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Research Article

Panel Data Analysis of the Relationship Between Digital Infrastructure and Access to Higher Education in OECD Countries

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Abstract

The aim of this study is to empirically examine the impact of the level of digital infrastructure on access to higher education in OECD countries. Digital infrastructure is represented by indicators such as the percentage of individuals using the internet, the density of secure internet servers, and per capita gross domestic product. Access to higher education is considered in two dimensions. The higher education enrollment rate, which indicates the overall level of participation, and the gender equality index, which represents equal opportunity, are the dependent variables of the study. Data from the period 2010–2024 were used in the study, and 37 OECD countries were included. Analyses were performed using the STATA 17.0 statistical program, employing the Driscoll–Kraay robust standard errors approach from panel data methods. This method was preferred because it addresses the problems of heteroskedasticity, autocorrelation, and cross-sectional dependence. Model 1 considered the higher education enrollment rate as the dependent variable. The findings showed that internet usage, secure internet servers, and R&D expenditures had positive and statistically significant effects on participation in higher education. In contrast, the coefficient for GDP per capita was found to be negative and significant. This finding suggests that it may be related to individuals' tendencies to enter the labor force at an earlier age or pursue alternative educational paths as economic well-being increases. Model 2 examined the gender equality index in higher education as the dependent variable. In this model, digital infrastructure indicators, R&D expenditures, and per capita income all showed positive and significant effects. In particular, the high correlation coefficient for R&D expenditures suggests that innovative and research-oriented educational environments may be closely linked to women's participation in higher education. Overall, the findings suggest that digital transformation is positively associated with indicators of social inclusion and equal opportunity in education and can therefore be considered an important component of development.

Keywords: Digital infrastructure, higher education, gender equality, panel data, Driscoll-Kraay

Introduction

Digitalisation has become one of the fundamental transformation dynamics profoundly affecting economic, social, and institutional structures in recent years. Rapid developments in information and communication technologies have brought about structural changes across a wide range of areas, from production processes to public services, social interactions to education systems.

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In the field of education in particular, digital transformation has reshaped access to education by enabling learning processes to transcend spatial and temporal limitations. In this context, digitalisation plays a decisive role in the accessibility, inclusiveness, and sustainability of education systems.

Studies examining the impact of digital infrastructure on educational outcomes in the literature reveal that the spread of internet access and digital technologies has increased participation rates in education (Parlak, 2017). Rising internet usage rates, the development of online education platforms, and increased opportunities for distance learning offer significant opportunities, particularly in accessing higher education. Increased investment in digital infrastructure in OECD countries, the proliferation of secure internet environments, and easier access to information are emerging as critical factors transforming the structure and functioning of higher education systems. This transformation directly affects not only the overall participation rate in higher education but also equality of opportunity and social inclusion in education.

The effects of digitalisation on higher education become even more significant when considered from a gender equality perspective. The socio-economic and cultural barriers women face in accessing higher education in traditional education systems can be partially overcome thanks to the flexible and accessible learning environments offered by digital technologies. In this respect, the development of digital infrastructure is considered an important tool that can contribute to reducing gender-based inequalities in higher education. However, the potential effects of digital transformation need to be empirically examined in the context of cross-country differences and economic conditions.

In this context, analysing the relationship between digital infrastructure and participation in higher education and gender equality in higher education constitutes an important area of research in terms of increasing the effectiveness of education policies. OECD countries provide a suitable sample for comparative analysis in terms of both their level of digitalisation and the sophistication of their education systems. Nevertheless, the literature shows a limited number of studies that address the effects of digital infrastructure on access to higher education and gender equality using a holistic approach.

This study aims to examine the effects of digital infrastructure on overall participation in higher education and gender equality in higher education in OECD countries using panel data analysis. The main research question revolves around how the level of digital infrastructure in OECD countries affects access to higher education and gender equality in higher education. Accordingly, the objective of the study is to empirically reveal the effects of digital and economic indicators, such as internet usage rate, secure internet infrastructure, R&D expenditures, and per capita income, on enrolment rates in higher education and gender equality in higher education.

Within this scope, the main problem of the research is defined as "How does the level of digital infrastructure in OECD countries affect access to higher education and gender equality in higher education?" The sub-problems created to find answers to the main problem are as follows:

1. Does the internet usage rate in OECD countries significantly affect the enrolment rate in higher education/gender equality index in higher education?
2. Does the density of secure internet servers in OECD countries significantly affect enrolment rates in higher education/the gender equality index in higher education?
3. Do R&D expenditures in OECD countries significantly affect the enrolment rate in higher education/gender equality index in higher education?
4. Does per capita income level in OECD countries significantly affect enrolment rates in higher education/gender equality index in higher education?

