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PORTRAYING THE LEVEL OF DIGITAL PERFORMANCE AND INNOVATION OF THE EUROPEAN PUBLIC SECTOR: CONTEXTUALISING THE RELATIONSHIP BETWEEN E-GOVERNMENT AND DIGITAL INNOVATION

Abstract: Due to the differences among European Union member states in governance quality, public governance effectiveness, financial resource management, and efforts to improve economic performance and well-being, digital innovation is essential for promoting digital governance. Achieving qualitative e-governance requires increased innovation, along with the effective adoption and implementation of digital technology. The main objective of this study is to analyse the connections between public governance and digital innovation in the European Union (EU). Two research methods were considered to carry out the longitudinal data compiled at the EU-27 member states (EU27) level from 2017 to 2022: bibliometric and Gaussian and mixed-Markov graphical (GGMs) analysis. This methodology allows a comprehensive approach to evaluating the interaction of digital innovation with public governance. Scientific documents from the period 2010-2023 from the Web of Science were analysed to explore the relationship between e-government and digital innovation. The analysis revealed that this subject is relatively new, with the most productive years being the last five years. It also identifies the countries and authors in this field that are most concerned and the most relevant documents. Based on GGMs and correlation analysis, the empirical part focused on digitalisation, innovation, world governance indicators, and economic variables from 2017 to 2022 across EU member states to identify links between these variables. Our findings support our assumption that digitalisation and innovation positively impact e-government services. The results reveal the need for countries to align their digital transformation plans to integrate digital technologies and continuous innovation to improve e-government effectiveness. Successful implementation of e-government relies not only on technology but also on well-planned strategies, adequate resource allocation, ongoing innovation, and governmental dedication to ensure accessible, secure, and user-friendly e-services for all citizens. The findings underscore the necessity for countries to reconfigure and align their digital transformation plans by integrating digital technologies into service delivery while continuously promoting innovation to improve the performance of e-government.

Keywords: graphical models, bibliometric analysis, e-government, digitalisation, innovation

1. INTRODUCTION

This study examines and contextualises the relationship between e-government and digital innovation in the European Union (EU27). Thus, our research aims to thoroughly study how the public sector in the EU performs in terms of its digitalisation services while also considering the best practices employed by some EU governments and how those can be translated into an EU-wide policy.

In this complex framework, this research focuses on determining the relationship between the public sector and digital innovation and how these two specific things interplay with one another. The analysis is grounded in two advanced approaches: thorough bibliometric analysis and Gaussian and mixed-Markov graphical analysis (GGMs). The findings emphasise that the public sector and digital innovation have a strong relationship with one another, showcasing that digitalisation has a very important role in assessing the performance of the public sector.

Digital technology has implications in all aspects of the national economy, notably aiding in the solution of problems and introducing novel technology and operational procedures. The growing interest in digitalisation is due to its ability to streamline operational efficiency, reduce working time, and improve e-government and public sector quality. To fully harness the potential of digital technology and ensure its effective implementation, governments should prioritise data-enabled digital governance (Arner et al., 2022). The importance of public sector development for the national economy is confirmed by the fact that many European Union member states are currently implementing complex and comprehensive programs to develop public sectors through digitalisation projects to improve their economies. Due to the disparities in the quality of governance between the member states of the European Union, it is necessary to have good public governance, a sufficient distribution of governmental funds, and rational public spending both in less developed countries and in developed ones.

There are two approaches that may be taken to the process of digital transformation: adding value via complexity and adding value through digital innovation, where the government can impact citizens' participation in public service delivery (Lopes et al., 2019). Doran et al. (2023) state that e-government is the solution for modernising and improving the efficiency of public administration. E-government supports modelling a specific type of public governance, where the presence of information and web services does not necessarily prove the presence of a communication channel but the emergence of a new philosophy of participatory bureaucracy management. Pathak et al. (2007) suggested that e-government could aid eradicate corruption and establish a strong link between the government and the citizens.

Implementing novel technological advancements for improving the e-government in different institutions faces many challenges; the majority of these difficulties differ between nations and between different e-government models. Beniwal et al. (2013) identified several challenges that may arise in the e-government process: technical infrastructure constraints (current telecommunication infrastructure is deficient, outdated equipment), financial limitations (such as the price of an internet membership and the limited availability of internet service providers in some locations, which makes it challenging for residents to obtain online services).

