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Hierarchical Clustering of the European Countries from the Perspective of E-government, E-participation, and Human Development

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Abstract:

The information society offers governments the opportunity to work closer with citizens and companies, to respond better to their requirements, and to create the conditions for the functioning of a modern, efficient, and democratic public administration. Due to the development of the information society, e-governance and e-participation appeared and developed, through which the communication of governments with stakeholders became more straightforward and less expensive. This research aims to identify and analyse comparatively how the telecommunications infrastructure and Internet users influenced the expansion and diversification of e-government and e-participation that contributed to the human development index in the EU states in 2010-2022. In the longitudinal data analysis, we apply fixed and random estimators to see the most critical determinants of the human development index. In the second part, we cluster the 27 EU countries in four clusters by Ward's hierarchical algorithm. The hierarchical clustering emphasised that there is still a digital divide among EU countries. The digital divide occurs because of the lack of Internet access of the population from marginalised communities of European countries, resulting in socio-economic disparities. Therefore, some EU states should have initiatives to bridge the gap to digital technologies. The research results are essential for

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those governments coordinating the policies and the entire process of integrating information technologies and dedicated e-government and e-participation applications in central and local administration.

Keywords:
e-government, e-participation, human development, Internet use

1. Introduction

The communications infrastructure and the continuous improvement of the capacity of administrations and citizens of European states to cooperate in the governance process and access public services of general interest have significantly changed the content and tools used in the e-government and e-participation processes and have significantly contributed to human development in Europe (Androniceanu, 2023; Al-Mannaei et al., 2023). The use of the Internet by public authorities confers the classic advantages of availability, accessibility and interaction for citizens and private companies. Therefore, the development of the communications infrastructure and the increase in access to the Internet ensures the development of e-government and e-participation and can significantly influence the quality of public services and communication with public administration stakeholders (Burger et al., 2020). As a result of these changes in the communication infrastructure and the accessibility of the Internet, most of the problems generated by the traditional bureaucracy began to be solved progressively in most states. In this context, various integrated application systems have been developed (Gancarczyk et al., 2022). They confirm the advantages of integrating information technologies in applications necessary for activities and processes, the decision-making process, and the development of policies of social and economic interest in a country. In the last three decades, most researchers have recommended replacing expensive bureaucratic procedures in terms of time and cost with accessible and efficient IT applications in the public sector. As a result, state governments have developed investment programmes both in communications infrastructure and increasing citizens' access to the Internet and their education. These efforts generated satisfaction for the administration and public institutions' stakeholders because they became partners in the process of digital transformation (Rodríguez-Martínez et al., 2023). The broader use of the Internet has made possible the development of another concept called electronic democracy (Martins & Veiga, 2022). Thus, citizens can communicate actively and without intermediaries with state institutions. In addition, it is possible to maintain a personalised relationship with the administrative institutions, all these benefits having the advantage of being obtained at low costs, high quality, and better productivity (Bouckaert & Van de Walle, 2001; Colesca & Dobrica, 2008; Eynon, 2007). The research question the paper answers is: How did e-government and e-participation based on IT infrastructure influence human development in the EU states from 2010-2022?

The paper is organised as follows. Section 2 contains a comprehensive literature review on recent approaches regarding e-government, e-participation, and human development. Section 3 contains the research frame, data description, including data sources, and descriptive statistics. Section 4 briefly presents the methodology of fixed and random effects estimators and Ward's hierarchical algorithm. Section 5 presents the main results, followed by discussions and interpretations. The paper ends with some conclusions.

2. Literature review

E-government dates back a few decades to the 1970s when governments started to use computers for data processing and record keeping (Zautashvili, 2017; Phimolsathien, 2022; Potter, 1998). In the 1990s, with the advent of the Internet, governments built their own official websites, increasing transparency. In the 2000s, citizens began interacting with governments electronically through online services. The enterprise architecture framework was extensively developed in the first decade of the 2000s, facilitating online communication and open access to public databases (Idzi & Gomes, 2022). Social media platforms allow citizens to communicate with government agencies.

E-governance represents the process of reinventing the public sector. It refers to providing public services in electronic format for citizens, civil servants, and the business environment. Three large classes of participants are involved in the governance process: citizens, administrations and companies (Gulati et al., 2014). Specific communication and transactional relationships are born between these participants, divided into several large groups of electronic government components (Colesca, 2009). Thus, over time, e-government and e-participation have become effective instruments for diversified cooperation based on smart communication between the main actors: government, citizens, and private organisations. E-government represents more than a bi-directional connection with public administration stakeholders (Gatautis, 2008). Implementing e-government means from top to bottom (from the state to the citizen). According to the literature (Martins & Veiga, 2022; Kézai & Páthy, 2023), a complete e-government solution can meet the following requirements:

(i) A single point of contact for providing electronic services 24 hours a day, seven days a week;
(ii) a bridge to the digital society;
(iii) reconstruction of the citizen's trust in the government (objective related to the variable promotion within the marketing mix, more precisely public relations);
(iv) acceleration of economic growth, and the like.