The answers to these questions are expected to contribute to the shaping of education policies in the digital transformation process.

Literature Review

The increase in social demand for and participation in higher education is considered one of the most significant structural transformations of the 20th century. According to Altunoğlu (2020), this rapid expansion in higher education has not been limited to a quantitative increase in student numbers; it has also given rise to strong expectations that the student body will become more heterogeneous in terms of socio-economic background, academic qualifications and expectations. However, it is evident that this expectation has not been fully met in many countries, despite the increase in higher education participation rates. Eurostudent (2012) data reveals that the expansion of higher education participation has not led to a commensurate improvement in diversity and representational justice among the student body. Similarly, the latest progress reports of the Bologna Process show that the representation rates of individuals with low socioeconomic status, those with a migrant background, and those with chronic illnesses or disabilities in higher education remain low (European Commission, 2018). Furthermore, it is emphasised that gender-based imbalances persist in some disciplines and that dropout rates are higher among disadvantaged groups. These findings indicate that quantitative growth in higher education does not automatically achieve the goals of inclusiveness and equality.

One reason why this expansion in higher education has not fully translated into a heterogeneous student body lies in the organisational and pedagogical structures of universities. Gilbert (2005) and Bates (2010) note that many higher education institutions exhibit standardised and inflexible structures reminiscent of industrial organisational logic. Teaching models based on fixed time and place, where the same content and assessment criteria are offered to all students, fail to adequately respond to different learning needs. In this context, inclusivity emerges as a multidimensional concept in higher education that is not limited to access alone but requires the redesign of learning and teaching processes (Cross, 2010).

The relationship between access to higher education and digital infrastructure can be explained within the framework of human capital theory, the information society approach, and the theory of digital inequality. According to human capital theory, individuals shape their investments in education based on the economic and social returns they expect to receive in the future (Becker, 1964). However, in order for these investment decisions to be made and sustained, the cost and information barriers to accessing educational opportunities must be reduced. Digital infrastructure reduces the costs of participating in higher education and increases individuals' likelihood of taking advantage of educational opportunities by facilitating access to information, enabling online application and enrollment processes, and offering remote and flexible learning options (Bates, 2010; Selwyn, 2022). The information society approach, on the other hand, argues that digital networks have become one of the key determinants of participation in economic and social life (Castells, 2010). In this context, internet access, broadband infrastructure, and secure digital systems are viewed not merely as technological elements, but also as strategic public infrastructures that enable individuals to access educational resources (van Dijk, 2020).

On the other hand, the theory of digital inequality argues that access to digital technologies is not evenly distributed across all segments of society and that this situation can create new inequalities in educational opportunities (van Dijk, 2006). Accordingly, while individuals in countries with well-developed digital infrastructure can access educational resources more easily, those living in regions with limited internet access may find themselves at a disadvantage when it comes to accessing higher education (Norris, 2001; Warschauer, 2003). Consequently, digital infrastructure is considered not only a factor that directly influences access to higher education but also a structural factor that shapes educational equity. This theoretical approach necessitates an empirical examination of how differences in the level of digitalization affect higher education participation rates and indicators of educational equity.

At this point, digitalisation is increasingly recognised in the literature as an important tool that can support inclusivity and equal opportunities in higher education. The proliferation of the internet and digital technologies facilitates access to information and enables educational resources to reach wider audiences. Virtual learning environments, open educational resources, and massive open online courses (MOOCs) offer new opportunities for individuals who face difficulties accessing higher education for physical, economic, or geographical reasons (UN, 2025; Acedo & Osuna, 2016). The free and reusable nature of open educational resources contributes to reducing structural inequalities in higher education (Schaffert, 2010). UNESCO (2002) emphasises that the adaptability and reusability of such resources through information and communication technologies is of critical importance, particularly for developing countries.

However, the effects of digital transformation on equal opportunities in education are not always positive. Regional and socio-economic differences in access to digital tools are among the key factors limiting the potential of digitalisation to promote equality (Burbules and Callister, 2000). Williamson (2017) states that, in addition to the supportive aspects of digital transformation in education, the digital divide creates serious disadvantages for students who do not have internet access and technological equipment and can deepen existing inequalities. Similarly, Selwyn (2022) highlights the potential of digital technologies to democratise access to information, but also notes that high-cost devices and internet access constitute a significant barrier for low-income groups and that this situation can reproduce socio-economic inequalities in education.

UNESCO's 2020 report highlighted digital access issues in the context of the COVID-19 pandemic and clearly demonstrated the impact of the digital divide on inclusivity and equality in education. While distance learning practices rapidly spread during the pandemic, it was noted that students without access to digital tools and the internet were excluded from the education process; students living in rural and low-income areas, in particular, experienced significant learning losses. It is emphasised that this situation has further deepened existing inequalities in education (UNESCO, 2020). The report presents policy recommendations such as strengthening digital infrastructure, increasing digital skills training for students and teachers, and providing financial support to low-income groups.