The current situation, nuanced by the pre-Covid 19 and post-Covid 19 periods, has demonstrated the importance of digital resources for a country's economy. Internet access, connectivity, artificial intelligence, and digital skills have supported the economy and facilitated its smooth functioning. The COVID-19 pandemic accelerated the transformation of the digital intensity of public and private institutions, forcing the adoption of digital tools, whose mission was to ensure the continuity and sustainability of the respective sectors. A significant number of information and communication technologies underpin the infrastructure of the digital economy (Nasution & Bazin, 2018). Introducing digital tools in the public environment (e-tax, e-transport, e-health) will benefit society, the government, and the dynamics between the government and citizens. The global pandemic has accelerated technological advancement in government services, compelling governments to reconsider their approaches to serving all societal segments (Mergel et al., 2019). Institutions and public administrations have seen several irreversible changes as digital governance has grown structurally and in terms of how governments and citizens interact.

The literature on the topic generally concurs that the relationship between e-government and digital innovation is synergistic and complementary. Authors have pointed out that the link between digital innovation and e-government leads to better public services, reduced waiting times, decreased bureaucracy, and increased citizen engagement with public authorities. Furthermore, the link between e-government and digital innovation is bidirectional (Mirandilla-Santos, 2008) and has a symbiotic relationship (Shofia et al., 2020).

This research contains a few significant additions. We might contend that our research's innovation in relation to earlier studies is influenced by the way empirical analysis is carried out, particularly the techniques employed, and the way the research framework was created. In this complex framework, this paper is an innovative attempt to investigate the links between the public sector and digital innovation in the European Union (EU) member states by utilising two advanced research methods: the bibliometric analysis using the R bibliometrics package and the Gaussian and mixed-Markov graphical (GGMs) analysis. We are able to showcase the pattern and strength of relationships between all the factors taken into consideration for the EU-27 nations by employing the mixed-Markov Graphic Model. Components of the Worldwide Governance Indicators and Digital Economy and Society Index were chosen as indicators to highlight the interaction between e-government and digital innovation. Furthermore, the recorded results indicate a dynamic and stable long-term interconnection between e-government and digital innovation. Also, a mutual influence (bidirectional) was identified between these two phenomena. The empirical findings are in line with the model developed by Hinings et al. (2018), which explored the interaction between digital innovation and transformation and government policy uncertainty, which in our case is represented by digital innovation and e-government.

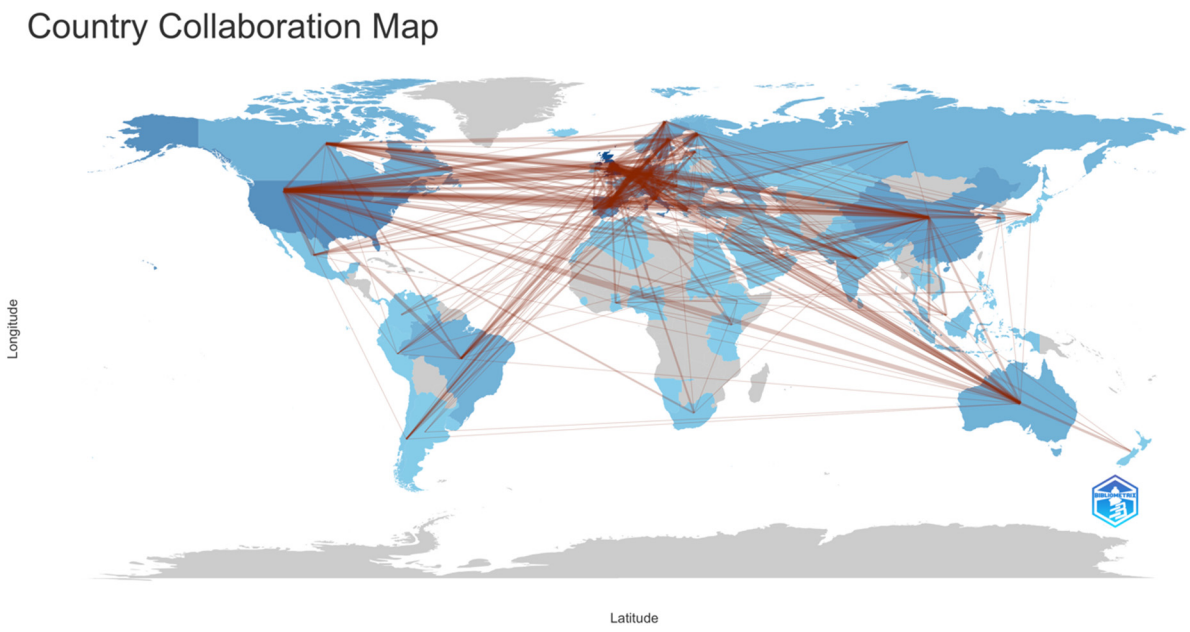
The research paper is structured as follows: section 1 explains the link between the public sector and digital innovation while also sharing insights into the criticism of the public sector and the disparities between the EU member states. Section 2 is devoted to the bibliometric analysis. Section 3 highlights the methodology employed, and Sections 4 and 5 state the data utilised for our research and the results. The conclusion is presented in Section 6.

