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Can the Digital Economy Outperform the Oil Economy in Terms of Achieving Human Development?

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Abstract: The digital economy is reshaping the global economic landscape, with advancements in artificial intelligence, robotics, and virtual reality revolutionizing industries and transforming how people work and live. While the digital economy has promise in terms of improving human capital development, for example, through increased access to education and healthcare services, it also presents challenges, such as job displacement and income inequality. This study aims to evaluate the impact of the digital economy on human development indicators in the Kingdom of Saudi Arabia, seeking to understand how it influences education, health, and income levels. This paper provides valuable insights for policymakers seeking to enhance the Kingdom's position in the global human development race by examining the relationship between the digital economy and human development using econometric models. This paper analyzes data from the World Bank and the United Nations Development Program to measure the impact of the digital economy on sustainable human development indicators. The findings show that while the digital economy has negligible or negative influence on other human development indicators, it has a limited beneficial impact on education in the long run. In addition, attaining sustainable human development—which is consistent with Vision 2030—requires expanding the economy beyond the oil sector and fostering scientific and technological progress.

Keywords: digital economy; sustainable development; human capital; oil economy; econometrics model; human development indicators

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1. Introduction

The global economy is witnessing tremendous developments in the digital economy, which involves the widespread and increasing spread of digital technologies and the use of artificial intelligence, robotics, virtual reality, and other innovations. These innovations have a strong impact on the formation and development of human capital in all areas of health, education, and the standard of living. The digital economy may positively impact the quality of life through the opportunities it provides regarding self-employment, the development of digital knowledge for workers through education and training, as well as health and social care for individuals through internet platforms [1–3]. These can help in providing health information and consultations, delivering medicines, reducing the state of information asymmetry between doctors and patients, improving health literacy, and reducing the monopolistic practices of medical institutions in a way that enhances the mental and psychological health of community members [4,5].

On the other hand, the digital economy may have a negative impact on human development, as it imposes on the economies of countries the necessity of continuous change and a new approach to education, as most workers will be forced to constantly change

jobs within short periods in accordance with the requirements of the digital economy [6,7]. Nevertheless, the digital economy increases the need for education throughout life and the need to identify gaps in one's knowledge and skills, in addition to the increase in the unemployment rate for unskilled workers. There is a resulting gap in income levels between skilled and unskilled workers, in addition to the negative impact of the internet on the health of individuals through addiction to some games and YouTube, depression, and the inability of the elderly to obtain required medical services and consultations via the internet [8].

This contradiction is also evident in the fact that some countries that have enjoyed tremendous development in the digital economy still suffer from weak levels of human development [9]. In contrast, some countries that have not seen the development of their digital economy have high levels of human development [10]. For example, despite China's leading role in the field of digital economy, it was ranked 11th globally according to Global Innovation Index 2022 [11]. However, it ranked 79th globally according to the Human Development Index (HDI) [12]. Meanwhile, the Saudi economy ranked 51st in terms of the Global Innovation Index, but it received a ranking of 35th at the global level in relation to the HDI. On the other hand, Argentina received a ranking of 69th according to the Global Innovation Index, which indicates the weak state of its digital economy; it received a ranking of 47th on the HDI [12].

Given the contradiction surrounding the digital economy's contribution to human development, it is imperative to examine the effects of the digital economy on particular indicators of human development.

The digital economy has an impact on human development indicators, given the opportunities and challenges this economy poses in terms of achieving the Kingdom of Saudi Arabia's Vision 2030 and its transformation from a rentier economy to a diversified economy based on scientific, technological, and human progress [13].

In light of the aforementioned discussion, the hypothesis of this paper is that the performance of a digital economy can be higher than the performance of an oil economy in terms of achieving human development. Consequently, the following questions can be used to summarize the study's problem:

1- To what extent does the digital economy impact sustainable human development indicators in the Kingdom of Saudi Arabia?

Several sub-questions emerge from this question:

- What is the impact of the digital economy on the education index?
- What is the impact of the digital economy on the health index?
- What is the impact of the digital economy on the income index?

2- What is the relative importance of the digital economy compared to the oil economy in influencing indicators of human development?

The main objective of this paper is to determine the impact of the digital economy on the various dimensions of human development in the fields of health, education, and income in a way that enables policymakers to advance these fields and enhance the Kingdom's pioneering role in the human development race at the global level.

This paper contributes to our knowledge of how the digital economy affects certain human development indicators, such as income level, health, and education. Additionally, contrasting the effects of the oil and digital economies is a novel addition, as the previous literature has only focused on education to explain human development [13]. This study employs an econometrics methodology to elucidate the concept, indicators, and significance of the digital economy in relation to human development. The motivation of this paper is to identify the primary channels through which it influences health, education, and income levels by examining prior research findings. The actuality of these indicators in the Kingdom of Saudi Arabia in relation to the country's primary industry—oil—is also covered in this paper.

Using a cointegration bounds testing methodology, this paper estimates an autoregressive distributed lag model (ARDL) to measure the equilibrium relationships over the short and long terms (1990–2020). Therefore, this paper tests for a causal relationship by applying the Granger causality test.

This paper is based on World Bank data, using the ratio of medium- and high-technology exports to total industrial exports. The number of mobile phone subscribers is used as an indicator of the digital economy. This paper relies on the Human Development Report to measure sustainable human development indicators, which is in agreement with most of the previous literature. The index presented by the United Nations Development Program covers the dimensions of health, education, and an adequate standard of living. Despite the efforts of some researchers and sources to define sustainability, the available data are limited to the index issued by the United Nations Human Development Report, which is what the current paper relies on.

The remaining part of this paper proceeds as follows: Section 2 presents the literature review of the digital economy that affects different dimensions. Section 3 analyzes the situation of both the digital economy and human development in the Kingdom of Saudi Arabia. This effect is then measured by formulating and estimating the econometric model in Section 4. Section 5 offers the findings of the research and recommendations.

2. The Literature Review

The digital economy contributes to improving the level of education, disseminating knowledge, and, thus, enhancing the standard of living for populations [14]. It develops and improves competencies in all fields, increases awareness about healthy living, and facilitates health treatment practices in a way that promotes human development. Human development is the foundational element needed to boost economic growth. A highly educated workforce leads to more innovations and inventions being created, which increases productivity, reduces production costs, and expands purchasing options due to market expansion, thereby stimulating economic growth [6]. Previous studies have confirmed this relationship by relying on indicators of the digital economy that are expressed using information and communications technology. For example, a study by Zhang and Danish [15] that included a sample of 29 developing Asian countries during the period from 1990 to 2016 used the cellular phone diffusion index (per 100 people), the Internet penetration rate, and the HDI. The results showed that the best HDI rankings and phone usage levels correlated with economic growth, standing in contrast with the findings regarding the internet usage index due to the weak internet infrastructure in these countries. This was corroborated by Kamil and Pratama [16], who investigated Southeast Asian countries during the period from 2011 to 2015. Similarly, a study by Audi et al. [17] emphasized the positive impact of Information Communication technology (ICT) on human development in Arab countries, but the significance of the indicators varied. They concluded that the index of the number of fixed telephone subscribers per 100 people, followed by the index of the percentage of personal internet use, had significant impacts, whereas the influence of the cellular telephone subscriber index per person on human development was not proven. Some studies have shed light on the dimensions of human development, namely, education, health, and income, in an attempt to examine the partial relationship between the digital economy and one of these dimensions, as will be examined below.

