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# Sustainable Technology in High-Income Economies: The Role of Innovation

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**Abstract:** The aim of this article is to examine the effects of innovation on the availability of cutting-edge technologies while controlling education, public funds and life expectancy in high-income countries from 2008 to 2018. In this study, Westerlund cointegration, fully modified ordinary least squares and dynamic ordinary least squares tests were applied. The research results indicate that: (i) there is a cointegrating link between the availability of the latest technologies and innovation, education, public funding and life expectancy; (ii) innovation increases the availability of cutting-edge technologies in high-income economies, whereas education, public funds and life expectancy contribute to sustainable technological availability; (iii) innovation, education, public funding and life expectancy result in the availability of cutting-edge technologies. The results are important in showing why policymakers in high-income economies should foster innovation capacity to sustain technological development.

**Keywords:** digital sustainability; technological innovation; sustainable development; imitation innovation

**JEL Classification:** C01; Q01; Q28; Q53; Q56

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## 1. Introduction

Sustainability is defined as finding ways to use scarce resources in our world more efficiently and adapting them to our lives. It is seen that innovation, which is the most important element of being able to stand out in the competition race in the world, has a critical role on the road to sustainability. For this reason, innovation is defined as an innovation that provides economic success and has recently been referred to with the word sustainability.

Sustainability consists of a set of goals set out in environmental, social and economic fields at the global level [1]. The United Nations [2] requests its member states to realize the 17 sustainable development goals (EHR) it has determined in order to create a balance in these areas until 2030 [3]. The digital transformation process, which gained momentum with the COVID-19 pandemic and continues to affect every aspect of our lives, is important in terms of revealing the importance of the digital dimension of sustainability. In this period, the transition to the working from home model in many workplaces, the transition to distance education in schools and the transfer of even grocery shopping to the online platform have revealed a great digitalization activity.

Just at this point digital sustainability refers to how digitalization can be used by countries in line with the sustainable development goals [4]. In fact, it is the idea of how digital information can be used to achieve sustainable (environmental, social and economic) development goals. Moreover, sustainable technology is an umbrella term describing innovation that considers natural resources and fosters economic and social development.

The goal of these technologies is to drastically reduce environmental and ecological risks as well as to create sustainable products. It is seen that the first definition of innovation in the literature was made by the economist Schumpeter [5]. Schumpeter [5] describes innovation as the introduction of a new product or a new feature of an existing product, the introduction of a new production method, the introduction of new markets, and the discovery of new products. Trott [6], on the other hand, defines innovation as technological development, production and production of new (improved) products or processes.

Based on these definitions, it is seen that sustainable innovation is a concept that goes far beyond the classical concept of innovation and takes into account social and environmental effects. In order for a technological innovation that makes our life easier to be considered a good sustainable innovation, it should not only provide economic and vital benefits, but also contribute to the world. The concept of sustainable innovation was first formulated by Elkington [7] as 3P (People, Planet, Profits). The formula clearly emphasizes social, environmental and economic dimensions.

Sustainable innovation is seen in many different examples that make our lives easier, protect the environment and serve the society. Today, rapidly developing technology also contributes significantly to the studies carried out in this field. Innovative business ideas focusing on supporting renewable energy sources, using recycled materials, saving resources and energy (software that directs the lights using traffic data and reduces the time spent in traffic, kiosks that enable easier collection of recyclable wastes, anti-allergic carpets made from recycled materials, etc.) are increasing day by day in the world.

Other important issues include absolute innovation and imitation innovation. In the statistical studies carried out by the Center for Statistics, the concept of innovation is defined as new products and processes on a global scale (absolute innovations) and new products and processes at the country level (imitation innovations). Imitation innovations are new only for a particular business, but the fields of activity that are already implemented in other businesses and countries are products and processes [8]. Imitation innovations today do not mean directly imitating or trying to emulate the exact product and brand. On the contrary, it is taking the success points of successful products and brands and revising and developing them according to their own market conditions. The point that should not be forgotten here is that imitation innovations can provide companies with a substantial competitive advantage, just like Microsoft, Apple, Samsung and hundreds of companies do. In fact, Samsung is a good imitation of Apple products and has very successful products.

As a result of innovation, society can gain significantly more income from its current production resources, because the production resources owned by the society are transformed into new products and services through innovation and then marketed. Product innovations are expected to have a positive impact on labour productivity, given other inputs [9]. Therefore, it is necessary to not only think of innovation as an economic system, but also as a social system in which technology is used innovatively for the benefit of people, increases employment and contributes to the protection of the environment [10]. Countries are still experiencing significant challenges in taking measures to reduce environmental pollution and implement policies that can make environmental quality sustainable while providing economic growth and development. In this regard, it should be ensured that the awareness level of citizens is increased and they are informed, and also that governments and policy makers restrict the use of carbon-intensive products, whereas green energy resources (Renewable Energy, Sustainable Agriculture, Recycling, etc.) should be particularly encouraged. Omri [11] states that technological innovations encourage investors in high-income countries to use innovative technologies to improve the environment and support environmentally friendly production. Nevertheless, Cheng et al. [12] suggested in their study that technological innovation, fiscal decentralization, GDP, and globalization are influential factors in explaining $CO_2$ emissions in China [12].

Innovation policies are the most important element that constitutes the whole of the comprehensive activities of the public institutions of the countries to shape the innovation processes [13]. It is seen that companies supported by public incentives produce more technological and commercialized innovation outputs than other companies due to their higher R&D expenditures. In addition, there are studies in the literature showing that R&D tax incentives increase the innovation output of firms [14].