2. BIBLIOMETRIC ANALYSIS

We have considered bibliometric analysis to understand better the available literature on the nexus between the public sector and digital innovation. The bibliometric analysis is a valuable technique for identifying trends in the literature and evaluating the calibre and significance of the available literature, which also aids in analysing and displaying the intellectual, conceptual, and social components of research and the dynamic elements of its evolution. The types of analysis that can be produced with the help of bibliometric analysis are vast and varied, such as citation analysis, co-authorship analysis, keyword analysis, author analysis, institutional analysis, citation network analysis, and collaboration analysis. Moreover, the choice of employing the R software, as opposed to other software, is because the R Studio's bibliometrix package offers greater flexibility, customisation, and advanced statistical analysis thanks to the packages that it contains.

Using the R Studio's bibliometrix package, we conducted a thorough bibliometric analysis to identify key contributors and trends in our research field. This analysis highlighted the prevalent keywords, co-citation of author's countries, the word cloud, and a treemap, which provided valuable insights into the specialised literature.

The data employed for our study was retrieved from the Web of Science Core Collection on March 8, 2024. The search terms utilised were "public sector" and "digital innovation"; the selected type of documents were "article", "book chapter", and "proceeding papers", while the period of analysis was from 2010 until 2023. Therefore, after applying relevant filters, 1221 publications were retrieved and imported into R studio to be analysed using the bibliometrix package (biblioshiny function). In order to better analyse the relationship between the countries, the co-citation world map was employed. Picture 1 highlights the results, and 1850 entries underline an essential collaboration between nations. Namely, the collaboration between the USA, EU states, and China represent the bulk of the link strength, where USA – EU states have a frequency of 73. Moreover, there is a significant collaboration between EU governments, such as Italy and Spain with the frequency 11, Italy and France, and Germany with the Netherlands with 10.