2.1. Education

Digital economy services contribute to social connectivity and data availability and invest in human capital education [18]. Moreover, they can enhance workers' skills in the labor market through training, learning platforms, and online certification. Rahman [19] highlights this in his study on leveraging the Indonesian digital economy to invest in human capital, provide social and economic support, and, thus, stimulate the economy. He notes that there is a need to increase the current investment in Indonesia's digital economy to leverage human capital's potential more effectively for the sake of healthier economic

growth. Corporate stakeholders and government policymakers, who are directly affected by the Indonesian economy, can leverage the benefits offered by the digital economy sector to invest in human capital and stimulate economic growth. This study included an analysis of the social and economic situation in Indonesia in 2020, analyzing trends in the economic capabilities of the population, digital data communication, and education levels. It showed that investing in the human capital of the country's population enhanced economic growth via economic empowerment, education, and technological progress for the general population.

Barykin et al. [20] attempted to identify changing trends in the educational system, which were in line with the conditions of the digital economy and the requirements of the labor market. They identified the main areas for improvement in the Russian educational system, showing that in the context of rapidly changing technologies, professions, and labor market requirements, it was better to divide the higher education system into several sectors. The first would be short-term higher education, and the second would consist of specialized training in the field of work. Their study concluded by proposing a new model for transformation in the higher education system based on this division. On the other hand, education is a crucial determinant of the development of the digital economy, as addressed by Miethlich et al. [21]. Their study emphasized the role of intellectual labor potential in economic development and digitalization and explored the features of intellectual labor and education as a primary source and component of the digital economy. It analyzed the achievements of Slovak, Ukrainian, and Russian digitalization and their main benefits in terms of the global transformation process. The development of the digital economy is closely linked to human labor potential and, primarily, levels of education. Higher education always implies high digital literacy. Currently, every educational process requires significant digital capacity to allow both students and teachers to benefit from digital technologies and ICT in the teaching and learning processes. This study concluded that the digital economy would lead to a new digital quality of life among Slovaks, Ukrainians, and Russians but also result in serious changes in social relationships and the organization of markets, with consequences for education, jobs, skills, and security. Furthermore, a study by Rodchenko et al. [22] stated that the effectiveness of human capital in light of the digital transformation of the economy depends on understanding the advantages and disadvantages of using digital technologies, as well as the efficient use of these technologies. The results showed that a low level of awareness of the human element of digitalization had a negative impact on developing business digitization, digital competencies, and a culture of digital development.

2.2. Health

The development of the digital economy has significantly impacted public health by enhancing the mechanisms for accessing information. The digital economy offers diverse platforms for obtaining health information, such as online health knowledge inquiries, complete medical treatments through contactless online consultations, and participation in offline medicine delivery [8]. This has effectively diminished the monopoly that medical institutions had over professional information and reduced information asymmetry between doctors and patients. Online health services can also improve personal health literacy and strengthen individual health management. Moreover, You, Zhong, Gao, Wei, and Zeng [8] indicate that users of platforms such as the internet can improve their health by searching for disease information and participating in online health activities. These mechanisms also facilitate communication through social activities, leisure, and entertainment, which can help alleviate personal loneliness, depression, or anxiety, thereby promoting mental health.

Several studies have focused on healthcare and health investment. For example, Abdurakhmanova et al. [23] emphasize the importance of investing in human health alongside education and science, highlighting the economic value of health and its significance for human capital accumulation. Investing in healthcare is a priority expense that can extend life, prolong the duration of human capital, and enhance labor productivity. Physically

weak and sick employees cannot fully utilize their human capital; therefore, companies have an economic incentive to invest in the health of their employees. Additionally, You, Zhong, Gao, Wei, and Zeng [8] explored the relationship between the development of the digital economy, measured by the growth rate of internet users and the rate of internet diffusion, and population health, measured by the rate of malnutrition in children under five, in China. They found that there might be structural changes in how the digital economy affected health as the population aged. The experimental results showed an increased positive impact on the part of the digital economy on the health of the general population compared to the aging population.

The digital economy has also streamlined numerous regulatory and operational processes for companies operating in the healthcare field, especially during the COVID-19 pandemic. Merzlyakova et al. [24] presented promising trends in the healthcare sector's development, which were driven by the adoption of artificial intelligence, robotics, 3D printing, and other comprehensive digital technologies. This study also highlighted specific limitations in this field, such as gaps in patent and licensing law, and suggested that the findings could serve as a theoretical basis for managing the development of the healthcare sector in the digital economy era. Lastly, Liu et al. [25] addressed how an open innovation strategy could aid the UK healthcare sector in responding flexibly to the COVID-19 crisis.

Global health crises are being managed differently by companies and society as a result of the pandemic's large and disruptive technology advancements in the healthcare industry [26]. Many creative initiatives have been developed, such as the quick design and production of personal protection equipment, medical equipment, and immunization, testing, and treatment technologies. Existing research recognizes the specific impact of digitalization during the pandemic on society, and it came to the conclusion that technological intervention with an emphasis on sustainability-oriented innovation was required for the healthcare industry and society to recover under digitalization [27,28].

2.3. Income

The digitization of practices has a profound influence on wages and income. It may lead to a significant number of layoffs among workers in traditional sectors and routine jobs, reducing the number of current positions that require an average level of qualifications. This also results in an increased disparity in wage levels between skilled and unskilled workers. On the other hand, as a result of the development and dissemination of digital technologies, digital platforms emerge, and these expand workers' possibilities of finding jobs, including workers with social or geographical restrictions. Digital technologies help employees develop additional professional skills and improve their qualifications, thereby enhancing their wages [29]. In addition, digitization contributes to the emergence of new professions related to processing information, as well as new high-paying jobs [30].

A study by Ogli and Ogli [31] regarding modern forms of employment in light of the tremendous developments in the digital economy in the Republic of Uzbekistan indicated that the development of information technology, combined with automation, computing, and robotics, will lead to technical, social, and economic changes. The digitization of employment can lead to not only the emergence of new professions in fields such as analysis and software development but also the disappearance of certain business areas that can be automated. As a result, it is expected that the gap between high-wage and low-wage jobs will expand. This includes the emergence of new forms of employment, such as virtual employment, part-time work, gig jobs, as well as an increase in temporary unemployment. In light of this, it is necessary to regulate relations between the state, employers, and employees to protect their benefits, which will only be possible through organizing wages and a remote-work rewards system and defining the obligations and rights of job owners.

Lee and Clarke [32] explored the economic impact of high-tech industries on workers with medium and low skill levels using data from UK domestic labor markets during the period from 2009 to 2015. They found that high-tech industries based in science, technology,

engineering, and mathematics sectors, such as oil, gas, and pharmaceuticals, have a positive job multiplier. For every ten new high-tech jobs created, about seven non-tradable local service jobs are generated, with about six of these being filled by low-skilled workers. While employment rates for medium-skilled workers will not increase, they will benefit from higher wages. Furthermore, the loss experienced by low-skilled workers may be represented by lower wages associated with reduced productivity. High-tech industries also stimulate innovation in other sectors through input–output links, but most new jobs are designed for low-skilled workers in the non-tradable sector. This study concluded that the growth of high-tech industries increases the number of jobs but reduces wage growth. The labor market may allow for the entry of marginalized workers, who will have low productivity and low wages, thereby creating new careers for low-skilled workers in non-trade businesses.