As Tomkova (2009) explained, e-government uses information and

communication technologies in the following areas: (1) improvement of processes: electronic administration (cost reduction, performance management, establishment of strategic connections in the administration, distribution of authority): (2) connecting citizens: e-Citizens and e-Services (informing citizens, identifying their needs, improving public services). This connection begins with the publication of information and continues through interaction (receiving and displaying information from citizens), ending in the transaction phase; (3) interactions with the outside: e-society (Pucheanu et al., 2022). In the United Kingdom, the Government Gateway System provides approximately 3,000 e-government and e-administration services (Kemeç, 2022). According to Dryzek (2000) there are the following four main components of e-government: G2C, which reflects the relationships between government and citizens; G2B, which integrates the links between government and business environment; G2E, which refers to the relationships between government and civil servants and G2G, government and other governmental institutions. The first e-government (G2C) component covers government-citizen relations achieved through new technologies. It is one of the most debated areas of government initiatives in all countries that have e-government development programmes. These types of communications demand further ICT penetration even in developed countries (Kersan-Škabić & Vukašina, 2023).

In essence, the services in this category mean bringing the government online closer to the citizens. First, the aim is to bring some simple information online; then, the citizen-government relationship becomes interactive, with communication and data exchanges in both directions. Finally, relationships become transactional, meaning that some services provided by the government to citizens can be provided online - on the websites of the respective public institutions or on global government portals - the so-called "one-stop shop" portals (Wauters & Lörincz, 2008). In most developed countries, all these services, due to their diversity, are grouped on a single website, from where a connection is made to the institutions' websites that can solve the respective request. The problem is solved on the portal site, without the beneficiary even knowing which institutions they turned to and on which databases they communicated with each other to receive their answer. Another example of success is in Singapore, where an "eCitizen Centre" provides services to citizens through the Internet developed by the Singapore government. Citizens can interact with the state online in a wide variety of situations. For example, they can buy a house, rent an apartment, sue, file a complaint, pay a tax or fee, enrol their child in school, register for military service, and the like.

The same types of government services are offered online in the United States and on the portal, www.firstgov.gov, with a centre called the e-citizen page (Martins & Veiga, 2022).

Local administrations conduct most public services that integrate e-government applications. For example, electronic services are provided as Infoville in Valencia (Spain) or NaestvedNet in Naestved (Denmark). In general, the services offered are the same. However, the portal's personalisation level is different, and the information circulated is much more specific in one administration than the other (Lombardi et al.,

2012). The Government of Valencia, working with Oracle, the world leader in database applications, built Infoville not only as a government website but as a portal that combines a wide variety of services from the public and private sectors. Infoville is an application that provides local information and integrates e-commerce, e-government, online education, and virtual government. In Naestved, there is a higher level of personalisation, in access to both data and public services.

The second component of e-government is G2B, referring to the government's relationship with companies. Considering that companies represent the engine of a country's economic growth, the services provided by the state on the Internet in favour of this sector should be commensurate with its importance. Currently, in most states, government purchases and auctions are increasingly online, meaning more transparency and lower costs. The first public procurement system was launched in Singapore by the IT department of the Ministry of National Defence. Since then, it has become evident how these new techniques can make the public procurement process more efficient by reducing the number of frauds, more efficient management systems for offers on electronic support, more accessible access to corporate suppliers worldwide, time saved by processing offers online and the development of databases rich in helpful information (Ringold et al., 2011). The Australian state government of Victoria worked with Oracle to improve the efficiency of the Department of Natural Resources and Environmental Protection and achieved a 70% improvement. Supporting digital environment development positively affects digital transformation in business processes (Jurczuk & Florea, 2022; Straková et al., 2022).

The third component of e-government (G2E) involves the use by the civil servants of an electronic means in communication and transactions through applications that facilitate the fulfilment of some public service responsibilities, such as, for example, the use of special databases by municipality employees for decisions in the real estate area, thereby reducing possible time losses generated by physical travel to another department and searching in physical archives. Thus, the limitations of space, the crowding of people looking for various information, and those of time are eliminated. Of course, these professional duties require an appropriate level of civil servants' digital skills which can be tested using the relevant tools (Bilan et al., 2023). The third component of e-government is about the interaction between government institutions (G2G) and communication between them by electronic means. This communication between public institutions occurs since solving some problems is achieved through complex solutions, which require data processing held by different institutions. For example, a beneficiary perceives the registration of a company as a single objective, when, in reality, it involves multiple steps: at the Trade Registry, the Court, the Financial Administration, and the like. G2G applications must integrate processes, including solutions accepted by all participants. However, for process integration to be possible, the integration of the technical infrastructure is also necessary. Not only must databases communicate with each other, but also the machines that support them - computers, web servers, and local networks must respect a certain level of standardisation. G2G,

therefore, means communication between several different public institutions to solve a unique citizen problem. Most of the time, this communication is undetectable by the citizen and involves the exchange of data at different levels of security between the computer systems of the two institutions. The big problem that appears in developed countries in implementing G2G solutions is the limited capacity of the public administration's human resources to cooperate with each other to optimise the operational time and reduce bureaucracy. The vertical organisation of public institutions often means that solving some problems requires collaboration between departments. Implementing G2G would solve a large part of these problems and lead to the limitation of bureaucracy. However, this depends on the interest that exists at the departmental level in implementing such inter-institutional bridges (Carter & Bélanger, 2005).