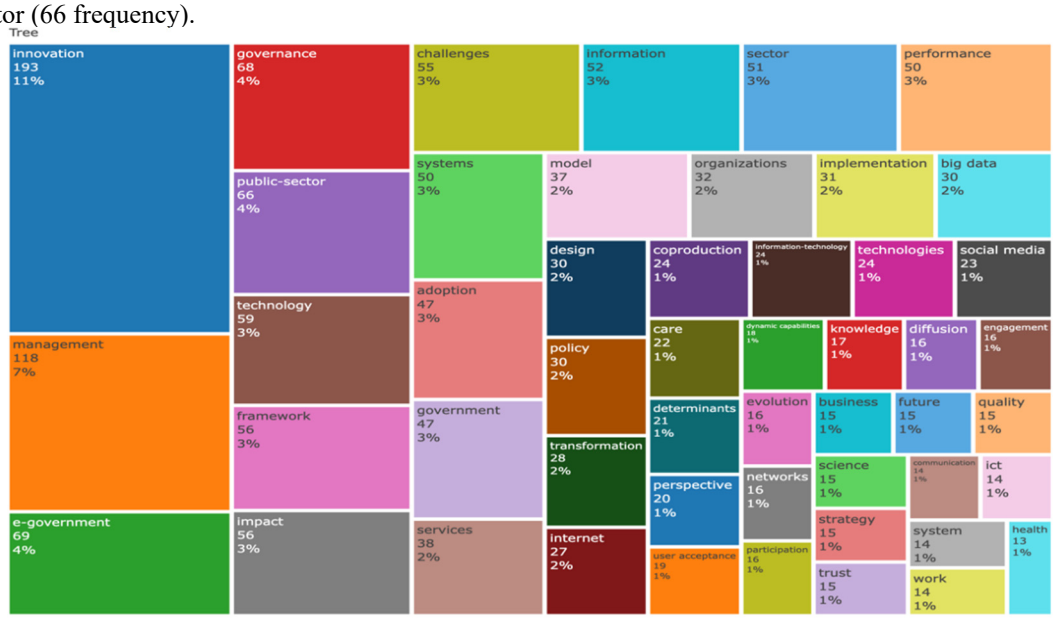


Picture 1: Map of the co-citation of author's countries
Source: author's own work in R studio "bibliometrix" package

Furthermore, by thoroughly analysing the frequency of the words that appear in the abstracts of the papers taken into consideration, Picture 2 showcases the words most often employed. Therefore, the top 5 most employed terms are innovation (193 frequency), management (118 frequency), e-government (69 frequency), governance (68 frequency), and public sector (66 frequency). Moreover, other additional topics such as "business", "performance", "organisations", "big data", "perspective", "policy", and "health" are also among the most used words related to the relationship between e-government and digital innovation. Thus, the link between the public sector and digital innovation is very interconnected, as technology plays an essential role in increasing the efficiency of the public sector.

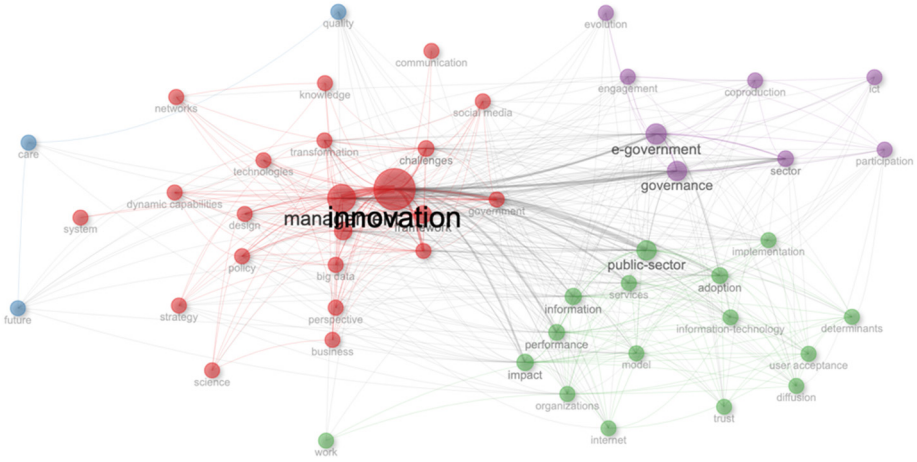
Picture 2: The word cloud Map
Source: author's own work in R studio "bibliometrix" package

A large number of pairs containing three words may be found in the treemap, this is also useful for identifying the set of three terms that frequently appear together in abstracts that use three terms. The most frequently employed word combinations are presented in Picture 3 The two relevant areas of our study were showcased in the treemap, namely innovation (193 frequency), management (118 frequency), e-government (69 frequency), governance (68 frequency), and public sector (66 frequency).



Picture 3: Treemap
Source: author's own work in R studio "bibliometrix" package

Picture 4 displays the co-occurrence analysis of the authors' terms. Similarly, the nodes stand in for the keywords, and the linkages provide the co-occurrence relationship between them. The co-occurrence of a term is higher in more noticeable nodes, and the keywords are more related to one another in thicker connection lines. Thus, four clusters are found, with the most essential nodes being "public sector," "e-government," "innovation," "management," and "governance."



Picture 4: The authors' keywords and their connections
Source: author's own work in R studio "bibliometrix" package

The relationship between digital innovation and the public sector has been extensively researched, as evidenced by the bibliometric analysis that we have concluded. The vast literature on the subject highlights that this topic is still relevant and contemporary. Innovation, management, e-government, and governance are essential topics which highlight how diverse this field of study is and how it continues to be written and researched by scientists and used in real-world settings (pursuing e-services, e-education, e-health, etc.). In conclusion, the analysis underscores the sustained significance and inventive possibilities of digital changes in improving public sector services and governance frameworks.