The equality dimension of digital transformation in higher education is also addressed in the context of gender-based differences. Hendricks and Olawale (2022) reveal that digital technologies offer significant opportunities for women's empowerment and increased civic participation in the digital sphere; however, digital skill gaps, literacy gaps, technology-based violence, and traditional social norms deepen digital gender inequality. In this context, it is recommended that higher education institutions develop special programmes and support mechanisms to enhance women's digital literacy.

Chelovechkova et al. (2021) state that the effective use of digital technologies in education provides students with broader access opportunities, improves the institutional performance of universities, and supports equal opportunities in education. Digital university projects and institutional digitalisation roadmaps are considered important tools for increasing the attractiveness and quality of higher education. Zhao (2023) states that digital learning resources do not always create equal opportunities for low-income students and that the digital divide negatively affects academic achievement. Self-regulation skills, motivation, and personalised learning content are highlighted as decisive factorsin the effective use of digital learning resources. Polyakova (2022) also draws attention to the critical role of self-regulation in digital learning processes.

Finally, studies indicating that digital technologies eliminate spatial and structural boundaries in education reveal that digitalisation has reshaped access to higher education on a global scale. Süel (2023) states that individuals with access to digital skills and technologies can benefit equally from educational opportunities in different parts of the world. Yalın (2023) states that educational technologies reduce geographical and physical limitations, offering students broader access opportunities and creating personalised learning opportunities tailored to individual needs. However, realising this potential depends on the integration of digital tools with pedagogical and institutional transformation (Orr, Weller & Farrow, 2018).

Although the effects of digitalization on education are frequently discussed in the existing literature, there are few studies that empirically examine, at the level of OECD countries, the mechanisms through which digital infrastructure affects access to higher education and how this effect relates to gender equality. In this context, the comparative and empirical examination of the effects of digital infrastructure on access to higher education and gender equality in higher education fills an important gap in the literature. Particularly in economies with relatively high levels of digitalisation, such as OECD countries, examining the effects of internet usage, secure digital infrastructure, R&D expenditure, and economic prosperity indicators on higher education participation and equality through panel data analysis makes it possible to more clearly reveal the role of digital transformation in education policies. This study aims to fill the aforementioned gap in the literature and provide empirical evidence on the effects of digital infrastructure on access to higher education and gender-based equality.

Methodology

Research Model

This study examines the effects of digital infrastructure and economic indicators on participation in higher education and gender equality in higher education using panel data analysis. Two separate models were created for the research. Explanations of the variables included in both models are provided in Table 1.

Table 1

Explanations of Variables

Variables	Explanation	Period	Database	Series Code
lnOK (Dependent)	School enrollment, tertiary (% gross)	2010-2024	World Development Indicators	SE.TER.ENRR
lnOKcee (Dependent)	School enrollment, Tertiary (gross), gender parity index	2010-2024	Gender Statistics	SE.ENR.TERT.FM.ZS

lnIKO (Independent)	Individuals using the Internet (% of population)	2010-2024	World Development Indicators	IT.NET.USER.ZS
lnGIS (Independent)	Secure Internet Server Density (per 1 million people)	2010-2024	World Development Indicators	IT.NET.SECR.P6
lnRD (Independent)	R&D Expenditures (Percentage of GDP)	2010-2024	World Development Indicators	GB.XPD.RSDV.GD.ZS
lnGDPper (Independent)	GDP per capita (current USD)	2010-2024	World Development Indicators	NY.GDP.PCAP.CD
Data is sourced from the World Bank database.				

In the first model (Equation 1), the gross enrollment ratio in teriary education is treated as the dependent variable. This variable is analysed in terms of how it is affected by variables representing digitalisation and economic development, such as the proportion of individuals using the internet, the number of secure internet servers, the share of R&D expenditure in GDP, and GDP per capita. All variables were included in the model after taking their natural logarithms.

$$lnOK_{it} = lnIKO_{it} + lnGIS_{it} + lnRD_{it} + lnGDPper_{it} + u_{it} \quad (1)$$

In the second model (Equation 2), the gender parity index in higher education is used as the dependent variable. The gender equality index for the gross enrollment rate in higher education is calculated as the ratio of the number of female students enrolled in public and private higher education institutions to the number of male students. This index is used to measure the level of equality between women and men in access to higher education. This model also includes the same independent variables and examines the effects of digital infrastructure level and economic indicators on gender equality in higher education.

$$lnOKcee_{it} = lnIKO_{it} + lnGIS_{it} + lnRD_{it} + lnGDPper_{it} + u_{it} \quad (2)$$

In both models, the error term u_{it} represents unobservable individual and temporal effects. Within this framework, the models aim to reveal the role of digitalisation and economic development in access to higher education and equality.