The studies of Schumpeter [5] and Solow [15] form the basis of the relationship between technology and innovation. In particular, Schumpeter is considered to be the first researcher to discuss the issue of economic development and the impact of technological innovation on him. Technological innovation includes the discovery of new technology and introduction of a new product, function, or service to the market as a result of the use of this technology. Technological innovation includes technological products and process innovation, where product refers to both a physical product and a service. In addition to the development of a technologically new product or process, significant technological changes in existing products and processes are also considered within this scope. Innovation is achieved by introducing the product to the market and using the process in production. Technological product innovation refers to the development/commercialization of a product with enhanced performance features to provide new or improved services to the consumer. Technological process innovation involves the application of a new or significantly improved production or distribution method.

The factors that determine the successful performance of countries with developed economies are their competitiveness in international markets and the high level of welfare of their people; it is seen that companies have the ability to produce new products in order to increase their production capacity and to make technological innovations in order to continuously improve their production processes. Studies on this subject generally emphasize that new technologies are the engine of economic growth, and the expected result is that technology will increase growth [16].

Countries that adopt technology and innovation-oriented growth strategies can achieve more sustainable economic growth compared with other countries. The technological innovations of countries also increase economic growth, improve environmental quality and support human development. The World Economic Forum's Global Competitiveness Report [17] states that countries based on innovation have increased competitiveness and achieve more sustainable growth than other countries. As shown in Figure 1, the 12 sections based on competitiveness are organized under three main topics, each in a different development (development) stage. Essentially, the goal is to establish the areas that determine the country's efficiency, identify areas where the country has a competitive advantage (strong) and disadvantage (weak), and guide policy makers.

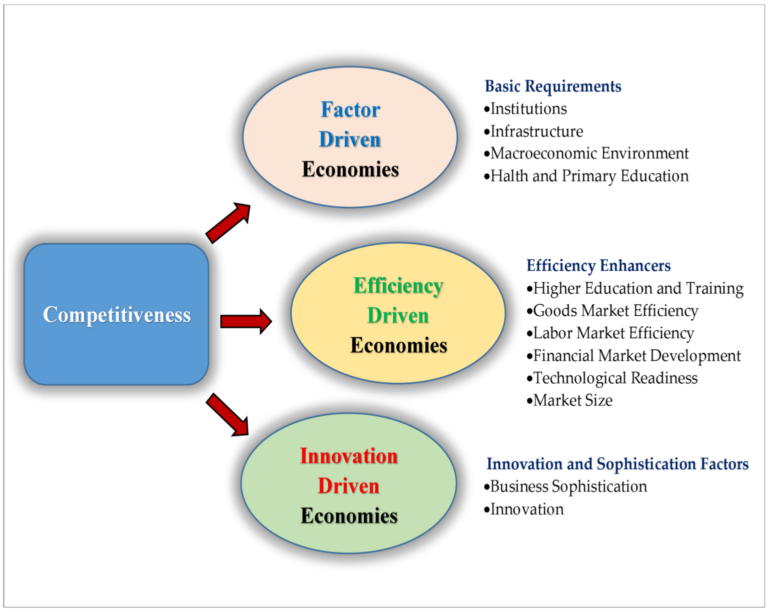


**Figure 1.** Competitiveness Source: [17].

In recent studies, countries have been differentiated as economies that determine their mode of production based on factors, productivity and innovation [18]. Underdeveloped and developing countries prefer the traditional mode of production based on the factors of production. This situation has a negative impact on the welfare of the respective countries. Efficiency-based economies that prefer to increase their capital stock are mostly defined as developing countries. There is an increase in welfare in these countries. Moreover, innovation is incremental, links with the official national innovation system are weak, and there is a lack of formal R&D. Formal methods of obtaining information play a minimal role, so spillovers to neighboring businesses are high [19]. Innovation-based countries are developed countries. These countries carry their welfare levels to higher levels with their innovative production style. Human capital efficiency comes to the fore in the relationship between the output level of countries that adopt innovative production styles and employment efficiency. The function of human capital is positive in the production of high-yield products and the increase in profitability of companies. Innovative investments should be directed towards the training of human capital, not just physical capital formation and product output [20]. In this process, the state should act with the mission of facilitating the bureaucratic obstacles in the public services it offers to its citizens and minimizing the obstacles in front of innovative practices [21].

Many researchers on sustainability, innovation and technology innovation are trying to fill the gap in the field by developing different methods and measurement tools. Technological innovation and economic growth; technological innovation and health education; human capital, innovation and economic growth; economic development, technological sophistication and use of innovation; innovation, information technologies, public finance, innovation and R&D investments are explained in detail in the literature section. It seems that many studies have been carried out [18,22–26]. Although there are some studies on technology and economic development in the EU and BRICS-T countries, there is still a lack of research on innovation and the use of new technologies in high-income economies [27,28].

When the literature is examined, no study has been found that examines the relationship between innovation and the use of new technologies in high-income economies with panel data analysis. Therefore, although this study deals with the relationship between innovation and sustainable use of new technologies, it differs from other studies in the literature in terms of both the country group included in the analysis and the selected variables.