3. METHODOLOGY

This paper employs graphic models of Gaussian and mixed-Markov (GGM, MGM) as network models of conditional associations to evaluate the correlations, weather positive or negative, and the interconnections between digitalisation and e-government. Therefore, we consider the research methods employed by Crăciun et al. (2023) and Cristea et al. (2023) in their papers. GGM and MGM are applied to analyse the connections between the public sector and digital innovation in the European Union (EU).

From a methodological perspective, a Gaussian graphical model for a random vector $X = (X_{1,\ldots\ldots,} X_n)$ is determined using graph G with p nodes. The model encompasses all multivariate normal distributions $N(\mu, \Sigma)$ whose inverse correlation matrix satisfies the condition $\Sigma_{jk} = 0$ when $\{j, k\}$ is not an edge in G (Williams, 2021). The undirected graph G = (V, E) includes a set of vertices V = {1,..., p} as well as a set of edges E ⊂ V ´V. Be $\Omega_d = (\omega_{y.d}) = \Sigma_d^{-1}$ for d = 1,2 to be the precision matrix for $X = [x^1, \ldots, x^{n1}]^T \in R^{n1xp}$ and $Y = [Y^1, \ldots, Y^{n2}]^T \in R^{n2xp}$. X and Y are the data matrixes. The precision matrix (the reverse covariance matrix) $\Omega = \Sigma^{-1}$ represent a GGM model (Williams, 2021).

Links between nodes are represented graphically in GGMs and MGMs as lines or margins. Red edges show negative correlations, and blue edges show partial correlations, or positive associations. The absolute forces (width and saturation) of the edges connecting the vertices (variables) show the intensity of the linkages.

4. DATA

All multiple dimensions have been decomposed into variables, and only the most relevant ones, along with those with a range of data availability, have been retained as indicators. To identify the implications of digitalisation and innovation on the economy, and to evaluate the positive and negative correlations and interconnections between digitalisation, innovation, and digital public services, as well as the consideration of all dimensions and below dimensions of digital transformation and e-government processes, we employed the graphical models Gaussian and Mixed-Markov (GGM) as network models of conditional associations.

In order to perform the two graphical models (GGM, MGM), data from 2017-2022 (annual data) were collected for all 27 member states of the European Union. The Eurostat database and the World Bank were the sources for the indicators employed; Eurostat for economic performance indicators; for the digitalisation dimension, we utilised the European

Commission database; and last but not least, for the innovation indicators, the data sources employed were the World Bank and Eurostat.
Based on the research objective, contextualising the relationship between e-government and digital innovation, the data are arranged in four groups: digitalisation, innovation, e-government, and economic performance. The dataset includes indicators for the EU-27 member states for the period 2017-2022. The time sample was utilised considering the availability of the data. The variables included in the empirical models, which were organised into four dimensions, are represented by the following dimensions:

- Digitalisation: (i) World Bank-Individuals using the Internet (% of population) (IUI); (ii) Digital economy and society index – (ii) Integration of digital technology (weighted score (0 to 100) (IDT); (iii) Human capital - according to the skills of internet users (weighted score (0 to 100) (HC); (iv) Connectivity - by mobile broadband (weighted score (0 to 100) (CMB); (v) Advanced Skills and Development, by ICT Specialists (weighted score (0 to 100) (ADVS);
- E-government: Digital economy and society index - (i) e-Government Users (Percentage of individuals who used Internet within the last 12 months) (EGOV), (ii) Digital Economy and Society Index - Digital Public Services-by e-government (weighted score (0 to 100) (DPS), (iii) Digital Economy and Society Index e-Government Users (weighted score (0 to 100) (OP); (iv) Eurostat- Digital public services (weighted score (de la 0 la 100) (Internet);
- Innovation: Eurostat- (i) Gross domestic expenditure on research and development (R&D), (ii) R&D personnel and researchers by sector of performance (fields of R&D and sex) (P_R&D), (iii) GERD by sector of performance and fields of R&D (GERD_R&D);
- Economic performance: Word Bank- (i) GDP growth (annual %) (GDPg); (ii) Unemployment, total (% of the total labour force) (Unempl); Eurostat- (iii) GDP per capita (annual %) (GDP per Cap);

Following Yang et al. (2023), Noja et al. (2019), and Dima et al. (2016) were the researchers who employed using similar indicators and related methodological credentials.
Table 1 contains specific descriptive data for each indicator utilised in the econometric models.