More recently, new concepts such as Industry 4.0, artificial intelligence, blockchain, and the Internet of Things appeared, and the term "smart government" was introduced (Zhang & Kimathi, 2022; Lăzăroiu et al., 2022; Kubíčková et al., 2021). Emerging technologies improved governance quality and citizens' services.

According to specialised literature (Matei & Dogaru, 2010), there is a direct connection between e-participation and e-government. Although since 2004, e-participation has been explained as a tool through which citizens can participate in decision-making in the governance process or in consultations in which they can express opinions, later on, other perspectives of approaching this concept appeared (Pollitt, 2001). Thus, in the literature, there is no unified point of view regarding what e-participation means. Some of the most important and relevant opinions are presented below. Most academics and practitioners (Macintosh et al., 2009; Sæbø et al., 2008; Medaglia, 2012; Welch, 2012; United Nations, 2014; Ntshangase & Msosa, 2022). Other academics and practitioners (Alderete, 2022; Sá et al., 2016). explained e-participation as a dynamic IT platform initiated by governments to involve citizens in different activities and services. Other specialists explained e-participation as a social activity that brings together citizens, state administrations and politicians (Sanford & Rose, 2007; Smith et al., 2011; Shava & Vyas-Doorgapersad, 2023). As it results from most of the definitions expressed in the literature, politicians are the main stakeholders who can initiate different social participation activities, analyse their content and consider it or not. Therefore, e-participation does not necessarily refer to civic actions or the involvement of citizens in consultations with the government but only to those activities initiated by governments using information technologies to achieve some public policy objectives or even to initiate public policies by selecting topics from the citizens' agenda. From this perspective, specialists (Barro, 1991; Barro, 2001; Anarfo et al., 2019; Okunola & Fakunle, 2021) consider that e-participation has become somewhat of a tool of e-government. In the last decade, e-participation has been used by governments as an instrument of e-government (United Nations, 2018a; United Nations, 2018b; United Nations, 2019).

The third essential variable integrated into our research is human development in

2010-2022, reflected by the Human Development Index (HDI). The United Nations has proposed HDI to assess each country's individual human development level.

According to the literature (Mishchuk et al., 2023; Morvai et al., 2022; Ferraz et al., 2020; Meyer & Meyer, 2020; Datta & Singh, 2019; Sen, 1997), HDI is a composite index of health, education, and income, more holistic than GDP, and has a more significant implication for digital transformation. HDI measures the well-being of individuals, while GDP refers to economic output. HDI refers to life quality connected to digitalisation in that digital technologies lead to social progress (Simionescu et al., 2021). Thirdly, HDI is an efficient instrument for policy-makers beyond economic growth. The impact of informational technologies and communications on the three components of HDI can, in turn, be assessed.

This paper is a continuation of the studies developed by the authors during 2021-2023 (Androniceanu & Georgescu, 2021; Androniceanu et al., 2022a; Androniceanu et al., 2022b; Androniceanu & Georgescu, 2023) where the significant impact of digitalisation on government effectiveness and well-being has been emphasised for EU countries, applying data mining techniques such as Principal Component Analysis and cluster analysis. The results showed that the Nordic countries are top, followed by West European countries and emerging economies in the last positions (Małkowska et al., 2021). Zambrano- Yépez et al. (2023) study the determinants of e-government expressed as EGDI: population, Internet use, GDP per capita, and the global innovation index (GII). More populated countries with a higher GDP have a higher EGDI. Lee et al. (2021) test a model of democratic e-governance called DEWEM. The model agreed with citizens' satisfaction and their willingness to use the platform. The digital divide refers to disparities in using digital technologies based on education, income, and other socioeconomic characteristics (Kézai & Páthy, 2023). The digital divide may have a socioeconomic impact (Sun et al., 2022a; Sun et al., 2022b; Oláh et al., 2021). People lacking access to digital technologies are hindered from education, healthcare, and job offers, creating social disparities (Doran et al., 2023; Marino et al., 2022; Bartczak, 2022; Marino & Pariso, 2021). Dobrolyubova (2021) overviews the literature on measuring government digitalisation. Implementing digital technologies should contribute to more effective public administration, communication and knowledge sharing (Zsigmond & Mura, 2023; Škare et al., 2023; Głodowska et al., 2023). Dobrolyubova et al. (2019) discuss the impact of digital transformation on government performance. Even if the impact is positive, as Durkiewicz and Janowski (2018) remarked, the ultimate influence is corruption reduction and environmental degradation (Androniceanu et al., 2022a; Krishnan et al., 2013). Waheduzzaman and Khandaker (2022) analysed a panel of 136 world countries, and by panel least squares regression finds a significant positive role of e-participation in government effectiveness and control of corruption. Abdulkareem et al. (2022) investigate the interposing influence of e-government trust on the association between e-participation and e-government quality using PLS-ESM. The findings indicate that the quality of e-government does not correlate directly with e-participation. Trust in e-government plays a comprehensive mediating role in this