Data Set

The data used in this study were obtained from the World Bank database. The research consists of annual data covering the period 2010–2024 and is in a panel data structure. The sample of the study consists of 37 OECD countries. The countries examined are Turkey, the United States, Canada, France, the Netherlands, Belgium, Luxembourg, Germany, Italy, Portugal, the United Kingdom, Denmark, Ireland, Greece, Switzerland, Austria, Sweden, Iceland, Norway, Spain, Japan, Finland, Australia, New Zealand, Hungary, Poland, Israel, Mexico, Lithuania, Estonia, Latvia, Costa Rica, Colombia, Slovenia, The Czech Republic, Chile, and the Slovak Republic.

The variables included in the dataset have been selected to represent indicators of access to higher education, gender equality in higher education, digital infrastructure, and economic development. The dataset used in the study contains complete observations for all countries and years for the relevant variables. Therefore, there are no missing observations in the dataset. The variables included in the analysis have been obtained completely for the relevant periods and countries, which increases the reliability of the estimation results. The dataset used in the research has a balanced panel structure, as it consists of observations covering the entire 2010–2024 period for each country. The balanced panel structure allows for consistent analysis of cross-country comparisons and timedependent changes.

The natural logarithms of all variables were used in the analyses. The main reasons for choosing the logarithmic transformation are to reduce scale differences between variables, to correct for any skewness that may arise in the distribution, and to estimate the relationships between variables in a more appropriate functional form. Furthermore, the logarithmic transformation allows the coefficients to be interpreted using the elasticity approach, thereby enabling a more meaningful assessment of the impact of percentage changes in the independent variables on the dependent variable. This approach contributes to mitigating issues that may arise from scale differences among variables, particularly in cross-country panel data studies that analyze economic indicators with different units of measurement, digital infrastructure variables, and higher education enrollment rates together. Furthermore, the logarithmic transformation helps to model nonlinear relationships between variables more appropriately and to mitigate the problem of heteroscedasticity. Since all variables used in the study have positive values, the logarithmic transformation was deemed statistically applicable.

Data Analysis

In this study, following the presentation of descriptive statistics, panel data analysis was performed for the two models developed within the scope of the research. In the econometric analysis process, the stages of first determining the appropriate estimation method for each model, then applying assumption tests, and finally interpreting the final estimation results were followed. The F test, Score test, Breusch–Pagan LM test, Likelihood Ratio Test (Chi-square test), and Hausman test were applied to determine the appropriate panel data estimator to be used in estimating Model 1 and Model 2. In addition to individual fixed effects, time fixed effects were included in both models to control for unobserved time-specific factors. This specification allows the models to account for global shocks, macroeconomic fluctuations, technological changes, and other period-specific effects that may influence all countries simultaneously during the 2010–2024 period. After determining the appropriate estimators, assumption tests were performed for the selected model. The assumption tests applied for Model 1 and Model 2 were the Modified Walt Test, Durbin-Watson Test, Baltagi-Wu LBI Test, and

Breusch–Pagan LM Test. In accordance with the results of the assumption tests, model estimations were performed for both models using the Driscoll-Kraay Robust Standard Error Estimator. The Driscoll–Kraay approach provides consistent results by generating reliable standard errors even when the error terms exhibit autocorrelation, heteroscedasticity, and cross-sectional dependence. For this reason, the Driscoll–Kraay estimator was used to mitigate the effects of the assumption violations identified in the model and to obtain more reliable statistical results (Yerdelen-Tatoğlu, 2018).These analyses were performed using the STATA 17.0 programme.

Findings

The findings related to the dataset created within the scope of the research are presented in a systematic manner. First, the mean and standard deviation values of the raw values of the variables used in the study were examined under the heading "Descriptive Statistics". Subsequently, the "Findings on the Higher Education Access Model" section empirically tested the relationship between digital infrastructure indicators and access to higher education. Finally, the "Findings on the Gender Equality in Higher Education Model," which analyses the effects of the level of digitalisation on gender equality in higher education, is presented. The findings obtained in this context are evaluated in line with the selected econometric methods; the test results and estimation findings regarding the assumptions of the models are interpreted within a holistic framework.

Descriptive Statistics

Table 2 presents descriptive statistics for the levels of the variables used in the study for the period 2010–2024, before applying logarithmic transformation.