Previous studies have attempted to demonstrate the positive effects of the development of the digital economy on the quality-of-life index, an indicator that reflects sustainability in human development. For example, a study by Tenio [33] used a comparative analysis approach between Algeria and the United Arab Emirates, highlighting the role of the digital economy in achieving quality of life as a new concept in sustainable development. It analyzed important digital economy indicators, such as the Network Readiness Index, the ICT Development Index, and quality of life indicators, such as the Human Development Index and the Mercer Index. This study concluded that the digital economy in the Emirates had a positive impact on economic and social development, which reflected positively on the quality of life of its citizens. Digital transformation contributed to economic growth, raised the level of healthcare by relying on digital technologies, and brought education to advanced positions due to e-learning. Digital technologies have also contributed to improving transportation, building smart cities, and alleviating environmental pollution. Meanwhile, a study by Kryzhanovskij et al. [34] linked achieving quality of life to human development. Through research, it explored how the digital economy can promote quality of life. Using correlation to determine mutual relationships, it employed indicators such as the Global Ranking of Digital Competitiveness (WDCR), the HDI, and the Happiness Ranking (RH) to express the quality of life. The results showed a close relationship between the subjective and objective indicators of quality of life represented by human development and the digital economy. This is consistent with the findings of the study by Grigorescu, Pelinescu, Ion, and Dutcas [6], which indicated that the digitalization of the economy and advanced human capital ultimately lead to increased well-being in the population.

To examine the relative importance of some digital economy indicators for the subindices of the HDI, Bankole et al. [35] investigated the impact of ICT investment on human development in 51 countries during the period from 1994 to 2003. It analyzed the relationship between the four dimensions of ICT investment (hardware, software, internal spending, and investments in wired and wireless communications) and the three components of the Human Development Index (standard of living, measured by GDP per capita; education, measured by literacy and school enrollment; and health, measured by average life expectancy). This study concluded that the four dimensions of investment in ICT impacted the components of human development in various ways and that these impacts varied across the economies of high-, middle- and low-income countries. Nipo et al. [36] evaluated the effect of internet use and digital literacy on human development, as expressed by the HDI, by applying it to 38 countries during the period from 2015 to 2018. The analysis results indicated that internet use and digital literacy had a positive impact on human development. This evidence suggests that having a large number of internet users and a high level of digital literacy is an important way to promote human development. This study also explained that digital literacy was an essential skill in promoting the effective use of the Internet in order to achieve greater social and economic well-being for the community.

Regarding the impact of the oil sector on HDI, Haque and Khan [37] found that government spending and oil exports were significant drivers of the HDI in Saudi Arabia.

This study estimated that an increase in oil production by 100 million barrels would lead to a 4% increase in the HDI. Similarly, a 1% increase in total government spending leads to a 10% increase in the HDI. This study forecasts that by 2030, the HDI will reach 0.94, positioning Saudi Arabia among the top five countries in terms of the HDI. In contrast, a study by Akoto et al. [38] on the relationship between oil revenues and the HDI in Ghana using a simple regression analysis of quarterly data on oil revenues from 2010 to 2018 found a weak negative relationship between petroleum revenues and the HDI. It also confirmed that increased oil revenues had no significant impact on the HDI. This contradicts the belief that increasing oil revenues should lead to an improvement in citizens' living standards. The reason may be that the quality of spending was low despite the increase in oil revenues; however, the fact that the quality of spending truly impacts human development was not tangible, and it did not improve citizens' living conditions.

It is clear from the above that previous studies have addressed the relationship between the digital economy and human development in general by using various indicators and applying them to countries and time periods that differ from those addressed in the current study. Additionally, the studies that investigated the dimensions of human development and the impact of the digital economy on them used indicators of ICT that differed from the indicators on which the current study is based. They were applied over a relatively long period of time, which did not reflect contemporary transformations and recent developments in the digital economy and human development. Furthermore, the comparison of the impact of the digital economy being greater than that of the oil sector in terms of achieving human development was not explicitly addressed in the previous literature. This indicates that there is a gap in the economic literature related to these relationships, especially in the Kingdom of Saudi Arabia from 1990 to 2020.

3. The Digital Economy and Sustainable Human Development in Saudi Arabia

This section is intended to highlight the digital economy in the Kingdom of Saudi Arabia, specifically assessing the extent of its success in terms of digital transformation. This assessment relies on a set of indicators to determine its level of development with respect to digital metrics. It is important to note that, thus far, no unified indicators have been adopted to measure the digital economy. This is due to the significant controversy surrounding this emerging economy and the challenges associated with measuring and distinguishing it from the oil economy.

Firstly, there is the Network Readiness Index (NRI). Saudi Arabia is ranked 41st out of 134 economies, according to the NRI. In terms of the specific dimensions or pillars used to evaluate this index, the Kingdom ranks 36th in technology, 31st in people readiness, 50th in governance, and 62nd in terms of impact, as shown in Figure 1.

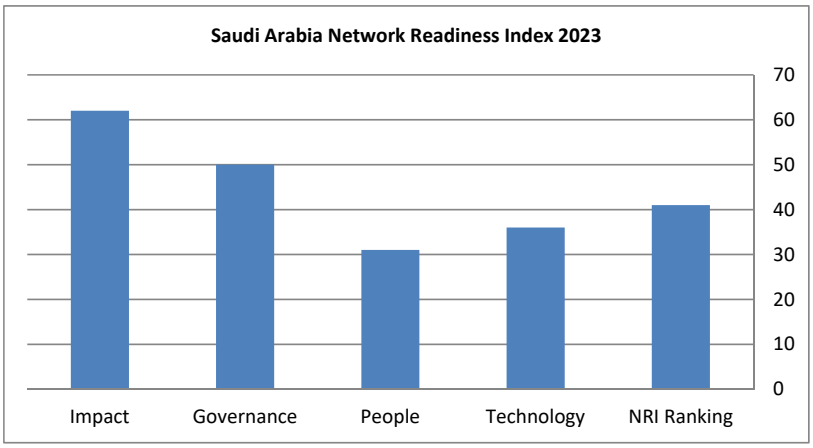

Figure 1. The global ranking of the Kingdom of Saudi Arabia according to the Network Readiness Index and its four dimensions for 2023. Source: prepared by the researcher according to data reported by Portulans Institute (2023) [39].

According to the performance and ranking of Saudi Arabia at the pillar or dimension level of the NRI, the strongest sub-sections of this index for Saudi Arabia relate to accessibility, future technologies, and individuals, among other indicators. However, there is a need for more concerted efforts to improve the Kingdom's performance in the sub-pillars of content, organization, and contributions to meeting sustainable development goals, as shown in Table 1.

Table 1. The Kingdom's ranking according to the sub-dimensions of the Network Readiness Index for the year 2023.