Table 1: Descriptive statistics of the data employed in the analysis

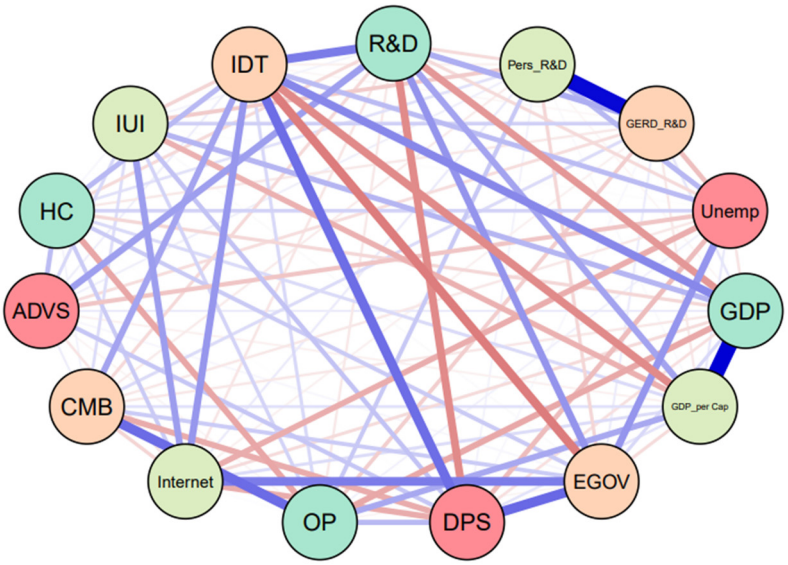
Variable	Mean	Sd	Min	Max
CMB	16.197	5.837	8.052	39.120
ADVS	14.030	1.780	6.333	26.660
HC	24.869	6.181	10.460	38.560
IDT	4.698	2.761	-1.073	12.385
IUI	85.311	7.981	31.130	98.865
OP	7.638	2.987	2.487	13.928
EGOV	65.062	18.920	12.090	94.084
DPS	61.929	16.826	10.271	99.640
Internet	70.588	12.684	31.130	90.610
Unempl	6.594	3.302	2.015	21.41
gdpg	2.838	4.312	-11.167	15.125
GDP_per cap	2.589	4.455	-11.600	18.732
GERD_r&d	11626	22342	65.928	121164
Pr&d	106601	165164	1529.700	782904
R&d	1.6855	0.888	0.460	3.490

Source: author's own processing in Eviews.

Regarding the dimensions of economic performance (ECON), the summary statistics (Table 1) highlighted that unemployment (unempl) recorded the highest index for Greece (21.41) and the lowest for the Czech Republic (2.015). However, GDP per capita (GDP_per cap) recorded the maximum value for Croatia (133590.1), with Spain at the opposite pole (-11.60). Regarding the digitalisation dimension (DIGIT), individuals using the Internet (IUI) variable recorded the maximum value in Denmark (98.86) and the minimum value in Italy (63.07). As for DESI components, ICT Specialists (ADVS) recorded the highest average value (13.00) among the three other dimensions–human capital, connectivity, and digital technology integration–with the highest maximum value (over 26 in Sweden) and the lowest minimum value (over 6 in Greece and Romania). Regarding gross domestic expenditure on research and development (R&D), the minimum value (0.46) is in Romania, and the maximum value (3.49) is in Slovakia. High values were obtained between the four components for the integration of digital public services (e-government), with an average value above 63, and significant discrepancies were obtained between EU-27 countries, which stated the minimum interval (Romania 10.27) and maximum interval (Sweden, 99.64).