Table 2
Descriptive Statistics for Variables

Variable	Period	Number of Observations	Mean ± SD
OK	2010-2014 (15 years)	555	73.79±21.04
OKcee	2010-2014 (15 years)	555	1.21±0.12
IKO	2010-2014 (15 years)	555	82.33±13.34
GIS	2010-2014 (15 years)	555	27651.37±45551.84
RD	2010-2014 (15 years)	555	1.87±0.11
GDPper	2010-2014 (15 years)	555	40695.83±25833.67

As shown in Table 2, the data set consists of 555 observations for each variable, indicating that the data set has a balanced panel structure. Among the dependent variables, the average enrollment rate in higher education (OK) for the countries in the OECD is 73.79%, with a standard deviation of 21.04, indicating significant differences in access to higher education among countries. This finding shows that there is no homogeneous structure in terms of participation in higher education among OECD countries. The Gender Parity Index in higher education (OKcee) averaged 1.21, with a standard deviation of 0.12, revealing that gender equality exhibits relatively limited variability across countries.

Looking at the independent variables, the proportion of individuals using the internet (IKO) averaged 82.33%, with a standard deviation of 13.34, indicating that internet access, a fundamental component of digital infrastructure, continues to vary across countries. The secure internet server density (GIS) variable is noteworthy, with an average of 27651.37 and a very high standard deviation (45551.84); this indicates that there are significant inequalities between countries in advanced components of digital infrastructure. The share of R&D expenditure in GDP (RD) was calculated as an average of 1.87%, with a standard deviation of 0.11, indicating that innovation and technology investments are concentrated at different levels among OECD countries. Finally, the GDP per capita (GDPper) variable averaged US$ 40695.83, while the standard deviation of 25833.67 revealed significant differences in economic prosperity levels between countries.

Overall, descriptive statistics show that the high variation in digital infrastructure and economic indicators makes it meaningful and necessary to examine the effects of these variables on access to higher education and gender equality econometrically.

Findings Related to the Higher Education Access Model

The F-test, Score test, LM test, Chi-square test, and Hausman tests were applied to determine the appropriate estimation model. Findings related to the tests used to select the appropriate model for estimating the research model are presented in Table 3.

Table 3

Findings Regarding the Determination of the Appropriate Estimation Model for Model 1

Tests	Maximum Likelihood	Fixed Effects	Random Effects
F test		228,834	
Score	1111801.877		
LM			3291.067
χ^2	1331.663		
Hausman			4.133
p	0.000***	0.000***	0.000***

As seen in Table 3, the F test conducted via the unit effects estimator, the LM test conducted via the random effects estimator, the likelihood ratio test (χ2 statistic) conducted via the maximum likelihood estimator, and the Score test results all indicate that the null hypothesis is rejected. Therefore, it has been determined that there is a unit effect. Consequently, the Maximum Likelihood and Random Effects estimation methods are not suitable for our model. When examining the results of the Hausman test, it is also seen that the null hypothesis is rejected. That is, the difference between the parameters is systematic. Therefore, it has been decided that the fixed effects estimator is valid for the first research model.

Table 4

Findings Related to Assumption Tests for Model 1

Assumption Tests	Test Statistic	p
Modified Wald Test	1939.81	0.000***
Durbin-Watson	0.543	0.543<2
Baltagi-Wu LBI	0.856	0.856<2
BP-LM	3701.341	0.000***

Table 4 shows that the Modified Wald test results (p=0.000) indicate the presence of heteroscedasticity between units in the model. The Baltagi–Wu LBI statistic of 0.856 and the Durbin–Watson statistic of 0.543, both below 2, indicate the presence of an autocorrelation problem. The p value of 0.000 for the Breusch–Pagan LM test reveals the presence of inter-unit correlation. In line with these findings, the Driscoll–Kraay robust standard errors estimator was used in the model. This method was preferred because it provides robust estimates against assumption violations such as heteroscedasticity, autocorrelation, and cross-sectional dependence. The findings related to Model 1 estimation are presented in Table 5.

Table 5

Findings Related to the Driscoll-Kraay Robust Standard Errors Estimator for Model 1

Independent Variables	Coefficient	Drisc/Kraay Standard Error	t	p
lnIKO	0.442	0.038	11.59	0.000*
lnGIS	0.006	0.003	2.26	0.024*
lnRD	0.041	0.015	2.83	0.013*
lnGDPper	-0.134	0.040	-3.31	0.005*
C	3.607	0.366	9.86	0.000*
* p<0,05			F(4, 14)=101,63 (0,000*)	

In Model 1, the high F-statistic (101.63) and p-value (0.000) indicate that the model is statistically significant overall. In other words, when the variables lnIKO, lnGIS, lnRD, and lnGDPper are considered together, they meaningfully explain the changes in the enrolment rate of students in higher education.