Ranking	Sub-Dimensions	Ranking	Sub-Dimensions
30	Access	44	Trust
80	Content	98	Regulation
19	Future technologies	30	Inclusion
10	Individuals	47	Economy
40	Businesses	38	Quality of life
35	Governments	104	SDG Contribution

Source: prepared by the researcher according to data reported by Portulans Institute (2023) [39].

Secondly, there is the Global Innovation Index. According to Table 2, Saudi Arabia's ranking in the Global Innovation Index improved from 68th in 2019 to 48th in 2023. The Kingdom's performance in innovation inputs also increased its ranking from 49th in 2019 to 37th in 2023. Regarding innovation outputs, the Kingdom of Saudi Arabia achieved a ranking of 67th in 2023 compared to 85 in 2019.

Table 2. Ranking of the Kingdom of Saudi Arabia according to the Global Innovation Index GII (2019–2023).

Year	GII	Innovation Inputs	Innovation Outcomes
2023	48	37	67
2022	51	37	65
2021	66	59	72
2020	66	50	77
2019	68	49	85

Source: Prepared by the researcher according to WIPO data, various issues [11,40].

As illustrated in Figure 2, regarding the components of the Global Innovation Index for the Kingdom of Saudi Arabia in 2023, Saudi Arabia demonstrates its strongest performance in human capital and research, market sophistication, institutions, and business sophistication. Conversely, its weakest performance is observed in the institution's component.

Third, there is the HDI. In 2020, the HDI value for the Kingdom of Saudi Arabia, at 0.854, remained unchanged from 2019, as shown in Figure 3. This consistent performance places the Kingdom in the 40th place among 189 countries. Saudi Arabia also ranked second among Arab countries and is listed among the countries with very high human development, according to the Human Development Report issued by the United Nations Development Program for 2020.

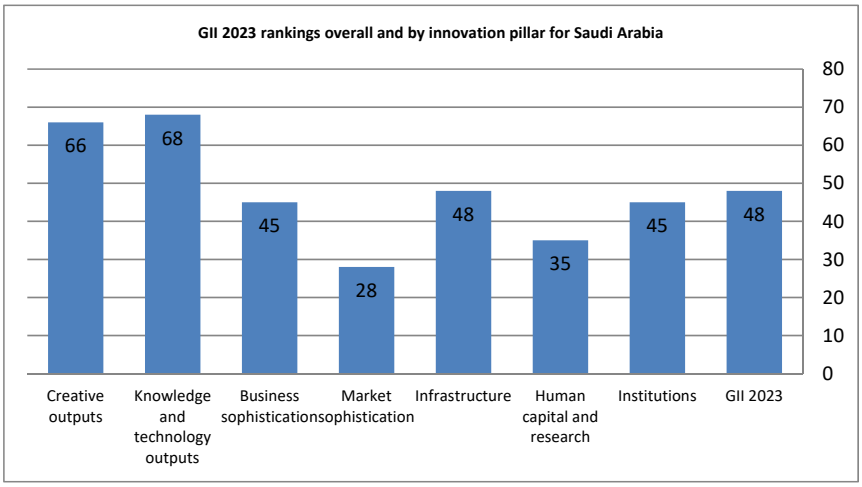

Figure 2. Areas of the Global Innovation Index for the Kingdom of Saudi Arabia in 2023. Source: prepared by the researcher according to WIPO data (2023) [40].

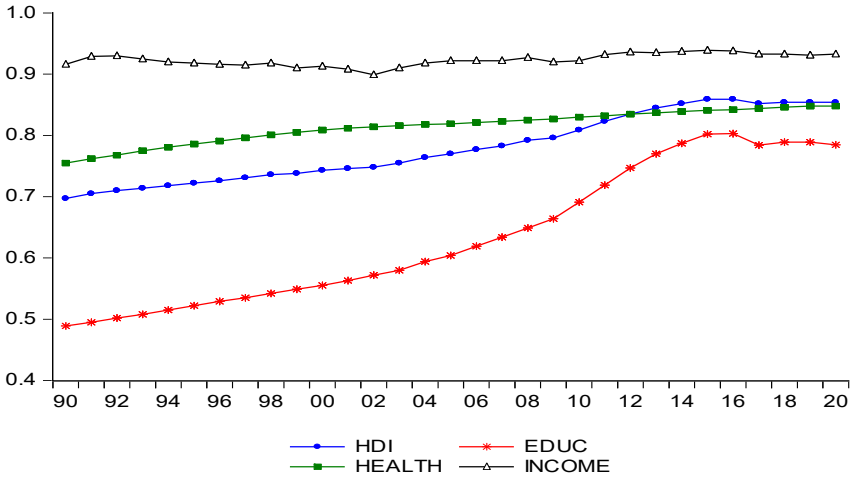

Figure 3. Evolution of human development indicators for the Kingdom during the period 1990–2020. Source: prepared by the researcher according to human development indicators by World Bank http://databank.worldbank.org/data/source/world-development-indicators, accessed on 23 December 2023 [41].

As illustrated in Figure 3, which details the development of human development indicators for the Kingdom of Saudi Arabia, there has been a clear increase in the Kingdom's focus on improving education, health, and the standard of living. Figure 3 also highlights a significant increase in the education index in recent years. This improvement reflects the Kingdom's dedication to developing educational systems and efforts to digitally transform education. This strategic shift toward distance education includes the provision of various tools and channels, such as electronic platforms, YouTube channels, and satellite channels, all of which are aimed at enhancing citizens' ability to adapt to the demands of the digital economy. Additionally, the Kingdom's commitment to enhancing the quality of life and well-being of its citizens is evident in the improvements seen in health and income indicators.

4. Methodology

This study employs the bounds tests for cointegration within the ARDL framework [42] to analyze the long- and short-term equilibrium relationships between the digital economy and sustainable human development indicators in the Kingdom of Saudi Arabia over the period from 1990 to 2020. Additionally, the causal relationships between variables

are estimated using pairwise Granger causality, which necessitates conducting unit root tests to ensure the stability of the time series.

This study sources its data from the World Development Indicators database provided by the World Bank, which offers digital economy indicators, and from the United Nations Development Program, which provides the general index of sustainable human development, along with its sub-indices. In cases involving oil-based economies, it is pertinent to underscore the relative significance of the digital economy compared to the traditional rentier economy, which relies on oil, in fostering Saudi Arabia's capacity for sustainable human development. This comparison includes referencing oil prices from the annual report of the Saudi Central Bank.

The general index of sustainable development is the HDI, which includes three sub-indices: knowledge, as measured by education (EDU) based on expected years of study and average years of study; a long and healthy life, as indicated by life expectancy at birth; and an adequate standard of living, as gauged by per capita GDP in US dollars at purchasing power parity.

Regarding digital economy indicators, LMHTECH_EX denotes the proportion of high- and medium-technology exports out of total industrial exports. Furthermore, LMOB_SUB represents the number of mobile cellular subscriptions. The rentier economy is represented by LOIL, which reflects the price of a barrel of Arab light oil in US dollars. The natural logarithms of these variables are used, and descriptive statistics for these can be found in Table 3.

Table 3. Descriptive statistics.