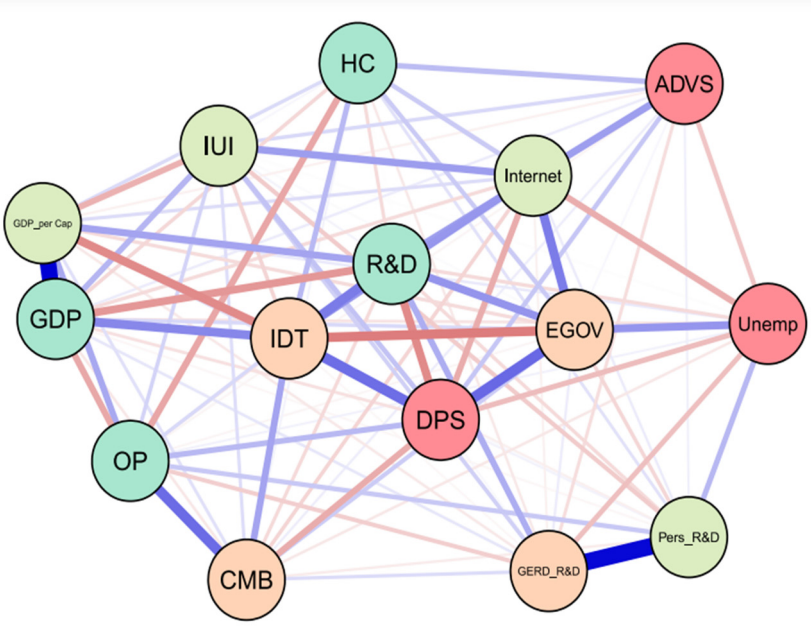
5. RESULTS

To investigate our research hypothesis, "there are strong connections (both positive and negative) between the aspects of digitalisation (including innovation) and digital public service credentials", we have created and evaluated two graphical models, based on GGM and MGM, using extensive Bayesian information criteria and partial correlation.
GGMs were analysed using partial correlation, extended Bayesian information criteria/contracting operator, and absolute minimum selection for the period 2017–2022. Each indicator represents a node in the configured network connected to other nodes by significant paths, reflecting their interdependencies. Estimates were made using two methods: estimation using partial correlation and those based on the Bayesian EBIC information criterion (Picture 5).



Picture 5: Results of the Gaussian graphic model (GGM)
Source: author's own work in R studio

A Gaussian graphical model (GGM) (Picture 6) highlights the strong interconnections between all the variables. The integration of digital technology (IDT) is noted in the network, being closely associated with Digital Public Services (DPS), GDP growth (GDP), Connectivity (CMB), and Research and Development (R&D). Gross domestic exposure to research and development (R&D) also has a partly positive correlation with the integration of Advanced Skills and Development (ADVS), e-government users (percentage of individuals who used the Internet over the last 12 months) (EGOV), and GDP per capita (GDP per_Cap). Digital Public Services (DPS) are also positively correlated with individuals using the Internet (IUI), advanced skills, and development of ICT specialists (ADVS) and Open Data (OP). Thus, our research hypothesis was confirmed. There are significant overall (positive and negative) implications of the dimensions of digitalisation and innovation on e-government in EU-27 countries.



Picture 6: Results of the Mixed-Markov Graphic Model (MGM)
Source: author's own work in R studio