This article consists mainly of three parts. In the first part of the study, the literature on the subject was examined. In the second part, the data set and methodology of the study are explained. In the first stage, panel unit root tests (ADF-Fisher chi-square and PP-Fisher chi-square) were applied to determine whether the variables were stationary or not. In the second step, the Pedroni [29] panel cointegration test was applied to examine whether there is a long-term relationship between the variables. In the third and final stage, the cointegration coefficients were estimated with the Panel FMOLS and Panel DOLS estimators, and the findings were discussed. In the Conclusion, evaluations and policy recommendations were made.

## 2. Literature Review

It is seen that the economies that emerged after the industrial revolution in high-income countries were developed on the basis of information technologies. It is seen that digital transformation, which was limited only to information technologies until the 2000s, is valid in current economic relations and its effect continues to increase today. In recent years, transactions in areas such as public services, education, communication, health, transportation, especially our daily life, have been moved to digital platforms. The developments in this process show us that the concept of digital transformation emerged in parallel with the sustainability discussions. [30]. It is also seen that technological innovations in high-income countries encourage companies to use innovative technologies and support environmentally friendly production [11]. Moreover, green technologies are defined as technologies that affect energy use, such as combustion processes or heat exchange devices, since an increase in energy prices can trigger both a substitution of inputs away from energy and innovation in green technologies [31].

It can be seen from the published reports that developed and developing countries have adopted technological innovations and represent the majority of the countries that have achieved success in this regard. For this reason, it is seen that underdeveloped and developing countries outside this group still face significant difficulties with regard to innovation and the adoption of new technologies [32].

In fact, it is seen that the economic growth experienced in the past due to capital accumulation in the past continued, depending on the technical developments in the knowledge economy. Before the classical theorists, Smith [33] and then Ricardo [34] referred to the role of advanced technologies in providing sustainable economic growth Solow [15]. As a result of his studies, in which both quantitative and qualitative approaches were used to determine how advances in capital, labor, and technology affect a country's total income, he revealed that there is a very strong link between the development of technology and economic growth. Romer [35] claimed that technological innovation is the fruit of individual actions, motivated by incentives offered by the market and technological progress occurs as a result of economic activities. Aghion and Howitt [36], who contributed to the new growth theory, developed Schumpeter's [5] theory of innovation by stating that the amount of work given to innovative firms increases through innovation production, and this increases economic productivity by supporting technological progress.

Using US production data in their empirical research study, Zachariadis [37] documented that R&D investments are a patent-enhancing incentive. In this study, it was found that the increase in the number of patents encourages more technological progress and thus supports economic growth. In Malaysia, Tang and Tan [18], stated that technological innovation is the most important determinant of long-term economic growth. In the same country, Bekhet and Abdul Latif [38] examined the quality of institutions and the effects of technological innovations in order to achieve sustainable growth in the period between 1995 and 2015. Their findings revealed that the interaction between management and technological innovation contributes positively to Malaysia's sustainable growth.

Among the 17 Sustainable Development Goals adopted by the United Nations General Assembly in 2015, the subject of "building a strong infrastructure, supporting inclusive and sustainable industrialization and promoting innovation" was clearly defined. To this end, developing countries are encouraged to promote sustainable industrialization based on innovation and improve economic development and human well-being by focusing on universal access at an affordable price. Technological innovation increases health, education, and welfare by improving productivity and income in this context [32]. It can also improve the reasonable and equitable delivery of these services for all. Therefore, technological innovation is seen as a tool for the development of human potential. It has positive effects on productivity, profits and human incomes, enabling access to better quality goods and services, and increasing life expectancy.

The concept of human capital is defined as people investing in themselves through education, training or other activities that will increase their future income by increasing their lifetime earnings. According to Schultz [25], these activities are health, on-the-job training, formal education organized as primary school, high school and university, non-formal education programs for adults, and immigration [25]. There is a reciprocal relationship between investments in health and human capital and economic growth. Allocating more resources to health services and increasing these services can increase people's life expectancy levels. When this is evaluated in the context of human capital investment and development expenditures, it is found that it increases the productivity of individuals. Individuals with increased productivity contribute more to the increase in output production, which in turn contributes to an increase in national income/economic growth. In the study conducted by Tzeremes [39], the effect of human capital and technological innovation on economic growth in 123 countries was analyzed using the time series method. As a result of the study, it was concluded that human capital and technological innovation increase economic efficiency. Pelinescu [27] examined the relationship between human capital and economic growth in EU member countries using the panel data analysis method. Their findings revealed the existence of a positive relationship between economic growth and the innovation capacity of human capital. In the study conducted by Şen and Pehlivan [28], the effect of technology and human capital on economic development was examined by the panel data analysis method for the BRICS-T countries and it was concluded that technology and human capital positively affect economic development. According to Bodenheimer [40], people living with one or more diseases should be supported and have access to the necessary technological tools and knowledge in order to better treat these health problems. The advancement of information and communication technologies (ICT) can offer these people new solutions by providing easily accessible self-management tools in their living environments, paving the way for the use of technological devices instead of traditional patient care systems [41].

The hypothesis suggesting that rapid economic changes affect the health of the population implies that a rapidly expanding economy leads to the improvement of health services, whereas on the contrary, rapidly shrinking economies cause health services to slow down [42]. Accordingly, achieving a rapid and sustainable level of economic development is very important in terms of population health.

In the research conducted by Tekin et al. [43], the effect of entrepreneurial activities and technological innovation on health services was examined. According to the analysis findings, it was determined that the increase in the technological innovation and entrepreneurial power of the countries positively affects the development of the health system in these countries. The research findings are in line with those of previous studies conducted by [44,45].