- The effect of the lnIKO variable, which represents the Internet usage rate, on the lnOK variable, which represents the higher education enrollment rate, is positive and significant.
- The effect of the lnGIS variable, which represents a secure internet infrastructure, on the lnOK variable, which represents the higher education enrollment rate, is positive and significant.
- The effect of the lnRD variable, which represents the share of R&D expenditures in GDP, on the lnOK variable, which represents the higher education enrollment rate, is positive and significant.
- The effect of the lnGDPper variable, which represents GDP per capita, on the lnOK variable, which represents the higher education enrollment rate, is negative and significant.

Findings Regarding the Gender Equality Model in Higher Education

As in Model 1, the F-test, Score test, LM test, Chi-square test, and Hausman test were applied to determine the appropriate estimation model for Model 2. The findings regarding the tests used to select the appropriate model for estimating the second research model are presented in Table 6.

Table 6

Findings Regarding the Determination of the Appropriate Estimation Model for Model 2

Tests	Maximum Likelihood	Fixed Effects	Random Effects
F test		228.760	
Score	1035708.569		
LM			3187.477
χ^2	1332.941		
Hausman			-8.161
p	0.000***	0.000***	0.000***

As seen in Table 6, the results of the F test, LM test, likelihood ratio test (χ2 statistic), and Score test all indicate that the null hypothesis is rejected. That is, a unit effect has been determined. Therefore, the Maximum Likelihood and Random Effects estimation methods are not suitable for this model. When examining the findings related to the Hausman test, it is seen that the null hypothesis is rejected. That is, the difference between the parameters is systematic. Therefore, it has been decided that the fixed effects estimator is also valid for the second research model.

Table 7

Findings Regarding Assumption Tests for Model 2

Assumption Tests	Test Statistic	p
Modified Wald Test	11848.14	0.000***
Durbin-Watson	0.222	0.222<2
Baltagi-Wu LBI	0.464	0.464<2
BP-LM	3454.398	0.000***

The results of the assumption tests for Model 2 indicate that the fundamental assumptions in panel data analysis have been violated. The test statistic of the modified Wald test being 11848.14 and the p-value being 0.000 reveals that there is unit-level heteroscedasticity in the model. The Durbin–Watson statistic taking the value of 0.222 and being well below 2 indicates the presence of an autocorrelation problem in the model. Similarly, the Baltagi–Wu LBI statistic taking the value of 0.464 and remaining below 2 supports the autocorrelation finding. On the other hand, the Breusch–Pagan LM test statistic value of 3454.398 and p-value of 0.000 indicate the presence of inter-unit correlation (cross-sectional dependence). When these results are evaluated together, it is seen that heteroscedasticity, autocorrelation, and cross-sectional dependence problems exist in Model 2. Therefore, in order to ensure the reliability of the estimation results, Model 2 was estimated using the Driscoll–Kraay standard error estimator, which is robust to the aforementioned assumption violations.

Table 8

Findings Related to the Driscoll-Kraay Robust Standard Error Estimator for Model 2

Independent Variables	Coefficient	Driscoll/Kraay Standard Error	t	p
lnIKO	0.075	0.016	4.73	0.000*
lnGIS	0.003	0.001	2.70	0.007*
lnRD	0.343	0.070	4.92	0.000*
lnGDPper	0.017	0.008	2.01	0.044*
C	-0.630	0.106	-5.96	0.000*
* p<0,05			F(4, 14)=108.54 (0.000*)	

The F-statistic for Model 2 is quite high (108.54) and the p-value is 0.000; thus, the model isstatistically significant overall. This indicates that the independent variables together significantly explain the level of gender equality in higher education.

- The effect of the lnIKO variable, which represents the Internet usage rate, on the lnOKcee variable, which represents the gender equality index for higher education enrollment, is positive and significant.
- The effect of the lnGIS variable, which represents a secure internet infrastructure, on the lnOKcee variable, which represents the gender equality index for higher education enrollment, is positive and significant.
- The effect of the lnRD variable, which represents the share of R&D expenditures in GDP, on the lnOKcee variable, which represents the gender equality index for higher education enrollment, is positive and significant.
- The effect of the lnGDPper variable, which represents GDP per capita, on the lnOKcee variable, which represents the gender equality index for higher education enrollment, is positive and significant.

Discussion and Conclusion

In this study, the relationships between digitalization indicators, R&D expenditures, and economic well-being in OECD countries and their effects on access to higher education and gender equality in higher education were examined using panel data analysis. The findings reveal that digital transformation indicators are significantly associated with participation in higher education and gender equality.