relationship. This outcome underscores the significance of transparency in the public sector, as this enhances citizens' confidence in the system. The study by Mellouli et al. (2020) focuses on the viewpoint of government personnel. The investigation delves into two dimensions of e-government public value: organisational performance and environmental quality. These dimensions are studied concerning three quality factors, together with the intentions to use and the satisfaction of users. Dhaoui (2021) delves into the impact of e-government on different dimensions of economic and social progress for a panel of 15 MENA countries spanning 2003-2018. The findings highlight that most indicators of good governance contribute positively to sustainable development. Digitalisation enhances control over corruption and government effectiveness. Ma and Zheng (2019) discuss an extensive survey of more than 28,000 participants from 32 European countries. The results indicate that e-government services that are ranked highly are met with positive reception from citizens, suggesting a specific alignment between the supply and demand of e-government. In the HDI ranking, from 2020, Norway finished first with an HDI value of 0.957, Ireland and Switzerland came second, while the United States ranked 17th with an HDI of 0.926. Our research identified and analysed the correlations between the three key variables, namely e-government, e-participation and human development in the EU countries from 2010-2022.

As can be seen, most of the papers identified in the specialised literature show a separate approach to the concepts we analysed, namely e-governance, e-participation, Internet use, ICT infrastructure, and human development. Our approach differs from the fact that the analysis of the variables is correlative for the entire analysed period. Within this, we identify changes and analyse correlations between various variables and measure their intensity. These changes and their impact on human development were analysed, and a hierarchical clustering was conducted. The originality of this research consists in the use of an integrated methodology, including hierarchical clustering, to demonstrate the changes in the EU countries from 2010-2022 and to rank the EU countries grouped in clusters according to citizens' accessibility to the Internet and digital infrastructure, e-governance, e-participation, and human development index.

The following section contains the purpose of the research, specific objectives, and research hypotheses, the research variables, and the statistical and econometric methods used to make correlations, analyse them and interpret the results.

3. The frame of the research and data description

The purpose of the research is closely correlated with the specific objectives and the research variables selected from different international databases.

This research aims to identify and analyse comparatively how the telecommunications infrastructure and Internet users influenced the expansion and

diversification of e-government and e-participation that contributed to the human development index in EU countries from 2010-2022.

The specific research objectives are:

(1) to discover the intensity of the correlations in EU countries between human development, on the one hand, and telecommunications infrastructure and the degree of Internet use, on the other hand;

(2) to know the type of correlations and its intensities between e-government, e-participation and human development in EU countries;

(3) to build up a deep hierarchical clustering of EU countries;

The research framework is completed with the research hypotheses we sought to verify and, based on the results, to discover which ones are validated and invalidated. There are three research hypotheses:

Hypothesis 1 (H1): E-participation significantly influences the Human Development Index in EU countries from 2010-2022;

Hypothesis 2 (H2): Internet use increases the Human Development Index in EU countries;

Hypothesis 3 (H3): There are significant gaps between EU countries regarding implementation of e-government and e-participation.

The research variables selected from different international databases helped us know their evolution over time and the significant correlations in different EU countries. Table 1 contains the main research variables. They represent time series from 2010-2022 and have been collected for the 27 EU members from databases such as Eurostat, the UN E-Government Knowledgebase, and the UN Development Program. The UN E-Government Knowledgebase is a benchmarking instrument, enabling a comparative evaluation of e-government progress among UN member countries. It offers an interactive service of e-government advancement in each country, both regionally and globally.

Table 1:

The research variables

Variable	***Acronym***	***Measurement unit***	***Source***
Internet use by individuals	INTUSE	Percentage of individuals	Eurostat
E-Government and Development Index	EGDI	[0.1]	publicadministration.un.org
E-Participation Index	EPI	[0.1]	publicadministration.un.org
Telecommunication Infrastructure Index	TII	[0.1]	publicadministration.un.org
Human Development Index	HDI	[0.1]	hdr.undp.org

Source: Authors' own, 2023.

Table 2 contains the descriptive statistics and the pairwise correlations of the data. Similar combinations of variables have been used in previous papers (Georgescu et al., 2023; Georgescu & Kinnunen, 2021) to check the still-existing digital divide and the similarities in public administration efficiency. Table 2 shows a low standard deviation of HDI, 0.03, compared to the mean, 0.88. It follows that the economic development of EU countries is comparable concerning the definition of HDI. The significant difference between the standard deviation and the mean belongs to INTUSE, which shows the existing digital divide among the EU countries, confirming hypothesis H3. The pairwise correlation matrix shows positive correlations. The variables can contribute positively to one another, as explained later in section 4.