Variables	HDI	EDU	HEALTH	INCOME	LMHTEC_EX	LMOB_SUB	LOIL
Mean	0.777100	0.630033	0.813267	0.923133	3.328609	14.94484	3.625852
Median	0.767000	0.599000	0.818500	0.922000	3.237174	16.24915	3.627212
Maximum	0.859000	0.803000	0.848000	0.939000	4.111242	17.80449	4.702478
Minimum	0.697000	0.489000	0.755000	0.899000	2.885003	9.605822	2.501436
Standard deviation	0.054593	0.109979	0.026290	0.010064	0.344082	3.147261	0.708597
Skewness	0.261030	0.394166	−0.665889	−0.254140	0.920645	−0.742817	0.085064
Kurtosis	1.632591	1.647091	2.448788	2.442735	3.082103	1.997532	1.555825
Jarque–Bera	2.677944	3.064788	2.596836	0.711116	4.246364	4.015059	2.643233
Probability	0.262115	0.216018	0.272963	0.700782	0.119650	0.134320	0.266704
Sum	23.31300	18.90100	24.39800	27.69400	99.85827	448.3452	108.7756
Obs.	30	30	30	30	30	30	30

To estimate the impact of the digital economy and the oil economy indicators as independent variables, along with the general HDI and its sub-indices as dependent variables, along with the general human development index and its sub-indices as dependent variables, the following general functions can be formulated:

$$\text{HDI_Index} = (\text{M\&Htech_ex, Mob_sub, Oil}) \quad (1)$$

$$\text{Edu_Index} = (\text{M\&Htech_ex, Mob_sub, Oil}) \quad (2)$$

$$\text{Health_Index} = (\text{M\&Htech_ex, Mob_sub, Oil}) \quad (3)$$

$$\text{Income_Index} = (\text{M\&Htech_ex, Mob_sub, Oil}) \quad (4)$$

where

HDI_Index: General Human Development Index.

Health_Index: Life expectancy at birth.

Income_Index: Average per capita GNP in US dollars based on purchasing power parity.

MHtech_ex: Represents high and medium technology exports as a proportion of total industrial exports.

Mob_sub: Number of mobile cellular subscriptions.

Oil: The price of a barrel of Arab light oil in US dollars.

It is necessary to estimate the equilibrium relationships in the short term and the long term using an Autoregressive Distributed Lag (ARDL) methodology to formulate the following models:

$$\Delta hdi_t = \alpha_0 + \sum_{i=1}^{m} \alpha_1 \Delta hdi_{t-1} + \sum_{i=1}^{m} \alpha_2 \Delta lmhtec_ex_{t-1} + \sum_{i=1}^{m} \alpha_3 \Delta lmob_sub_{t-1} + \sum_{i=1}^{m} \alpha_4 \Delta Loil_{t-1} + \alpha_5 \Delta hdi_{t-1} + \alpha_6 \Delta lmhtec_ex_{t-1} + \alpha_7 \Delta lmob_sub_{t-1} + \alpha_8 \Delta Loil_{t-1} + \epsilon_{1t} \quad (5)$$

$$\Delta edu_t = \gamma_0 + \sum_{i=1}^{m} \gamma_1 \, \Delta edu_{t-1} + \sum_{i=1}^{m} \gamma_2 \, \Delta lmhtec_ex_{t-1} + \sum_{i=1}^{m} \gamma_3 \, \Delta lmob_sub_{t-1} + \sum_{i=1}^{m} \gamma_4 \, \Delta Loil_{t-1} + \gamma_5 \, \Delta edu_{t-1} + \gamma_6 \, \Delta lmhtec_ex_{t-1} + \gamma_7 \, \Delta lmob_sub_{t-1} + \gamma_8 \, \Delta Loil_{t-1} + \epsilon_{2t} \quad (6)$$

$$\Delta health_t = \sigma_0 + \sum_{i=1}^{m} \sigma_1 \, \Delta health_{t-1} + \sum_{i=1}^{m} \sigma_2 \, \Delta lmhtec_ex_{t-1} + \sum_{i=1}^{m} \sigma_3 \, \Delta lmob_sub_{t-1} + \sum_{i=1}^{m} \sigma_4 \, \Delta Loil_{t-1} + \sigma_5 \, \Delta health_{t-1} + \sigma_6 \, \Delta lmhtec_ex_{t-1} + \sigma_7 \, \Delta lmob_sub_{t-1} + \sigma_8 \, \Delta Loil_{t-1} + \epsilon_{3t} \quad (7)$$

$$\Delta income_t = v_0 + \sum_{i=1}^{m} v_1 \, \Delta income_{t-1} + \sum_{i=1}^{m} v_2 \, \Delta lmhtec_ex_{t-1} + \sum_{i=1}^{m} v_3 \, \Delta lmob_sub_{t-1} + \sum_{i=1}^{m} v_4 \, \Delta Loil_{t-1} + v_5 \, \Delta income_{t-1} + v_6 \, \Delta lmhtec_ex_{t-1} + v_7 \, \Delta lmob_sub_{t-1} + v_8 \, \Delta Loil_{t-1} + \epsilon_{4t} \quad (8)$$

where Δ is the first difference; ε is the random error term, and $\alpha_{1:4}$, $\gamma_{1:4}$, $\sigma_{1:4}$, $v_{1:4}$ are short-term dynamic parameters. The parameters $\alpha_{5:8}$, $\gamma_{5:8}$, $\sigma_{5:8}$, $v_{5:8}$ are long-term parameters, which are assumed under the null hypothesis of 'no cointegration' when they are equal to zero.

H0: $\alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = 0$;
H0: $\gamma_5 = \gamma_6 = \gamma_7 = \gamma_8 = 0$;
H0: $\sigma_5 = \sigma_6 = \sigma_7 = \sigma_8 = 0$;
H0: $v_5 = v_6 = v_7 = v_8 = 0$.

The null hypothesis is rejected if a statistical F value is greater than the critical value of the upper critical bound, indicating the existence of a cointegration relationship between the dependent variable and the independent variables.

5. Results

Unit root tests are crucial in determining the degree of cointegration between variables. However, relying solely on standard unit root tests, such as the augmented Dickey–Fuller (ADF) and the Phillips–Perron (PP) tests, without accounting for structural changes in the time series, may lead to biased results. Typically, accepting the null hypothesis—indicating the presence of a unit root—suggests that the time series is not stationary if these structural changes and breakpoints are ignored. Such breakpoints are often linked to external shocks to macroeconomic variables or changes in government policies. Ignoring them results in an inaccurate estimation of the degree of cointegration between the variables. Perron [43] highlighted this issue and emphasized the importance of incorporating structural changes or breakpoints into the tests, an approach that has been further developed by Zivot and Andrews [44].

This paper has utilized the breakpoint unit root test, which employed an innovative outlier's model, allowing for a gradual shift in the mean of the time series. To ensure robust results, unit root tests will initially be conducted without considering breakpoints, as shown in Table 4, followed by tests that take these breakpoints into account in Table 5.

Based on the results presented in Tables 4 and 5, the variables are stationary at the first level of difference, which indicates the validity of applying the ARDL approach to test for an equilibrium relationship in the short and long terms.