According to Allas [23], effective science and innovation policies have key features. These are adequate public funding in the knowledge creation process, privately funded and conducted research projects, the ability to train and retain world-class researchers, a high-quality research infrastructure, and a willingness to invest in new areas adequately and decisively.

In the study of Balli [46], the relationship between innovation and economic growth was examined using panel data analysis for the period 1996–2014 for upper- and upper-middle-income countries. According to the period reviewed and the method applied, it was concluded that the number of patent applications and the size of the educated labor force affected the economic growth of the countries in a significant and positive way.

Osterlaken [24] states that technology plays an important role in increasing people's abilities. On the other hand, Bilbao et al. [47] explained the role of technological progress in this process by stating that technological innovations increase human abilities by creating a dynamic change or providing an environment suitable for change. Walsham [26], in their study where they analyzed the relationship between innovation, information and communication technologies and human development, revealed that ICT-based innovation supports human development. Erkut [48] stated that as a result of digitalization, governments can create more sustainable government policies by using the available data. Policy makers can also use big data when making decisions about education, health and the economy in order to provide fast, transparent and personalized 24/7 public services through e-government applications. With human-oriented technological configurations, a significant contribution can be made to the goal of achieving a more sustainable environment [48]. In the study conducted by Kanwar and Evenson [49], it was confirmed that the relationship between the economic development levels of countries and their technological development levels is positive; using the data from the period 1981–1990, the determinants of innovation and technological change in 32 developed and developing countries were examined by applying the panel random effect model estimation method. The study used R&D expenditures, GDP per capita, literacy rate, interest rate, exchange rate, and intellectual property rights as variables. According to the results of the study, it was determined that although credit facility, human capital, intellectual property rights protection, demand-pull factors and trade openness affect innovation positively, interest rates and political instability have negative effects. In the study conducted by Bujari and Martinez [50], the relationship between technological innovation and economic growth in twelve Latin American countries was examined using the dynamic panel GMM method, using data from the period 1996–2008. In the study, GDP per capita, investment, R&D expenditures in GDP, number of patents, high technology product exports and total production factors were used. According to the results of the analysis, it was concluded that technological innovation has a positive effect on economic growth.

## 3. Data and Methodology

In order to obtain more reliable results in the study, the panel data analysis method, in which cross-section and time-series are used together, was preferred [51]. Panel data analysis is superior compared with time series and cross-section data as it reduces the possibility of linearity between variables [52]. Panel data analysis is the collection of cross-sectional observations such as countries, companies, household statistics, etc., covering a certain time period. In recent years, panel data analysis has emerged as a method frequently used in the mutual comparison of country data (purchasing power parity, the convergence of growth, international R&D expansion, innovation, etc.) [53]. Although panel data analysis has features specific to both time series and cross-section data analysis, it can also eliminate the disadvantages of these methods [54].

The generally accepted equation in panel data analysis is as follows [55].

$$Y_{it} = \beta_{0it} + \beta_{1it}X_{it} + \beta_{2it}X_{2it} + \beta_{3it}X_{3it} + \ldots + \beta_{kit}X_{kit} + \varepsilon_{it} \tag{1}$$

According to Equation (1), $Y_{it}$ = the dependent variable value of the ith cross-section unit at time t, $X_{it}$ = the value of the ith unit of the independent variable at time t, $\beta_{it}$ = the coefficient of the independent variable, $i$ = 1, 2, . . . , n cross-section units, $t$ = 1, 2, . . . , t is the time period, and $\varepsilon_{it}$ = the error term [55]. While estimating the model in panel data analysis, different approaches can be applied in the estimation of unobservable effects, taking into account the covariance structure of error terms [56].

### *3.1. Data*

In the panel data analysis, annual data for the period 2008–2018 obtained from the Global Competitiveness Report published annually by the World Economic Forum [57] were used. Among the countries in the high-income economy category, the 10 countries with the highest Global Competitiveness Index score and whose data sets can be fully accessed were used in the study. These countries are Switzerland, United States, Singapore, Netherlands, Germany, Hong Kong SAR, Sweden, United Kingdom, Japan and Finland.

In this study, the aim is to examine the effects of innovation on the availability of the latest technologies. In this context, the linear regression model prepared using the panel data format in order to determine the relationship between the variables is presented in Equation (2).

$$TECH = f\ (INN, EDU, PUB, LIFE) \tag{2}$$

$$TECH_{it} = \alpha_{0i} + \alpha_{1i}\dot{I}NN_{it} + \alpha_{2i}EDU_{it} + \alpha_{3i}PUB_{it} + \alpha_{4i}L\dot{I}FE_{it} + u_{it} \tag{3}$$

In the model, *TECHit*: Availability of the latest technologies in country i in year t, INNit: design and development of innovation, cutting-edge products and processes in country i in year t, *EDUit*: quality of higher education and training and vocational staff training in country i in year t, *PUBit*: training of professional personnel in country i in year t Direction of Public funds in country i, *LIFEit*: healthy life expectancy in country i in year t, $\alpha$: constant-coefficient, i: countries included in the analysis, t: time. EDU, PUB, LIFE data were added to the established linear regression model as control variables. The data of the variables used in the model were obtained from the World Economic Forum Global Competitiveness Index historical data set (2008–2018).