Table 2:

Descriptive statistics and pairwise correlation

	HDI	***EGDI***	***EPI***	***INTUSE***	***TII***
Mean	0.882025	0.772931	0.661748	80.93836	0.700703
Median	0.884	0.7817	0.7079	82.17	0.7039
Maximum	0.972	1.7474	1	98.93	0.9979
Minimum	0.782	0.5421	0.0263	40.01	0.3093
Std. Dev.	0.039889	0.112995	0.243271	11.91885	0.139573
Skewness	-0.266733	1.695486	-0.715196	-0.695344	-0.247912
Kurtosis	2.36398	18.68028	2.681432	2.993161	2.473402
	HDI	***EGDI***	***EPI***	***INTUSE***	***TII***
HDI	1	0.648113	0.463881	0.768605	0.673443
EGDI	0.648113	1	0.618867	0.71877	0.782042
EPI	0.463881	0.618867	1	0.581192	0.562817
INTUSE	0.768605	0.71877	0.581192	1	0.814431
TII	0.673443	0.782042	0.562817	0.814431	1

Source: Authors' own, 2023.

The positive relationship between EGDI and EPI is significant because both concepts concern the use of digital technologies in governance. EPI complements EGDI through the integration of online consultations, public platforms, or participatory

budgeting. These aspects improve the EGDI.

4. Research methods and main steps of the research methodology

4.1 Fixed and random effects

The following section will apply the fixed and random approach method, a frequently used econometric technique to discover unobserved heterogeneity in a panel data set.

The steps of the fixed and random effects models are the following (Baltagi, 2014):

1. Determine the pooled OLS regression (POLS).
2. Determine FEM.
3. Determine REM.
4. Choose between POLS and FEM by means of the redundant fixed effects test.
5. Choose between FEM and REM by means of the Hausman test.

In longitudinal studies, fixed and random effects models are used to analyse data that involves repeated measurements of the same individuals over time. We point out some reasons why fixed and random effects models are important in the case of longitudinal data.

Longitudinal studies aim to capture individual-level trajectories of change, enabling unique growth, decline, or stability patterns over time. Longitudinal data exhibits temporal correlation where observations closer in time are more related. Fixed and random effects models account for these correlations, trying to avoid autocorrelation and providing more accurate standard estimates.

A panel data regression is described by equation (1):

$$Y_{it}=a + bX_{it} + \varepsilon_{it} \quad (1)$$

where Y is the dependent variable, X is the explanatory variable, Ɛ is the error term, t is time, i is the individual, and a and b are coefficients.

The fixed effects model (FEM) includes individual-specific and time-invariant characteristics, which cannot be directly observed in data. The random effects model (REM) assumes that the individual-specific effects are not correlated with the observed variables. REM parameters are estimated employing the maximum likelihood function by pooling information across individuals. The choice between FEM and REM is made according to the problem's nature, the data set's specificity and underlying assumptions. The Hausman test (Hausman, 1978) is applied to compare the suitability of FEM or REM.

The panel data model (2) has the following specification (2):

$$HDI_{it} = a_0 + a_1 EPI_{it} + a_2 TII_{it} + a_3 EGDI_{it} + a_4 INTUSE_{it} + \delta_i + \varepsilon_{it} \quad (2)$$

δ_i represents the fixed or random effects for country i, i=1,…, 27 countries. ε_{it} is the error term, i=1,…, 27, t is the time from 2010 to 2022. δ_i captures heterogeneity across countries.

The fixed and random effects model is continued with hierarchical clustering of the 27 EU countries for 2022 using the same 5 variables.

4.2 Hierarchical clustering and Ward's algorithm

The advantages of hierarchical clustering are detailed information about the similarities among the observations, not being sensitive to initial conditions, and being less sensitive to outliers and cluster shapes. A property specific only to hierarchical clustering is the clusters' granularity levels, which can be analyzed as sub-clusters.

In order to deepen the analysis and identify the hierarchical peculiarities of the subclusters, we chose to use Ward's algorithm. Ward's method (Ward, 1963) is frequently used for hierarchical clustering based on a sum of squares criterion (Kaufman & Rousseeuw, 2005; Nowak, 2021). In the first sequence of the research process, we clustered the EU countries into four clusters. In the second sequence, we represented the dendrogram as a graph with a tree structure. The leaves of the dendrogram are the graph nodes and the branches are the graph edges.

We applied Ward's algorithm in the third sequence to produce compact and even-sized clusters (Szmrecsanyi, 2012). First, each cluster contains only one object. A predefined number of clusters denoted by n are merged such that finally, only one cluster containing the whole dataset is obtained. As new clusters are created, the variance is minimised such that the total sum of squared is computed (Romesburg, 2004; Kassambara, 2017; Roszko-Wójtowicz & Grzelak, 2021).

Ward's algorithm has the following steps:

1. Determination of a cluster's mean.
2. Identifying the distances between the objects of a cluster and the cluster's mean.
3. Squaring and summing the differences between the objects of a cluster and the mean of that cluster.
4. Adding all sums of squares.
5. Computing the total sum of squares.

Ward's algorithm is based on maximising the degree of cluster homogeneity of clusters or, equivalently, on intracluster variability minimisation given by the total sum of squares. The merger of two clusters increases the total sum of squares. The cophenetic

coefficient checks the clustering validity (Farris, 1969).

In the next section, we present the empirical results and discussions.

5. Main results and discussion

In this paper, we first compare the fixed effects, random effects, and OLS estimations for the 27 EU panel data sets to see the most critical determinants of HDI. In the second part, we cluster the 27 EU countries in 4 clusters by Ward's hierarchical algorithm. A cophenetic coefficient tests the clustering reliability.

