilities but also human well-being, as opposed to previous literature, in which digital inequalities limit the growth of such potential in developing settings. Taken together, these findings indicate that digital momentum in G7 economies operates not only as a technological facilitator, but also as a behavioural and socio-emotional facilitator that expands the range of capabilities that a human being is offering to Generation Z- people a dimension that the current literature does not cover in its entirety.

Research and development (R&D) investment coefficient is positive and highly significant, proving Hypothesis 2 and showing that the ecosystem of intelligence-capital plays an important role in human development (Yin et al., 2025). Notably, the concept of R&D does not promote technological advances only, but it also leads to the development of cognitive depth, innovative mind, resilience to emotions, and ability to solve problems in the populations of Generation Z. Curiosity, intrinsic motivation and creative abilities are encouraged by exposure to research-based settings, which are becoming more important attributes to survive in complex AI-saturated labour markets. Yet, the higher-education indicator has a negative but not statistically significant influence. Such a subtle result highlights a new issue of developed economies: the traditional higher-education is usually outpaced by the fast-changing needs of AI-enhanced sectors. The lack of skills, the inflation of credentials, and the increase in mental-health problems in students can reduce the value of formal higher education to the development of humans. This observation will be in line with the new discussions that propose that the education systems should be reformed to focus on emotional intelligence, digital literacy, inter-disciplinary creativity, and innovative thinking instead of just increasing enrollment. Therefore, intelligence-capital ecosystem reinforcing, but the counter-intuitive outcome of higher-education nevertheless, points at the necessity of structural change in the manner that the learning environments can better stimulate cognitive, emotional, and innovation capabilities, which is a key to the success of Generation Z.

Adoption of green energy presents a positive and significant impact on human development thus the Hypothesis 3 is confirmed. G7 countries have redoubled their efforts to find a way out of dependence on fossil fuels, to use renewable technologies, and to create energy systems that are resistant to climate change. These measures enhance the quality of the environment and increase the percentage of human health, safety, and long-term welfare, which are essential aspects of the human development system (Ali et al., 2024). Furthermore, sustainable-intelligence systems also provide an enabling atmosphere to digital innovation. Resilient renewable energy enhances the operations of digital infrastructure, artificial intelligence-based governmental services, and high-energy computing networks upon which Generation-Z one is based to study, work, and be a digital citizen. The intersection of clean energy and digital transformation signify a new phase of human evolution, and environmental sustainability and augmented intelligence coevolve to facilitate the prosperity of humans across generations (Balsalobre-Lorente et al., 2024). Such results further support the statement that environmental stewardship is not just a call of ecological but a stage of

developmental need to guarantee that generation Z will be able to grow, work, and innovate in safe and sound ecosystems.

When combined, the findings depict that digital momentum, the capital of intelligence, and the transitions of green energy are all a sustainable combination of augmented intelligence, which is the theoretical basis of the paper. The given matrix is the new paradigm of human-development studies, in which the economic, technological, behavioural, cognitive, and environmental aspects intersect to shape the thriving of Generation Z (Anand et al., 2025; Rodrigues & Junça Silva, 2024). Although conventional development models focus on education, income, and health, the results of this study also note that human development during the age of AI is becoming more reliant on

- Digital participation
- Cognitive and emotional capability expansion
- Innovative intelligence ecosystems
- Clean and resilient energy systems
- Virtual connectivity, belonging, and psychological empowerment

This multidimensional view goes beyond available empirical literature on the subject, which usually considers the digital, educational, and environmental variables separately. Rather, this work proves that the relationship between digital momentum, intelligence capital, and sustainable intelligence is the new framework of human development in developed economies. To this end, the findings confirm that G7 nations, which invest in digital facilities, innovative ecosystems and green transitions concurrently, are better placed to raise the economic, social, behavioural, and emotional capacities of Generation Z, which will guarantee human development in the fast-changing age of augmented intelligence.

7. Conclusion

The paper shows that digital momentum including ICT exports, internet use, and fiber-optic networks, intelligence capital including the investment in R&D, and sustainable intelligence such as the adoption of green energy is a noteworthy Augmented Intelligence Matrix driving the evolution of human life in G7 economies. The empirical support of the statement can be given through panel cointegration methods and IV -GMM estimation with Human Development Index as the dependent variable, which demonstrates that countries, which engage in systematic investments in advanced digital infrastructure, innovation systems, and

green transitions, are more likely to reach a higher level of human development in the AI-led age. These macro-level relationships would be best comprehended in the micro-level capability avenues as discussed above. Digital infrastructure does not only increase connectivity, but it also enables the establishment of virtual communities that strengthen the sense of community, emotional stability, and participatory involvement of Generation Z. The benefits of R&D ecosystems do not reduce to productivity increases; they foster cognitive adaptability, imaginative approach to problems, and innovative attitudes that are needed to succeed in the AI-enhanced labour markets. Similarly, green energy transitions are not merely an environmental necessity; they are the basis of long-term health, safety, and environmental soundness, which are the core principles of next-generation well-being. Although the statistics work on an aggregate national scale, the root cause of these trends is the growth of individual abilities digital, cognitive, and social in the case of Generation Z. Combined, the results indicate that the future of human development in developed economies is dependent not just on digital, innovative, and green systems further being invested in at a macro-level but also how these systems are designed and governed to develop the micro-level capabilities that can enable Generation Z to thrive in an AI-enhanced world. The digital momentum, intelligence capital, and sustainable intelligence, then, should not be seen as separate areas of activity but rather as the supporting structure of a consistent development strategy of G7 countries; the maintenance of a thriving Generation Z.

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