### 3.2. Method and Empirical Results

In the study, the effect of innovation on the availability of the latest technologies in high-income countries is investigated by panel data analysis. It is planned to test the said relationship in three stages. In the first stage, the stationarities of the variables will be tested with the panel unit root tests (ADF-Fisher chi-square and PP-Fisher chi-square) developed by [58,59]. In the second stage, the Pedroni [29] panel cointegration test will test whether there is a long-term relationship between the variables. In the third and final stage, the cointegration coefficients will be estimated with the Panel FMOLS and Panel DOLS estimators, and the effect that innovation has on the availability of the latest technologies will be investigated.

#### 3.2.1. Panel Unit Root Test Findings and Evaluation

In panel data analysis, unit root tests should firstly be performed to investigate whether the series is stationary or not. In order to investigate the presence of a unit root in panel data analysis, both DF (Dickey–Fuller) and ADF (Augmented Dickey–Fuller) tests have been developed for panel data analysis, and many unit root tests in panel data analysis are based on the extension of the ADF test. Analyses with non-stationary variables create a spurious regression problem and lead to incorrect results and misinterpretations due to the analysis. In order to prevent the problem of spurious regression from being encountered, the analysis should be conducted with stationary series. Many different unit root tests are used to determine stationarity. To avoid this problem, the panel unit root tests developed by [58,59] were used in the study. Appropriate lag length, which eliminates the problem of autocorrelation between errors, was chosen according to the Schwarz information criterion.

The most important factor in panel data analysis is heterogeneity. In particular, every individual in the panel cannot have the same characteristics; in other words, they all differ in terms of being stationary or non-stationary (cointegrating or non-cointegrating). This means that, although some panels have a unit root and some do not, performing a unit root test complicates the situation [60,61].

In the unit root test, a trial is firstly made at level I(0), and if stationarity is detected, these values are taken as the basis before proceeding to the fixed and non-fixed trial process. The hypotheses in the unit root tests are as follows:

**Hypothesis 1 (H1).** *Series contains a unit root.*

**Hypothesis 2 (H2).** *Series does not contain a unit root.*

If the probability value is less than the significance level in the unit root tests, the null hypothesis will be rejected, and it will be concluded that the series is stationary. If the probability value is greater than the significance level, the null hypothesis cannot be rejected, and it will be concluded that the series is not stationary.

As can be seen in Table 1, in the unit root test results applied to the levels of the variables, it is seen that the t statistics and probability results of all series to be used in the econometric analysis are not stationary at level I(0) and contain a unit root problem. However, in order to perform cointegration tests, all variables must be stationary at the same level and the series must be freed from the unit root problem. For this reason, the primary unit root tests of the series were investigated again. The fact that the probability values of the findings obtained from the primary differences of the series I(1) are less than 0.05 indicates that all the series are stationary.

**Table 1.** Panel Unit Root Test Results.

| | At Level | | At First Difference | |
|---|---|---|---|---|
| **Method** | **Statistic** | **Prob.** | **Statistic** | **Prob.** |
| | | INN | | |
| Im, Pesaran and Shin W-stat | 0.34999 | 0.6368 | −2.78456 *** | 0.0027 |
| ADF—Fisher Chi-square | 20.7808 | 0.4101 | 40.9007 *** | 0.0038 |
| PP—Fisher Chi-square | 15.6363 | 0.7389 | 47.2054 *** | 0.0016 |
| | | EDU | | |
| Im, Pesaran and Shin W-stat | 1.69018 | 0.9545 | −3.20332 *** | 0.0007 |
| ADF—Fisher Chi-square | 11.1408 | 0.9425 | 48.6112 *** | 0.0003 |
| PP—Fisher Chi-square | 8.42340 | 0.9887 | 83.7961 *** | 0.0000 |
| | | PUB | | |
| Im, Pesaran and Shin W-stat | −1.45135 | 0.0733 | −3.42708 *** | 0.0003 |
| ADF—Fisher Chi-square | 28.5892 | 0.0962 | 48.2609 *** | 0.0004 |
| PP—Fisher Chi-square | 19.8946 | 0.4645 | 56.5451 *** | 0.0000 |
| | | LIFE | | |
| Im, Pesaran and Shin W-stat | 1.16158 | 0.8773 | −10.4699 *** | 0.0000 |
| ADF—Fisher Chi-square | 16.0529 | 0.7133 | 114.302 *** | 0.0000 |
| PP—Fisher Chi-square | 16.5283 | 0.6834 | 148.061 *** | 0.0000 |
| | | TECH | | |
| Im, Pesaran and Shin W-stat | −0.19606 | 0.4223 | −2.85037 *** | 0.0022 |
| ADF—Fisher Chi-square | 21.8751 | 0.3473 | 41.8164 *** | 0.0029 |
| PP—Fisher Chi-square | 26.7019 | 0.1439 | 40.5944 *** | 0.0042 |

Note: ***, ** and * denote statistical significance at 0.01, 0.05 and 0.10 levels, respectively. The appropriate lag length was chosen according to the Schwarz information criterion.