Table 6 displays the results of bounds testing for the existence of a long-term equilibrium relationship between variables. Four models were estimated to express the relationship between digital economy indicators and the general HDI and its sub-indices. The

rentier economy index was also included as an independent variable. The optimal lag periods for estimation were determined based on the Akaike information criterion.

Table 4. Results of ordinary unit root tests without breaking points.

Variables	ADF		PP	
	The Level	The First Difference	The Level	The First Difference
HDI	−2.967193 (0.1591)	−2.351052 (0.3955)	−1.638604 (0.7530)	−2.420947 (0.3619)
EDU	−3.007656 (0.1485)	−1.775041 (0.6906)	−1.809829 (0.6747)	−1.770905 (0.6926)
HEALTH	−5.273914 (0.0009) *	−2.480782 (0.3343)	−4.189365 (0.0128) *	−2.363264 (0.3895)
INCOME	−1.826780 (0.6664)	−5.400929 (0.0007) *	−1.826780 (0.6664)	−5.400929 (0.0007) *
LMHTEC_EX	−2.093622 (0.5242)	−5.228406 (0.0015) *	−3.150184 (0.1136)	−5.566263 (0.0005) *
LMOB_SUB	−0.451921 (0.9795)	−3.667128 (0.0433) **	−0.203291 (0.9898)	−4.817322 (0.0032) *
LOIL	−1.313035 (0.8651)	−4.375500 (0.0089) *	−1.507018 (0.8046)	−4.222956 (0.0122) **

The tests were evaluated in the case of secant and direction. * Significant at 1%; ** Significant at 5%.

Table 5. Results of unit root tests Z&A with breaking points.

Variables	The Level		The First Difference	
	t-Statistics	Breakpoint	t-Statistics	Breakpoint
HDI	−4.945582 (0.0387)	2010	−5.397699 (<0.01)	2015
EDU	−4.858666 (0.502)	2017	−5.640480 (<0.01)	2009
HEALTH	−4.986941 (0.345)	2018	−3.898218 (0.4368)	2009
INCOME	−2.894679 (0.9380)	2000	−5.735093 (<0.01)	2015
LMHTECH_EX	−2.962027 (0.9224)	2009	−6.392254 (<0.01)	2005
LMOB_SUB	−4.296587 (0.2089)	2004	−3.527496 (0.6765)	2006
LOIL	−3.705716 (0.5615)	2014	−5.604171 (<0.01)	2015

Table 6. Bounds test results ARDL for cointegration.

Sample	Dependent Variable	Optimal Lag Period	The Condition	F-Statistic	Results
(1)	HDI	ARDL(1, 2, 4, 4)	Trend	20.95811	There is long-term relationship
(2)	EDU	ARDL(2, 4, 3, 3)	None	8.955854	There is long-term relationship
(3)	HEALTH	ARDL(4, 3, 4, 4)	constant	5.142104	There is long-term relationship when 5% *
(4)	INCOME	ARDL(4, 0, 3, 4)	Trend	14.60242	There is long-term relationship

How to choose the slowdown period: Akaike info criterion (AIC); * Less than the upper limit I1 Boundat 1%, which equals (5.61).

The results in Table 7 indicate a long-term cointegration equilibrium relationship, as the statistical F-values are greater than the critical values of the upper bound. The year marking the breakpoint was incorporated into the model estimations. The results of the unit root tests indicate that the time series of the variables has a structural change in this specific year. The significance of this year was confirmed by the estimation results, validating the importance of including it in the model to ensure structural stability, as supported by the Cumulative Sum (CUSUM) and CUSUM of Squares tests, as shown in Figure 4.

Table 7. Results of the equilibrium relationship in the short and long terms.

Variables	HDI		EDU		HEALTH		INCOME	
	Parameter Value	Probability	Parameter Value	Probability	Parameter Value	Probability	Parameter Value	Probability
Short term								
D(LMHTEC_EX)	−0.021583	0.0010	−0.015062	0.0711	−0.000907	0.3311	−0.011733	0.0374
D(Mob_sub)	−0.002555	0.0213	−0.004589	0.0643	−0.000598	0.4454	−0.004075	0.0081
D(LOIL)	0.002856	0.1575	0.001100	0.8371	0.001593	0.1291	0.007493	0.0116
Breakpoint(2009)	0.012466	0.0006	-	-	-	-	−0.008720	0.0112
Breakpoint(2017)	−0.023237	0.0047	-	-	0.002963	0.0322	-	-
D(@TREND)	0.002621	0.0882	-	-	-	-	0.003385	0.0002
CointEq (−1)	−0.418317	0.0040	−0.276397	0.0005	0.050979	0.7059	−1.495939	0.0001
Long term								
LMH_EX	−0.052726	0.0084	0.104250	0.0001	0.015568	0.6920	−0.007843	0.0509
LMOB_sub	−0.005631	0.1297	0.010864	0.0227	0.023624	0.5522	−0.006926	0.0000
LOIL	0.029176	0.0004	0.035440	0.2369	−0.063855	0.6339	0.020751	0.0000
Breakpoint(2009)	-	-	-	-	-	-	−0.005829	0.0164
Breakpoint(2010)	0.029801	0.0008	-	-	-	-	0.944236	0.0000
C	0.838664	0.0000	-	-	0.623437	0.0001	-	-
D(@TREND)	0.006266	0.0084	-	-	-	-	0.002263	0.0000