5.1 Results discussions based on the fixed effects estimator versus the random effects' estimator

First, we compare the pooled OLS regression (POLS) and FEM (Fixed Effects Model) employing the redundant fixed effects test. We check the null hypothesis, which says that POLS is chosen, versus the alternative hypothesis that FEM is chosen.

Table 2:

Redundant fixed effects test results

Effects Test	*Statistic*	*d.f.*	*Probability*
Cross-section F	73.22	-26.29	0.00
Cross-section Chi-square	651.67	29	0.00

Note: d.f. = degrees of freedom

Source: Authors' own, 2023.

Both probabilities being less than 0.05, one accepts the alternative hypothesis that FEM is chosen. Next, we choose between FEM and REM (Random Effect Model) employing the Hausman test. The null hypothesis of choosing REM is checked versus the alternative hypothesis of choosing FEM. The Hausman test statistic asymptotically follows the Chi-square distribution. Using the Chi-square statistic of 32.85, we obtain the p-value p=0.00.

Table 3:

Hausman test results

Test summary	*Chi-square statistic*	*Chi-square d.f.*	*Probability*
Cross-section random	32.85	4	0.00

Source: Authors' own, 2023.

Since the p-value of the Hausman test is less than 0.05, the alternative hypothesis, namely, FEM, is selected. Table 4 contains the panel data estimation using HDI as a dependent variable. The estimations include REM, FEM, and POLS.

Table 4:

Panel least squares with cross-section random and fixed effects

	Cross-Section Random Effect		***Fixed Effect***		***POLS***	
Variable	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**	**Coefficient**	**t-statistic**
EPI	0.014	4.79 (0.00)	0.019	5.35 (0.00)	-0.006	-0.86 (0.39)
TII	0.032	3.53 (0.00)	0.036	3.91 (0.00)	0.009	0.49 (0.61)
EGDI	-0.009	-0.98 (0.32)	-0.011	-1.28 (0.20)	0.070	3.30 (0.00)
INTUSE	0.00	5.26 (0.00)	0.0006	4.22 (0.00)	0.002	9,81 (0.00)
C	0.790	89.51 (0.00)	0.799	98.04 (0.00)	0.656	56.82 (0.00)
Cross-section random S.D./Rho		0.02 (0.81)				
Idiosyncratic random S.D./Rho		0.009 (0.18)				
R-squared		0.56		0.94		0.61
Adjusted R-squared		0.55		0.92		0.60
S.E. of regression		0.009		0.009		0.02
F-statistic		101.45 (0.00)		178.36 (0.00)		124.80 (0.00)
Akaike Information Criterion				-6.37		-4.52
Schwartz Criterion				-6.01		-4.46

Source: Authors' own, 2023.

From Table 4, we can see that in the FEM estimator, all regressors, except EGDI, positively influence HDI with a p-value less than 0.05. The probabilities are shown in parentheses. Among REM, FEM and POLS, FEM has the most explanatory power, given by R-squared. FEM is a good fit since F-statistic=178.36 (p=0.00<0.01).

A 1% increase in TII leads to a 0.036% increase in HDI, meaning advancements in telecommunication infrastructure can improve human development. A positive

relationship between TII and HDI is given by the following factors: access to information and knowledge, economic development, health and well-being, and social inclusion. Internet access and mobile connectivity facilitate the exchange and spreading of information and knowledge. People have enhanced access to education. Telecommunication infrastructure means improved communication networks and investments in e-commerce and digital services, stimulating economic development. Telemedicine services and remote consultations provide a higher level of medical expertise, also improving HDI. Increased connectivity reduces the digital divide (Mesa, 2023) and enables remote communities access to public services.

A 1% increase in EPI leads to a 0.019% increase in HDI. E-participation makes access to information and public issues easier by engaging citizens in making public their opinions. Thus, it contributes to transparency and good governance. Through e-participation, the communication channels between citizens and public administration are facilitated. The HDI components, social welfare, education, and healthcare, are improved through more efficient service delivery.

The above confirms hypothesis H1. The study by Pirannejad et al. (2019) enhances EPI with additional dimensions, namely HDI and the Democracy Index, to encompass societal aspects. The most important criteria for evaluating e-participation initiatives are political rights and civil liberties.

A 1% increase in INTUSE exerts a 0.0006% increase in HDI. The individuals have facile access to information and learning resources. The Internet offers significant economic opportunities such as e-commerce platforms, online businesses, and remote work. These online activities improve economic growth, leading to more proficient Internet users with improved digital skills, which could increase productivity, thereby validating hypothesis H2.

A 1% increase in EGDI exerts a statistically insignificant 0.011% decrease in HDI. This relationship is generally positive because e-government initiatives increase transparency and accountability. This relationship can be influenced by socio-economic factors specific to each country, such as income inequality or the quality of governance.

The advantage of FEM over REM is its ability to control for unobserved time-invariant heterogeneity across individuals. FEM requires fewer assumptions than REM. In an FEM, one does not need to make assumptions between the individual-specific effects and the independent variables. FEM is often preferred when one is interested in causal relationships and policy implications.