#### 3.2.2. Panel Cointegration Test Results and Evaluation

After testing whether the series contains a unit root, it was seen that the series were stationary at the I(1) level and the existence of a reciprocal relationship in the long run was investigated by the Pedroni [29] cointegration test. Pedroni [29,61] proposed a test that allows heterogeneity in the cointegration vector in cointegration analyses [62]. This test not only allows dynamic and fixed effects to differ between sections of the panel, but also allows the cointegrating vector to differ between sections under the alternative hypothesis. The positive features of the Pedroni tests are that they allow more than one explanatory variable (regressor), the cointegration vector diversifies across different parts of the panel, and heterogeneity of errors across cross-section units is also allowed. In order to test the null hypothesis of Pedroni that there is no cointegration relationship, seven different cointegration tests were presented and these tests were divided into two different categories in order to include the effects within and between the panel. The first category contains four tests pooled in the "within" dimension. The second category includes three other tests in the "between" dimension [62]. The first three of the four tests in the first category are non-parametric tests. The first test is a variance ratio type statistic. The second statistic is similar to the Phillips–Perron (PP) (rho) statistic, and the third statistic is similar to the PP (t) statistic. The fourth statistic is a parametric statistic similar to Augmented Dickey–Fuller (ADF) (t). In the second category, the first of the three tests is similar to the PP (rho) statistic, whereas the other two are similar to the PP (t) and ADF (t) statistics [63]. The results of the tests applied are shown in Table 2.

According to the Pedroni cointegration test, in which the long-term relationship between innovation and the availability of the latest technologies was investigated, the H0 hypothesis (there is no cointegration between the series) was rejected. Two of the panel statistics from the test results are statistically significant at the 5% level. One of the group statistics is statistically significant at 1%, and the other at the 5% significance level. When evaluated in general, the results of four of the seven tests that make up both panel and group statistics in the Pedroni cointegration test reveal the existence of a cointegration relationship between the series. In this context, there is a movement between innovation and the availability of the latest technologies in high-income countries in the long run. The results of all the cointegration tests show a long-term relationship between the variables. In other words, there is a cointegration link between the availability of the latest technologies and innovation, public funds, education, and life expectancy. After applying the cointegration tests, FMOLS (Full Modified Ordinary Least Square) and DOLS (Dynamic Ordinary Least Square) methods were applied to determine the coefficients of the relationships between the variables.

**Table 2.** Panel Cointegration Test Results.

| | **Weighted Statistic** | **Prob.** |
|---|---|---|
| Panel v-Statistic | −0.370805 | 0.6446 |
| Panel rho-Statistic | 2.298460 | 0.9892 |
| Panel PP-Statistic | −2.299445 ** | 0.0107 |
| Panel ADF-Statistic | −1.979272 ** | 0.0239 |
| | Statistic | Prob. |
| Group rho-Statistic | 3.741739 | 0.9999 |
| Group PP-Statistic | −4.649332 *** | 0.0000 |
| Group ADF-Statistic | −1.995210 ** | 0.0230 |

Note: ***, ** and * denote statistical significance at 0.01, 0.05 and 0.10 levels, respectively.

3.2.3. Findings and Evaluation of Cointegration Coefficients with FMOLS and DOLS

After applying the unit root and cointegration tests, in the third and final stage, the degree and direction of the long-term relationship between the variables were determined by using the DOLS (Dynamic Ordinary Least Square) and FMOLS (Full Modified Ordinary Least Square) estimation methods developed by Pedroni [64,65]. The coefficient estimation results are shown in Table 3.

**Table 3.** Coefficient Estimation Results.

| **Fully Modified Least Squares (FMOLS)** | | | | |
|---|---|---|---|---|
| **Variable** | **Coefficient** | **Std. Error** | **t-Statistic** | **Prob.** |
| INN *** | 0.319929 | 0.046137 | 6.934310 | 0.0000 |
| EDU *** | 0.006132 | 0.002454 | 2.498981 | 0.0147 |
| PUB | 0.348945 | 0.057944 | 6.022094 | 0.0000 |
| LIFE * | 0.074219 | 0.037364 | 1.986372 | 0.0508 |
| R-squared | 0.777889 | Mean dependent var | | 6.388308 |
| Adjusted R-squared | 0.706936 | S.D. dependent var | | 0.195063 |
| SE of regression | 0.105598 | Sum squared resid | | 0.802867 |
| Long-run variance | 0.002972 | | | |
| **Dynamic Least Squares (DOLS)** | | | | |
| **Variable** | **Coefficient** | **Std. Error** | **t-Statistic** | **Prob.** |
| INN *** | 0.186930 | 0.068571 | 2.726072 | 0.0077 |
| EDU | 0.000743 | 0.002769 | 0.268308 | 0.7891 |
| PUB ** | 0.186022 | 0.091207 | 2.039564 | 0.0442 |
| LIFE * | 0.057423 | 0.032395 | 1.772584 | 0.0796 |
| R-squared | 0.639485 | Mean dependent var | | 6.366633 |
| Adjusted R-squared | 0.589090 | S.D. dependent var | | 0.213283 |
| SE of regression | 0.136719 | Sum squared resid | | 1.738370 |
| Long-run variance | 0.027061 | | | |

Note: ***, ** and * denote statistical significance at 0.01, 0.05 and 0.10 levels, respectively.

As reported in Table 3, the independent variables, namely innovation, the quality of education, the direction of public funds, and the healthy life expectancy, explain the availability of the latest technologies, which is the dependent variable, by 77% (0.777889) according to FMOLS and 63% (0.639485) according to DOLS.

In the literature, studies by [11,18,36,46,49] showed that innovation has a positive effect on technological development and economic growth. Similarly, the findings of our study support the theory that innovation has a positive effect on the availability of the latest technologies. According to the FLOMOS test results, a 1% increase in the innovation variable increases the use of the latest technologies by 0.319%.