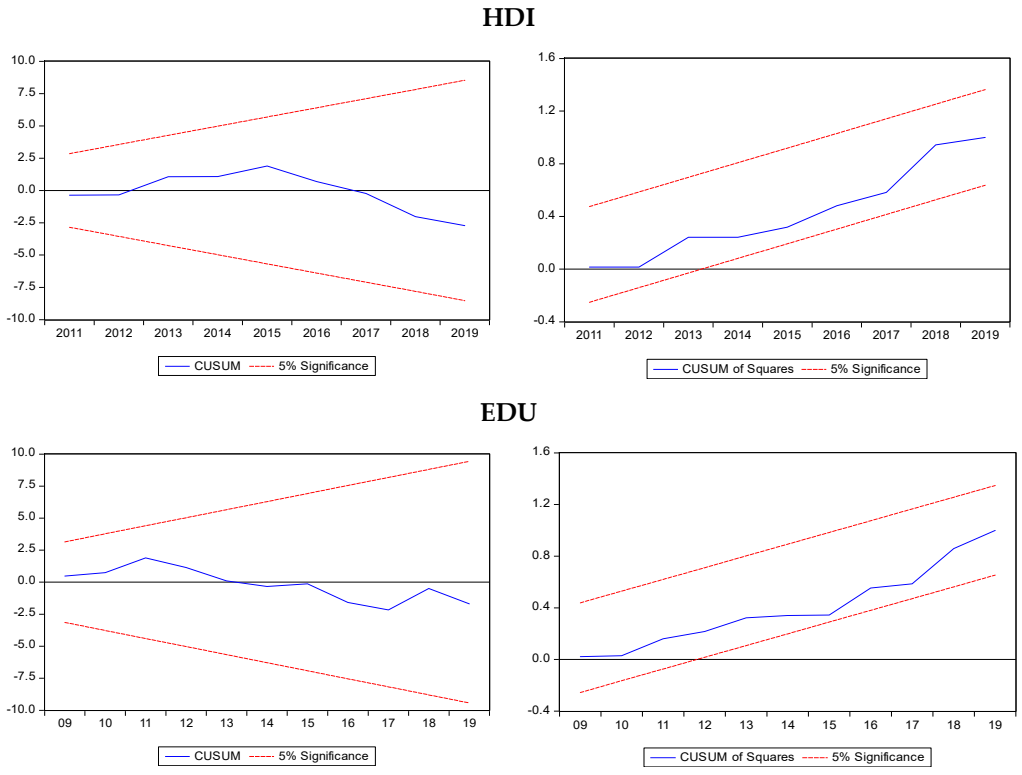

Figure 4. *Cont.*

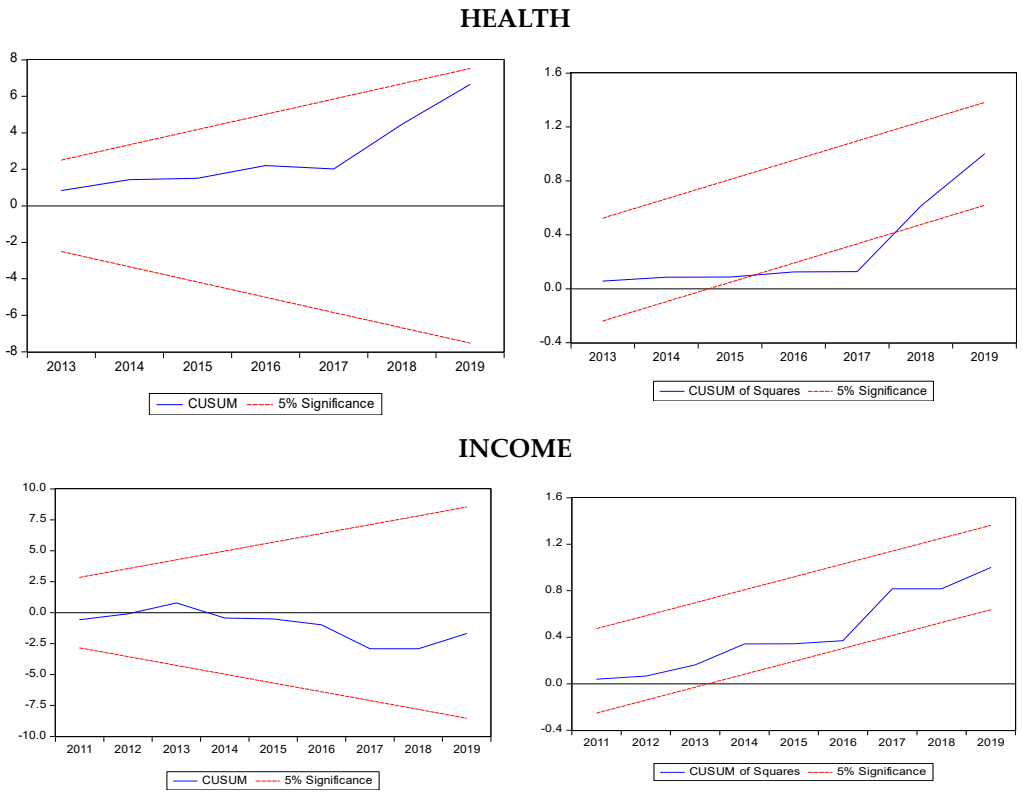

Figure 4. Structural stability of the Econometric models.

The results' robustness was verified by conducting the diagnostic tests listed in Table 8 to ensure that they were free of serial correlation between the residuals. A Breusch–Godfrey serial correlation test was conducted, and the residuals were normally distributed according to a Jarque–Bera test. In addition to verifying the stability of the error term variance with an ARCH test, this paper verified the validity of the mathematical description of the model with a Ramsey Reset test, in which the probability value of a statistic was derived from an F-value higher than 5%. Accordingly, it is clear from the results of estimating the equilibrium relationship in the short and long terms, which are presented in Table 8, that the digital economy, as expressed by the index of the ratio of medium- and high-technology exports to total manufacturing exports and the number of mobile cellular phone subscribers, negatively affects general HDI in the short term.

Table 8. Diagnostic tests of results robustness.

The Decision	INCOME		HEALTH		EDU		HDI		The Problem	Test
	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.		
There is no serial link problem	0.3135	1.375214	0.2128	2.142766	0.4971	0.763688	0.1919	2.109374	Serial correlation	Breusch-Godfrey Serial Correlation LM Test
The residuals are normally distributed	0.666755	0.810665	0.780994	0.468930	0.769706	0.523494	0.721238	0.653573	Normal distribution	Jarque–Bera
There is no problem with the stability of the error term variance	0.6688	0.187767	0.4441	0.606343	0.2233	1.566435	0.0574	4.0021013	Constancy of error term variance	ARCH
The model description is correct	0.2874	1.298826	0.5467	0.407742	0.9910	0.000135	0.9933	7.53×10^{-5}	Model description	Ramsey RESET

Although the index of medium- and high-tech exports has proven significant over the long term regarding affecting the general IHD, the relationship is negative. This result answers the study's question of how the digital economy impacts sustainable human development indicators in the KSA. As for the human development sub-indices, in the short term, the digital economy negatively affects both the education and income indices, and its significance in terms of affecting the health index has not been proven. This finding was unexpected and suggested that the quality of education in accordance with the growth of the digital economy could be positive or negative in the short term [45]. In the long term, it has a positive impact on the education index and a negative impact on the income index, and its significance in terms of affecting the health index has not been proven. Compared to the oil economy, it is clear that it only affects the income index in the short and long terms and that its impact on the general HDI is limited to the long term due to its impacting only the income index, as the significance of its impact on the education and health indicators in the short and long terms has not been proven.

Granger causality tests whether Xi causes Y by determining whether the current value Yt can be predicted using the previous value Xt−1 [46]. The results in Table 9 indicate that there is a causal relationship that extends from human development to income and the digital economy index, comprising medium- and high-tech exports, and from education to income and the digital economy index. Furthermore, the income index also explains variations in the health index, which influence the digital economy index, as measured by the number of cell phone subscribers. Oil prices influence the general HDI, income, and education. Overall, the results of the Granger test suggest that the primary direction of influence is from human development and its sub-indicators toward the digital economy rather than the reverse. Human development, according to this analysis, is largely dependent on the oil economy, which answers the question of the digital economy's relative importance compared to the oil economy in influencing indicators of human development.

Table 9. Pairwise Granger Causality Test.