The findings of Model 1 indicate that internet usage rates, secure internet infrastructure, and R&D expenditures have a positive impact on access to higher education. This result is consistent with studies suggesting that digitalization increases educational inclusivity by facilitating access to information (Acedo and Osuna, 2016; Schaffert, 2010). In particular, UNESCO (2002) emphasizes that online learning environments and open educational resources support participation in higher education by reducing physical and economic barriers. The positive impact of a secure internet infrastructure aligns with the views of Orr, Weller, and Farrow (2018), who note that digital transformation is not limited to access alone but must also be supported by sustainable and reliable digital environments. The positive impact of R&D spending supports the view that universities' research capacity and academic appeal increase student demand (McArthur, 2013). Conversely, the negative effect of per capita income on the higher education enrollment rate indicates that economic prosperity alone does not increase participation in higher education. This situation can be explained by the tendency of individuals to enter the labor market directly as income levels rise, and it parallels studies showing that quantitative growth in higher education does not always produce more inclusive outcomes (Eurostudent, 2012; Altunoglu, 2020).

The results of Model 2 revealed that the internet penetration rate, secure internet infrastructure, R&D expenditures, and per capita income have a significant and positive impact on gender equality in higher education. These findings are consistent with studies arguing that digital technologies can reduce gender-based inequalities by facilitating women's access to information and educational opportunities (Hendricks and Olawale, 2022; Selwyn, 2022). In particular, the strong impact of R&D spending demonstrates that women's academic representation can be strengthened in education systems with high research and innovation capacity, and supports the literature on increasing women's presence in STEM fields (Chelovechkova et al., 2021). The positive impact of per capita income aligns with UNESCO (2020) findings, which show that increased economic well-being strengthens families' tendency to invest in their daughters' education and facilitates women's access to higher education. These results suggest that, when considered together, digitalization and economic development can contribute to supporting gender equality in higher education.

The findings of this study indicate that there are significant relationships between digitalization indicators, R&D expenditures, and economic well-being in OECD countries, on the one hand, and access to higher education and gender equality in higher education, on the other. In this context, the following recommendations can be made for policymakers, higher education institutions, and relevant stakeholders:

- Given that internet usage rates and a secure internet infrastructure are positively correlated with access to higher education and gender equality in higher education, it may be beneficial to evaluate initiatives aimed at developing digital infrastructure within the framework of education policies.
- Given the positive correlation between digital access indicators and higher education indicators, it is believed that efforts to increase internet access—particularly in rural areas and among disadvantaged groups—could be among the factors that support educational opportunities.

- The potential effects of higher education institutions' initiatives aimed at strengthening their research capacity on educational outcomes could be examined in greater detail.
- To better understand the impact of digital transformation processes on equal opportunity in higher education, it may be helpful to increase monitoring and evaluation efforts regarding women's and disadvantaged groups' access to and use of digital technologies.
- Since the study is limited to OECD countries, it is recommended that future studies include developing and least developed countries in the analysis.

In conclusion, the findings of this study reveal that digital infrastructure, R&D investments, and economic well-being indicators are significantly associated with access to higher education and gender equality in higher education. The findings suggest that digital transformation may be a key factor in terms of access and equality in higher education. Therefore, it may be beneficial to view digital transformation not merely as a technological process, but also as a policy area linked to the goals of equality, inclusivity, and sustainable development. However, further research supported by various methodologies is needed to better understand the causal mechanisms underlying these relationships.

Research and Publication Ethics

This study complies with all rules specified in the "Higher Education Institutions Scientific Research and Publication Ethics Guidelines." None of the actions listed under the heading "Actions Contrary to Scientific Research and Publication Ethics" in the second section of the guidelines have been carried out.

Authors' Contribution Rates

The first author contributed 40%, the second author contributed 30%, and the third author contributed 30%.

Conflict of Interest

There is no conflict of interest among the authors.

References

Acedo, S. O., & Osuna, S. M. T. (2016). *ECO European project: inclusive education through accessible MOOCs.* [Conference paper]. In Proceedings of the Fourth International Conference on Technological Ecosystems for Enhancing Multiculturality (p. 881-886). Association for Computing Machinery, New York.

Altunoğlu, A. (2020). Yükseköğretimde kapsayıcılığın uygulanabilirliği üzerine bir tartışma. *OPUS–Uluslararası Toplum Araştırmaları Dergisi, 16*(27), 672-699. https://doi.org/10.26466/opus.755015

Bates, T. (2010). New challenges for universities: Why they must change. D. Schneckenberg & U. D. Ehlers (Eds.), In *Changing cultures in higher education* (pp. 15-25). Springer.

Becker, G. S. (1964) Human capital: A theoretical and empirical analysis, with special reference to education. University of Chicago Press.

Burbules, N. C. & Callister, T. A. (2000). *Watch IT: The risks and promises of information technologies for education.* Westview.