The endogenous growth models developed with the contributions of economists such as [35,66–68] draw attention to the advantages of increasing returns to scale and technology (internal) intensive economic growth. Internal growth models suggest that economic growth will be positively affected as a result of R&D studies and the development of innovative production techniques and products. The main driver of economic growth is accepted as technological development, which develops through R&D activities. In this context, public policies, which were ignored in traditional growth models, assumed an important role in endogenous growth models. Active government policies such as spending and investments in the public sector on R&D activities or supporting them with tax incentives are included. Barro [67] stated that governments should make public expenditures or provide tax incentives in productive areas such as R&D activities and technological development. Consequently, by providing technological development, economic growth accelerates. It can be seen that in the case of Poland, from 1 January 2016, entrepreneurs were given the possibility of an additional deduction from the tax base of expenditures incurred on research and development, which provided special tax relief for R & D. The relief enables research entrepreneurs to achieve real financial benefits regardless of the industry in which the operate [8].

In the literature, studies by [13,21,23,47] show that public finance has a positive effect on R&D finance with the availability of the latest technologies. Similarly, the findings of our study support that public funding has a positive effect on the availability of the latest technologies. According to the FLOMOS test results, a 1% increase in the public expenditure variable increases the use of the latest technologies by 0.348%. This ratio and the literature indicate that the use of public expenditures primarily in R&D financing is important in developed economies.

One of the main determinants of the wealth of nations is the increase in the quality of human capital accumulation through a well-established health system and educational attainment [69]. Today, investing in the fields of education and health is one of the issues to which states attach importance. Human capital, which has an indispensable role in economic growth together with physical capital, brings education and health expenditures with it [70]. Investments in human capital such as education and health expenditures play an important role in raising the quality of life of individuals, while helping to encourage factors such as productivity, knowledge and invention, which contribute to the economic growth of countries [71].

In the literature [13–15,20,25,26,40,44], studies have shown that education and healthy living have a positive effect on technological development and economic growth. Similarly, the findings of our study support that education and healthy living variables have a positive effect on the usability of sustainable technologies. The FLOMOS test results of our study show that the contribution of education and healthy life variables to the use of sustainable technologies is lower in developed economies.

According to the findings obtained from the panel FMOLS analysis, the long-term coefficients of the INN, EDU, PUB and LIFE variables are significant at 1% and 5% significance levels, and their signs are positive. Therefore, the innovation (INN), education quality (EDU), directing public funds (PUB) and healthy life expectancy (LIFE) variables positively affect the TECH variable, which represents the availability of the latest technologies. Innovation increases the availability of the latest technologies in high-income economies, whereas education, public funds, and life expectancy contribute to sustainable technologies.

According to the DOLS coefficient estimation results, the education quality variable, which seems to be statistically insignificant, has a positive value, and similar to the FMOLS results, it has a positive effect on the use of the latest technologies together with other variables. A 1% increase in the innovation variable increases the use of the latest technologies by 0.186%. A 5% increase in the public expenditure variable increases the use of the latest technologies by 0.186%. In summary, the key findings from the FMOLS and DOLS estimation methods confirm the positive impact of innovation, quality of education, diversion of public funds, and healthy life expectancy on the use of cutting-edge technologies. According to the FMOLS and DOLS results, innovation, education, public funding, and life expectancy result in the availability of the latest technologies. Figure 2 illustrates the main empirical findings of the present study.