Assumption of Null	Obs	F-Statistic	Prob.
EDUC does not Granger Cause HDI	29	2.83251	0.0786
HDI does not Granger Cause EDUC		2.27564	0.1245
HEALTH does not Granger Cause HDI	29	1.37743	0.2715
HDI does not Granger Cause HEALTH		2.51287	0.1021
INCOME does not Granger Cause HDI	29	3.15874	0.0606
HDI does not Granger Cause INCOME		4.17025	0.0279
LMHTEC_EX does not Granger Cause HDI	29	0.50502	0.6098
HDI does not Granger Cause LMHTEC_EX		4.71066	0.0188
LMOB_SUB does not Granger Cause HDI	28	2.48998	0.1050
HDI does not Granger Cause LMON_SUB		0.43843	0.6503
LOIL does not Granger Cause HDI	29	5.61104	0.0100
HDI does not Granger Cause LOIL		0.06935	0.9332
HEALTH does not Granger Cause EDUC	29	1.12330	0.3417
EDUC does not Granger Cause HEALTH		2.21882	0.1306
INCOME does not Granger Cause EDUC	29	0.50624	0.6091
EDUC does not Granger Cause INCOME		4.38372	0.0238
LMHTEC_EX does not Granger Cause EDUC	29	2.82213	0.0793
EDUC does not Granger Cause LMHTEC_EX		5.89676	0.0083

Table 9. *Cont.*

Assumption of Null	Obs	F-Statistic	Prob.
LMOB_SUB does not Granger Cause EDUC	28	2.35266	0.1176
EDUC does not Granger Cause LMOB_SUB		0.43825	0.6504
LOIL does not Granger Cause EDUC	29	7.70715	0.0026
EDUC does not Granger Cause LOIL		0.17998	0.8364
INCOME does not Granger Cause HEALTH	29	3.66636	0.0408
HEALTH does not Granger Cause INCOME		2.05460	0.1501
LMHTEC_EX does not Granger Cause HEALTH	29	1.18676	0.3225
HEALTH does not Granger Cause LMHTEC_EX		1.07450	0.3573
LMOB_SUB does not Granger Cause HEALTH	28	0.20007	0.8201
HEALTH does not Granger Cause LMON_SUB		3.65125	0.0420
LOIL does not Granger Cause HEALTH	29	0.61510	0.5489
HEALTH does not Granger Cause LOIL		1.88680	0.1734
LMHTEC_EX does not Granger Cause INCOME	29	2.70790	0.0870
INCOME does not Granger Cause LMHTEC_EX		1.32408	0.2848
LMOB_SUB does not Granger Cause INCOME	28	2.57926	0.0976
INCOME does not Granger Cause LMON_SUB		1.85494	0.1791
LOIL does not Granger Cause INCOME	29	3.55526	0.0444
INCOME does not Granger Cause LOIL		0.61250	0.5503
LMOB_SUB does not Granger Cause LMHTEC_EX	28	1.42646	0.2606
LMHTEC_EX does not Granger Cause LMON_SUB		0.54984	0.5844
LOIL does not Granger Cause LMHTEC_EX	29	1.05522	0.3637
LMHTEC_EX does not Granger Cause LOIL		0.53181	0.5943
LOIL does not Granger Cause LMON_SUB	28	0.73320	0.4913
LMOB_SUB does not Granger Cause LOIL		3.34227	0.0532

6. Discussion and Conclusions

This paper investigates whether the impact of the digital economy surpassed that of the oil economy in terms of achieving human development in the Kingdom of Saudi Arabia from 1990 to 2020. This research specifically examines the relationship between the digital economy and the general HDI, along with its three sub-indices: education; health; and an adequate standard of living. The objective is to assess the influence of the digital economy relative to the traditional rentier oil economy on sustainable human development indicators, thus evaluating Saudi Arabia's current status and its potential to fulfill the United Nations' sustainable development goals and Vision 2030.

Oil prices were included as a variable in the econometric model, which utilized the bounds test methodology for cointegration. This model tests the short- and long-term equilibrium relationships between the digital and oil economies as independent variables and human development, as represented by the general index and its three sub-indices, as dependent variables in four distinct models. To ensure the reliability of this analysis, unit root tests for the stability of the time series were applied, including the ADF and (PP) tests, and the breakpoint unit root test was used to avoid the potential biases caused by non-stationarity assessments in earlier tests. The suitability of the variables for estimating the ARDL model was validated through these unit root tests to estimate both the short- and long-term equilibrium relationships. Diagnostic tests were conducted to verify the robustness of the results. Furthermore, the cointegration relationships between the variables

enabled the use of Granger causality tests to verify the causal relationships between the variables, as well as these relationships' directions.

The results showed that the effect of the digital economy indicators in the short term on human development indicators is insignificant or negative and that this effect extends to the long term, except for education. This may be explained by the shift in the structure of jobs and wages resulting from digital transformation, in line with Lee and Clarke [32] and Ogli and Ogli [31]. These results proved that the digital economy had a direct impact on the education index in the long term, as stated in Rahman [19]. This means that the digital economy, in the long term, can avoid some of its negative effects on human development through its contribution to developing education and expanding educational sources to better qualify them to deal with new technologies and face new challenges. Although the export capacity of the Kingdom's high- and medium-technology industries developed at the end of the period under study, reaching three times what it was at the beginning of the period, the results of this increase were not adequately reflected in human development. Meanwhile, the oil economy exerts an impact on human development only through its impact on income. Despite the digital development the Kingdom witnessed on the ground in the health sector during the COVID-19 pandemic [47], the results did not prove this, and this may be because the time period considered did not reflect the recent transformations.

The results of the Granger causality test confirmed that the relationship between the digital economy and human development tended to be primarily from human development to the digital economy, not the other way around. That is, human development explains the development of the digital economy, which may be mainly due to the development of education, in line with Podgorny and Volokhova [48]. The results also highlight the importance of the oil economy in achieving human development in the Kingdom of Saudi Arabia compared to the digital economy. Oil prices play an important role in explaining human development, especially the income index, which reflects the standard of living for citizens in alignment with Haque and Khan [37].

The results of this research project suggest that decision makers must work on developing the digital economy in a way that suits human development needs. The digital economy should be adapted to raise the standard of living not only by facilitating consumption but also by enhancing production efficiency [49]. Because the results show that education is the only indicator that is directly proportional to the development of the digital economy, this shows the effective role of the digital economy in developing education. However, it is necessary to pay attention to the negative effects of digital transformation on wage disparity and the loss of some of their traditional jobs by providing more rehabilitation and training programs for workers to adapt to digital development and the modern jobs that accompany it, as well as encouraging the academic specializations necessary for it. In addition to establishing wage legislation and a system of rewards for remote work to ensure the quality of the relationship between the employee and the project owner from one side and the digital economy from the other side.

More attention should be directed toward the automation of the health sector. The government should also provide health services fairly and efficiently and establish effective policies for online assistance for the elderly. There is no doubt that continued government support for traditional workers by ensuring their basic living needs until their capabilities reach a level that qualifies them to join new jobs is vital. Similar to how the oil sector plays an important role in human development, greater economic diversification in order to achieve the Kingdom's Vision 2030 will contribute to relying on other foundations of human development based on scientific and technological progress rather than only the oil economy, which despite its large contribution to achieving sustainable human development, is vulnerable to fluctuations.

The data shortage of the main indicators of the digital economy is the essential limitation of this paper, where its availability in the future will enable further research to re-examine the relationships analyzed in this study depending on recent trends and updates. Despite its limitations, this paper certainly adds to our understanding of the impact

of the digital economy in terms of achieving human development. More research applying cross-section data may provide the economic literature with new contributions that enhance sustainability-oriented research and innovations.

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