5.2 Results discussions using the hierarchical clustering and Ward's algorithm

Next, we apply the Ward hierarchical clustering and identify the following four clusters:

Cluster 1 contains Bulgaria, Hungary, Romania, and Slovakia.

Cluster 2 contains Croatia, Czechia, Latvia, Lithuania, Poland, Slovenia, Greece, Italy, and Portugal.

Cluster 3 contains Estonia, Netherlands, Finland, and Denmark.

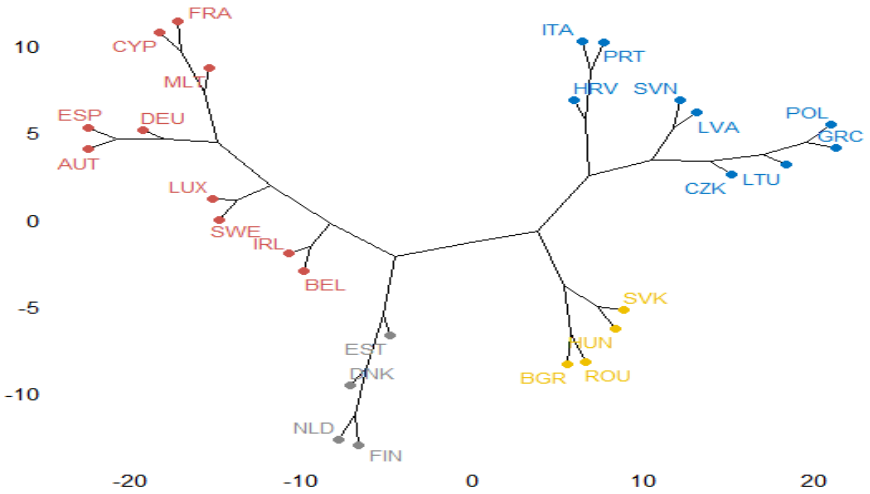
Cluster 4 contains Belgium, Germany, Ireland, Spain, France, Cyprus, Luxembourg, Malta, Austria, and Sweden.

Then, we represented them as a figure and cluster plot (see Figures 1 and 2).

In the dendrogram in Figure 1, we check the clustering validity by computing the correlation coefficient between the cophenetic distances and the distance matrix (Kassambara, 2017). In our case, a correlation coefficient of 0.62 is considered acceptable for proving that the hierarchical clustering reflects the data structure.

Figure 1:

The figure's cluster's structure determined by Ward's algorithm



Source: Authors' own, 2023.

The cluster characterisation is made according to the cluster means in Table 5.

Table 5:

Cluster means

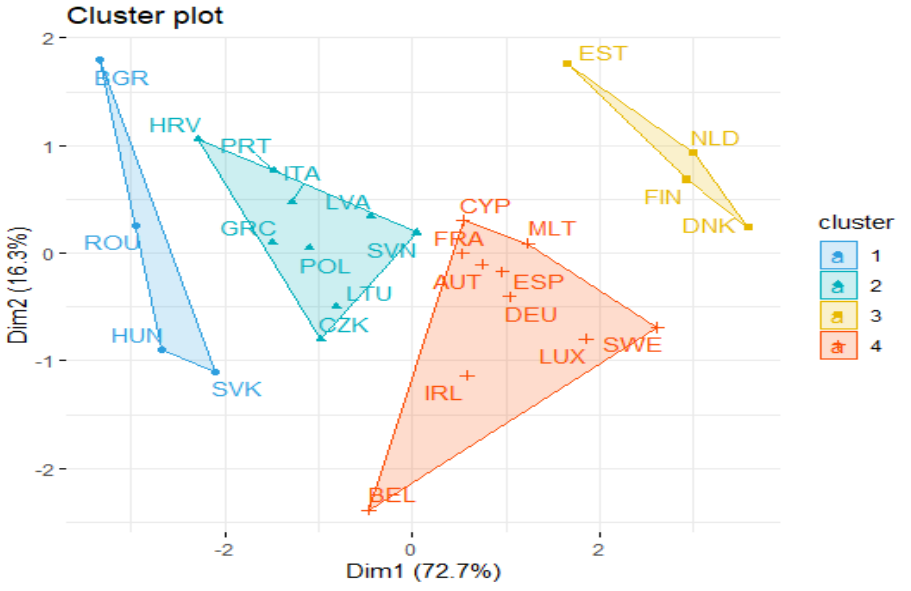
Cluster	INTUSE	EGDI	EPI	TII	HDI
1	85.71	0.78	0.59	0.80	083
2	86.70	0.84	0.68	0.82	0.88
3	95.34	0.95	0.95	0.94	0.93
4	93.65	0.88	0.71	0.89	0.92

Source: Authors' own, 2023.

As shown in Figure 2, Cluster 3 contains two Nordic countries, Estonia and Netherlands and places first concerning all variables. Cluster 4, containing most of the well-developed economies, occupies second place. Romania, Bulgaria and the other two economies from Cluster 1 place last.

Figure 2:

Cluster plot of Ward's method



Source: Authors' own, 2023.