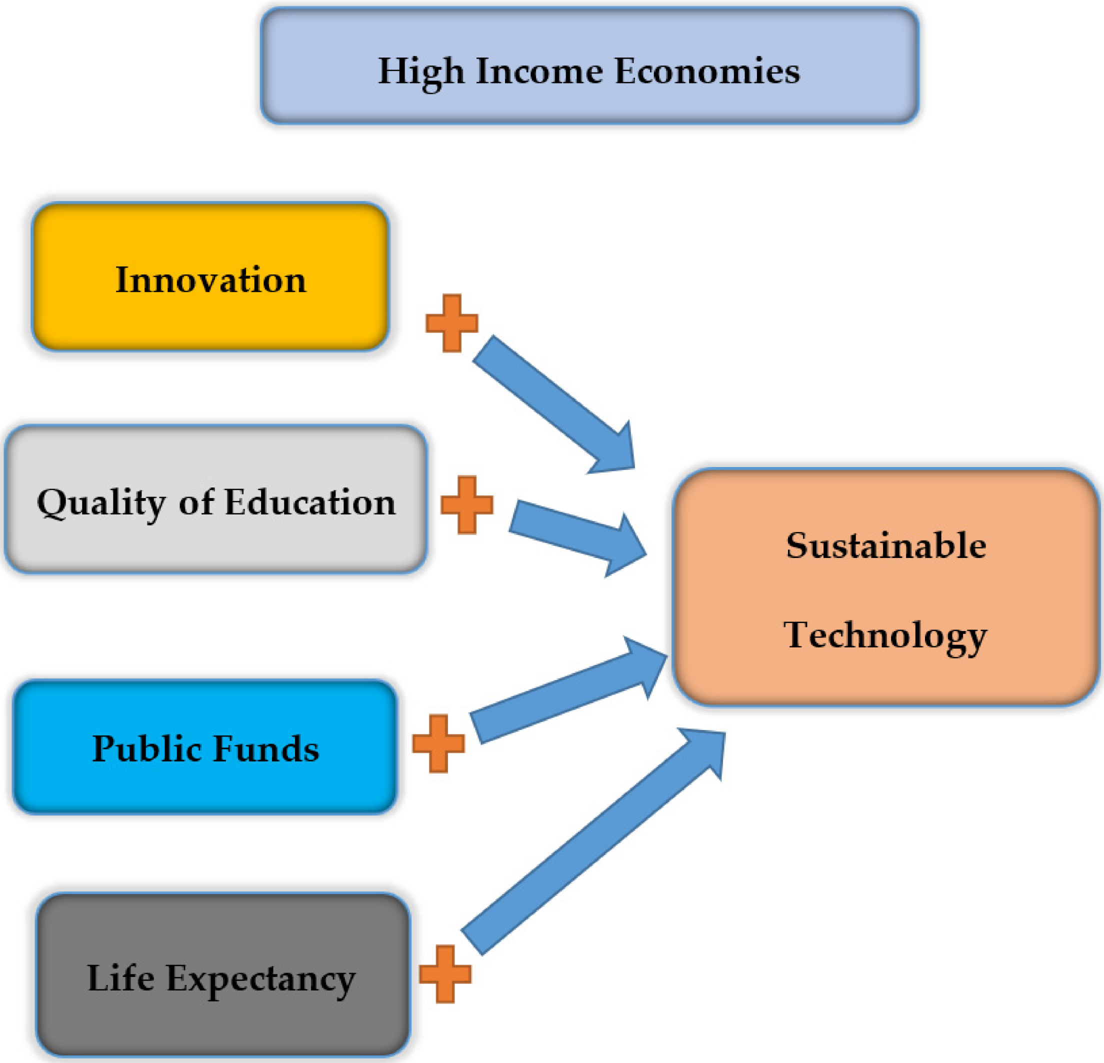


**Figure 2.** Graphical Illustration of Empirical Findings.

## 4. Conclusions and Policy Direction

Sustainability is an umbrella concept that we come across in every aspect of our lives. Today, studies are carried out under the leadership of technological developments in many subjects such as environment, economy, health, education, transportation and renewable energy. Countries in the world are demanded to carry out more serious studies towards the sustainable development goals determined by the United Nations. The simplest expression of sustainability is finding ways to use scarce resources in our world more efficiently and adapting them to our lives. Therefore, the importance of innovative approaches in our lives is increasing day by day. From this point of view, it is considered that our study will contribute to the innovation and sustainable technology literature in terms of revealing the relationship between innovation and sustainable technology in countries with high-income economies. Many researchers have been trying to fill the gap in this field by developing different methods and measurement tools in order to reach the goal of a more sustainable world. Although it is seen that the studies on this subject are concentrated on the axis of sustainability and economic development, there are studies that reveal the effect of human capital and technological innovation on economic growth. However, the lack of research on sustainable technology and innovation in high-income economies has led us to research on this subject. Countries with high-income economies are in a position to explain the relationship between sustainable technology use and innovation and to be taken as a role model by other countries. Our study facilitates the understanding of how and to what extent the socio-economic structures and human capital levels of these countries affect sustainable technology and innovation, and provides necessary policy recommendations.

In addition to the structural measures that must be taken to ensure the development and sustainability of innovation, it is necessary to increase the share of public expenditures for technological innovation production from income, develop practices that encourage innovation projects based on R&D. In addition, due to the need for the individuals who will realize the innovation to have a high level of education, increasing investments in education should be a priority.

Today, countries with developed economies, which understand the importance of innovation in the world, implement various mechanisms to encourage to allocate resources for innovation and realize the necessary legal and administrative regulations for the successful continuation of innovation activities. In this way, countries can continue to develop technologically and maintain their global competitiveness.

The impact of innovation on economic growth is significant. For this reason, the primary goal of countries in terms of sustainable economic growth should be to identify areas where innovation capacities are strong. Then, policies that will encourage the development of new technologies in these areas should be formed in which public financial resources can be directed correctly. In the process of policy making, qualified manpower should be planned by policy makers, and necessary financial resources should be allocated for the development of higher education and vocational education.

According to the findings from the analysis, the long-term coefficients of the INN, EDU, PUB and LIFE variables are significant at 1% and 5% significance levels and their signs are positive. Therefore, the innovation (INN), education quality (EDU), directing public funds (PUB) and healthy life expectancy (LIFE) variables positively affect the TECH variable, which represents the availability of the latest technologies. Innovation increases the availability of the latest technologies in high-income economies, whereas education, public funds, and life expectancy contribute to sustainable technological availability.

In the literature, studies show that public finance has a positive effect on R&D finance with the availability of the latest Technologies [23,37]. Similarly, the findings of our study support that public funding has a positive effect on the availability of the latest technologies.

The results of our research show that another variable that contributes to sustainable technology use is healthy life expectancy. Allocating more resources to health services and increasing these services are in line with the results of studies showing that people's life expectancy levels increase and increase productivity [32]. For this reason, countries need to provide the necessary financial support to health investments in order to increase human productivity. It should not be forgotten that individuals with increased productivity will contribute more to the increase in output production and this will contribute to the increase of national income/economic growth.

Romer [35] states that human capital that produces innovations triggers growth [27,39,46] The fact that developed countries have more qualified human capital accumulation, education, life expectancy and the effective use of public finance opportunities in these countries reveal the increase in innovation. In line with the thesis that technology, which has a wide place in the economics literature, leads to economic growth, the results of our study show that sustainable technology is supported by innovation [18,24,47].

Our study, in line with the results of studies in the literature, supported the strong link between the level of economic development and technological development [49]. At the same time, it has revealed the need to develop policies to improve the quality of human capital, increase, and develop innovation in order to support the sustainable use of technology by countries with high-income economies.

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