Castells, M. (2010). Globalisation, networking, urbanisation: Reflections on the spatial dynamics of the information age. *Urban studies*, *47*(13), 2737-2745. https://doi.org/10.1177/0042098010377365

Chelovechkova, A., Adamenko, Y. V. & Medvedev, A. A. (2021). *Digital transformation of education as overcoming the global digital inequality within the framework of sustainable development of civilization*. [Conference paper]. In Proceedings of the International Scientific and Practical Conference on Sustainable Development of Regional Infrastructure (ISSDRI 2021) (pp. 696-700). Kurgan State University, SciTePress. https://doi.org/10.5220/0010596106960700

Cross J. (2010). They had people called professors…! Changing worlds of learning: Strengthening informal learning in formal institutions? U. D. Ehlers & D. Schneckenberg (Eds.), In *Changing Cultures in Higher Education* (pp. 43-54), Springer. https://doi.org/10.1007/978-3-642-03582-1_4

Eurostudent (2012). *Report on Quality Assurance in Eurostudent IV*. https://www.eurostudent.eu/download_files/documents/QA_Report_WP6_240212.pdf

EuroStudent (2018). *Eurostudent VI: Overview and selected findings.* https://www.eurostudent.eu/download_files/documents/EUROSTUDENT_VI_short_report.pdf

Gilbert, J. (2005). *Catching the knowledge wave? The knowledge society and the future of education*. New Zealand Council for Educational Research.

Hendricks, W., & Olawale, B.E. (2022). Bridging the gender-based digital divide: Empowerment of women through ICT. *Tenth Pan-Commonwealth Forum on Open Learning*. https://doi.org/10.56059/pcf10.9136

McArthur, J. (2013). *Rethinking knowledge within higher education: Adorno and social justice*. A&C Black.

Norris, P. (2001). Digital divide: Civic engagement, information poverty, and the internet worldwide. Cambridge University Press.

Orr, D., Weller, M. & Farrow, R. (2018). *Models for online, open, flexible and technology enhanced higher education across the globe – a comparative analysis*. International Council for Distance Education. https://icde.org/wp-content/uploads/2023/01/Models-report-April-2018_final.pdf

Parlak, B. (2017). Dijital çağda eğitim: Olanaklar ve uygulamalar üzerine bir analiz. *Süleyman Demirel Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 22 (*Kayfor15 Özel Sayısı), 1741-1759. https://izlik.org/JA79UC39JW

Polyakova, A. Y. (2022). Digital transformation of mathematical education as overcoming the digital gap. *Informatics in School 2* , 4-17. https://doi.org/10.32517/2221-1993-2022-21-2-4-17.

Schaffert, S. (2010). Strategic integration of open educational resources in higher education. D. Schneckenberg & U. D. Ehlers (Eds.), In *Changing Cultures in higher education*. (pp. 119-131). Springer.

Selwyn, N. (2022). *Education and technology: Key issues and debates*. (3rd Edition). New York: Bloomsbury Academic.

Süel, H. (2023) *Eğitimde fırsat eşitliğinin yolu dijitalleşmeden geçiyor.* Ekonomim. https://www.ekonomim.com/kose-yazisi/egitimde-firsat-esitliginin-yolu-dijitallesmeden-geciyor/704075

UNESCO (2002). *Forum on the impact of Open Courseware for higher education in developing countries final report.* https://unesdoc.unesco.org/ark:/48223/pf0000128515

UNESCO (2020). *Global education monitoring report 2020: inclusion and education, all means*. France: UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000373724

van Dijk, J. A. (2006). Digital divide research, achievements and shortcomings. *Poetics, 34*(4-5), 221-235. https://doi.org/10.1016/j.poetic.2006.05.004

van Dijk, J. (2020). *The network society* (4th ed.). Sage.

Warschauer, M. (2003). *Technology and social inclusion: Rethinking the digital divide*. The MIT Press.

Williamson, B. (2017). *Big data in education: The digital future of learning, policy and practice*. Londra: SAGE Publications.

Yalın, Y. (2023). *Eğitim teknolojileri, eğitimde fırsat eşitliği sağlıyor mu?* Construvtor Tech. https://www.advancity.com.tr/post/egitim-teknolojileri-egitimde-firsat-esitligi-sagliyormu

Yerdelen-Tatoğlu, F. (2018). *Panel Veri Ekonometrisi*. (4. Baskı). İstanbu: Beta Basım Yayım Dağıtım A.Ş.

Zhao, B. X. (2023). Educational inequality: The role of digital learning resources. *Lecture Notes in Education Psychology and Public Media 7* (1), 634-642. https://doi.org/10.54254/2753- 7048/7/2022980