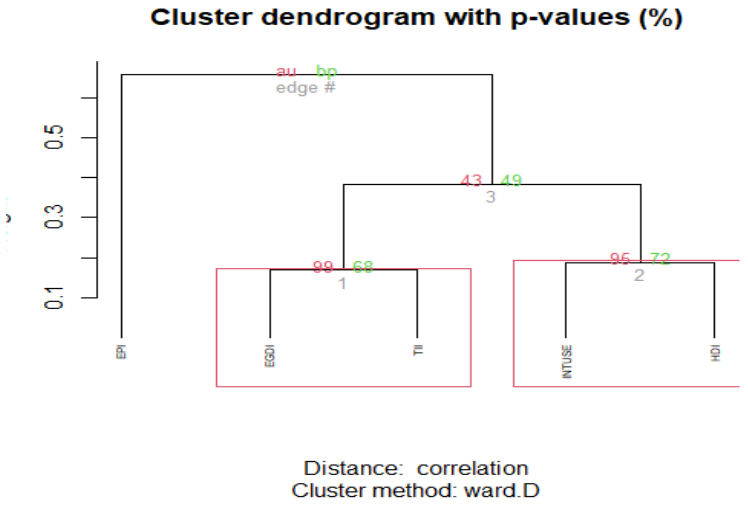
These results are approximately similar to papers by Androniceanu and Georgescu (2023), Androniceanu et al. (2022b), and Shishmanov (2022). A similar classification of

EU countries is made using the DESI index, which shows a positive trend from one year to the next both for Romania and Bulgaria, which occupy the last two places, constantly swapping them (Shishmanov, 2022). The Nordic countries are the most digitalised and rank in top positions according to global indices. They invest considerable sums in digital infrastructure, education, and public services. Their industries focus on innovation and technology. The Netherlands has programmes to promote digitalisation in e-commerce, cyber security and smart cities. Estonia is among the digital leaders in its innovative e-government solutions. Estonia's programmes include a digital electoral system, a digital identity system (e-Residency) and other public digital services. The success in digitalisation of the countries in cluster 3 is owed to supportive policies and regulations, political will, significant investments in innovation, and striving to bridge the digital divide. The countries in cluster 1 face challenges concerning digitalisation and EGDI compared to other countries. Their position in the lower rankings is caused by factors such as the digital infrastructure, e-government services and the digital divide. Even though these countries have made substantial progress in implementing initiatives, there are still considerable disparities in the use of digital technologies by the population in remote regions. The delivery of e-government services has to improve in terms of user-friendliness and accessibility. The results of hierarchical clustering confirm hypothesis H3.

For each hierarchical clustering, it is necessary to compute the p-value employing the bootstrap clustering method (Suzuki & Shimodaira, 2015). The columns of the datasets are clustered, resulting in the cluster dendrogram presented in Figure 3.

Figure 3:

Cluster dendrogram in columns



Source: Authors' own, 2023.

Bootstrap probabilities (BP) measure the frequency of cluster identification in the bootstrap copies. Approximately unbiased probabilities (AU) are obtained by bootstrap resampling (Suzuki & Shimodaira, 2015). In Figure 3, the clusters marked by red rectangles have AU greater than 95%, representing that dataset. Higher AU values suggest more reliable clusters. In our case, EGDI and TII form one cluster, while INTUSE and HDI form a second cluster. EPI is a singleton. EGDI and TII are complementary indicators helpful in understanding a country's digital ecosystem. Both EGDI and TII are enablers of digital transformation. EGDI relies on technological innovation, while e-government programmes facilitate TII. In another cluster, HDI and INTUSE are interconnected, as INTUSE impacts a country's human development. Through digital skills development programmes, people become involved in online activities. Internet access generates economic opportunities, generating income and reducing unemployment, key elements of HDI.

5.3 Limitations of the research

The main limitations of the research are the small number of variables included in the research and the time period. In future research, we intend to increase the number of variables, deepen the correlative analysis and extend the time interval for the analysis.

6. Conclusion

In this paper, we applied the fixed effects versus random effects model to study the implications of INTUSE, TTI, EPI, and EGDI on HDI for the EU panel dataset from 2010-2022. By the Hausman test, FEM was chosen to reflect these implications. The FEM results showed that INTUSE, TTI and EPI have a positive and statistically significant effect on HDI. The only not statistically significant explainer of HDI proved to be EGDI. This result could be motivated by considering additional variables, other data sources, or limited available datasets.

In the second part of the paper, we applied Ward's method to obtain a hierarchical clustering of the 27 EU countries using the same indicators collected for 2022. Four clusters were obtained, among which Cluster 4 of two Nordic countries, the Netherlands and Estonia, rank on top. At the same time, Romania, Bulgaria, and the other two countries occupy the last place. The hierarchical clustering emphasised the still-existing digital divide among EU countries. The digital divide occurs because of the lack of Internet access for marginalised populations, resulting in socioeconomic disparities. Therefore, some EU countries should have initiatives to bridge the gap to digital technologies. Another implication of digital technologies at the level of public administration is corruption reduction (Santiso, 2022).

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