In the Gaussian Graphic Model (MGG) presented in Picture 6, stronger links capture various associations related to digital innovation and the dimensions of e-government. These include positive links with the integration of digital technology (IDT) associated with gross domestic exposure on research and development (R&D), with GDP, Digital Public Services (DPS), connectivity (CMB), and so on, Human Capital (HC), and Open Data (OP). On the other hand, there are negative synergies with individuals using the Internet (IUI). A favourable influence on gross domestic exposure on research and development (R&D) is observed in GDP per capita growth (GDP per_Cap), Integration of Digital Technology (IDT), Internet use: finding information about goods and services (Internet), and e-government users (EGOV). On the other hand, adverse influences are identified regarding Internet users who use fewer activities involving digital devices, such as other online activities (HC) and public services that have integrated digital technologies (DPS).
Thus, the findings are consistent with the ones found by Kuhlmann and Heuberger (2021) and Arief et al. (2021), highlighting that innovative digital technology is generally considered a potential solution for alleviating pressure on the digitalisation of the public sector.
Considering the findings, tailor-made strategies for public policies for integrating digital technologies and continuous innovation are required to improve the effectiveness of e-government. These are particularly necessary in areas such as digital public services, internet users, and connectivity through digital means, aiming to enhance the integration of digital technologies into digital public services and establish appropriate regulations to increase citizens' confidence in using digital technologies in interactions with public authorities.
According to our estimates, using digital tools in delivering public services—such as e-government, open data, and citizens' proficiency with digital technologies and public services—improves the quality of e-government in the digital age. This is because digital technology helps to enhance and simplify several institutional aspects, including security, communication, high-quality service delivery, and institutional well-being. This finding was also supported by Mergel et al. (2019). Moreover, digital innovation can be closely associated with the efficiency of the government (Karkin et al., 2021), suggesting that these accreditations' beneficial effects may encourage the digital transformation of public government. However, it is essential to carefully manage the implementation of digital innovation in e-government initiatives to avoid unintended negative effects on public employees and citizens (Guo, 2011).
Based on GGM findings (Picture 5) and MGM (Picture 6), effective collaboration between policymakers and all societal sectors can improve the public sector's digital innovation. High-quality services, such as information sharing, quick communication, unfettered access to technologies, safe and sustainable digital infrastructure, and enhanced security and connection, result from integrating digital technology.
However, there are several drawbacks to digital innovation, including the need to enhance resource quality, the demand for novel services, technical inequalities, and policy conflicts that could result in particular ambiguities when it comes to the implementation of standard operating procedures (Windapo, 2021; Caruso, 2023; Chen et al., 2022). In addition, it is recommended that governments integrate information technology into several domains to foster societal advancement (Kamer, 2011).

6. CONCLUSION

This study analysed the relationship between the public sector and digital innovation. Two research methods were considered to assess the connections between the public sector and digital innovation in the European Union (EU): bibliometric, Gaussian, and mixed-Markov graphical models. Empirical results highlight that digital innovation has positively and negatively impacted e-government services in the European Union. These findings significantly impact understanding of the link between digitalisation and Digital Public Services in the EU-27.

Moreover, digital technology plays a crucial role in improving e-government effectiveness. However, Gaussian and mixed-Markov graphical analyses allow interaction between digital innovation and the public sector. The results also reveal that over the past few years (2017-2022), significant improvements in digital infrastructure have resulted in a more extensive incorporation of digital networks within the public sector. This has consequently facilitated more accessible access to information, aligning with the similar results reported by Tassabehji et al. (2019).

Moreover, the bibliometric analysis allowed the review of specialised literature by identifying and mapping the most cited keywords and the co-citation between them, the co-citation of the author's countries, and the most employed three-word groups. The results allowed the identification of the most relevant keywords, an analysis based on the countries in which the works addressed the relationship between the public sector and digital innovation.

Comparing the results for GGM and MGM of EU member countries for the period 2017-2022, innovation and e-governance of digitalisation have directly influenced economic performance, and we have demonstrated the significant (negative and positive) impact of digitalisation on e-government. Therefore, it can be concluded that nations with extensive digitalisation significantly influence the provision of Digital Public Services (DPS), along with the associated implications for intense innovation (R&D).

The main results indicate that countries with extensive digitalisation also demonstrate strong governance. Finland, Denmark, and Sweden recorded the highest levels of digitalisation intensity. Additionally, the findings showed that EU nations have accelerated their use of digital technology and the Internet in response to the COVID-19 pandemic and other unforeseen events, which have impacted public governance and additional macroeconomic and microeconomic side effects. Moreover, Romania and Bulgaria continue to present a low level of digitalisation in technological processes; this resistance to change can be attributed to the perception of digitalisation as a cost rather than a long-term investment.

Based on the findings of the study, several policy guidelines and recommendations can be suggested: (i) the EU states should ensure that their digital transformation strategies incorporate digital technologies and ongoing innovation to enhance the effectiveness of e-government; (ii) adequate distribution of resources, ongoing creativity, and government dedication are essential to ensure that electronic services are accessible, secure, and easy to use for everyone. Integrating digital technologies into service delivery while continually promoting innovation to improve e-government effectiveness.

Additionally, given these issues, we state that policymakers should broaden their scope beyond mere cost considerations to evaluate whether digital advancements improve value in delivering public services to citizens and generate broader socioeconomic advantages.

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