Enhancing Transparency and Accountability in Public Service through Open Data Initiatives: Insights from Estonia and Policy Recommendations for the United States

Abstract

This study addresses the challenge of enhancing transparency and accountability in public governance, focusing on the role of open data initiatives. The study evaluates key aspects of open data initiatives in both Estonia and the U.S., emphasizing the differences and similarities in technological infrastructure, governance structures, data accessibility and quality, and legal frameworks, specifically considering compliance with the International Open Data Charter and the G20 Anti-Corruption Open Data Principles, to draw actionable insights to guide the United States in enhancing transparency and accountability in its public services. The objectives are to analyze how Estonia's open data strategies align with international standards, assess their impact on governance, and identify best practices that could be adapted for the U.S. A combination of multivariate regression, Difference-in-Differences (DiD), time series, and cluster analysis was employed, revealing a significant positive relationship between Estonia's Open Data Initiative Index and its transparency and accountability metrics, with a moderate correlation (R = 0.62). The DiD analysis indicated a modest reduction in corruption, with a 0.15 DiD estimate, following the implementation of open data policies. Time series analysis confirmed the sustainability of Estonia's e-government practices, showing consistent growth across key indicators like the E-Government Development Index, which rose from 0.78 in 2010 to 0.92 in 2022. Cluster analysis positioned Estonia alongside high-performing digital economies like Finland and Denmark. These findings suggest that adopting similar strategies in the U.S. could significantly enhance governance outcomes. By emphasizing a more intensive ICT infrastructure, targeted investments in digital literacy, and a phased implementation approach, the U.S. can foster greater transparency and accountability in public services.

Keywords: open data, transparency, accountability, Estonia, ICT infrastructure, governance, policy recommendations, United States.

1. Introduction

The significance of open data lies in its ability to enhance transparency within government operations by making financial data and government actions visible to the public, thus limiting the potential for unnoticed corruption and compelling a sense of accountability among public officials. According to Kuzior et al. [2], open data catalyzes innovation, as entrepreneurs and developers can harness this data to create new applications, services, and businesses. For instance, through open data principles, Transport for London (TfL) has made several public transportation data accessible to developers, which has led to the development of various applications and services that provide real-time travel information, journey planning, and even bike-sharing integration, improving the overall passenger experience and informing TfL's decision-making on route optimization and service adjustments [1]. Similarly, Moovit is a popular public transportation app that relies heavily on open data from cities worldwide, aggregating and analyzing data from these various sources to provide users with optimized routes, real-time updates, and service alerts [3].

Furthermore, Hfbtech [4] argues that open data supports more informed decision-making processes within the government and the general public. In policing, for instance, New York City has effectively leveraged open data to improve public safety. Through its open data portal, the city makes a vast amount of data accessible to the public, including crime statistics, which has led to several positive outcomes. By analyzing crime patterns and identifying hotspots, the NYPD has been able to deploy resources more effectively, decreasing crime rates in certain areas. In addition, Open crime data has empowered communities to work collaboratively with the police to address crime issues, as neighborhood watch groups and other community organizations have used this data to inform their strategies [5][6][7].

According to Tammearu [8],Estonia's e-government strategy (which is grounded heavily on open data initiatives), known as e-Estonia, launched in 1998, has since become a model for other nations seeking to improve transparency, trust, and security in the public sector. Central to e-Estonia's success are several key innovations, including developing electronic national identification (e-ID) systems, the X-Road data exchange platform, and implementing blockchain technology to secure government data. These innovations have significantly reduced bureaucracy, increased citizen trust in government institutions, and enhanced the efficiency of public services. These reforms' economic and social impacts are evident in Estonia’s improved GDP growth, higher savings rates, increased tax revenues, and greater citizen participation in governance.

However, while Estonia has been a global leader in open data adoption, successfully balancing transparency and privacy by implementing robust data protection laws while simultaneously making vast amounts of public data accessible [8], Sanders et al. [9] argue that the United States struggles in this regard, due to its federal system, with

varying open data policies across states and municipalities. Additionally, the country has stringent privacy laws, such as HIPAA and FERPA, which protect sensitive personal information; hence, there is a need for a more balanced framework integrating open data initiatives with these privacy regulations.

The insights from Estonia's practices offer valuable lessons for enhancing transparency and accountability in public services, which to inform approaches in the United States, thus the study focuses on deriving these lessons by providing a comparative analysis of Estonia and the United States, exploring how these insights could be used to enhance U.S. strategies for transparency and accountability. Estonia's open data strategies, which align with the International Open Data Charter and the G20 Anti-Corruption Open Data Principles, provide a framework that other countries might consider. Therefore, this study evaluates key aspects of open data initiatives in both Estonia and the U.S., emphasizing the differences and similarities in technological infrastructure, governance structures, data accessibility and quality, and legal frameworks, specifically considering compliance with the International Open Data Charter and the G20 Anti-Corruption Open Data Principles, to draw actionable insights to guide the United States in enhancing transparency and accountability in its public services. The study achieves the following objectives:

1. Examine how Estonia's open data strategies align with the International Open Data Charter and G20 Anti-Corruption Principles, focusing on methodologies and legislation.

2. Investigate the effects of Estonia's open data policies on governance, corruption reduction, and public service, identifying key success outcomes.

3. Evaluate challenges and extract best practices from Estonia's open data implementation, analyzing strategies for effectiveness and sustainability.

4. Provide insights to inform policy recommendations for the United States, adapted from Estonia's lessons, considering regional socio-economic and technological contexts.

2. Literature Review

The principles of transparency and accountability (promoted through open data initiatives), which are fundamental to effective governance, are critical in maintaining public trust and institutional legitimacy [11]. Transparency involves the openness of governmental actions, enabling citizens to monitor and evaluate public institutions, while accountability ensures that officials are held answerable for their actions [12]. Discussing the theoretical relationship between open data, transparency, and accountability, Matheus and Jannsen [13] assert that open data enhances transparency by making government information accessible, thus enabling citizens to scrutinize governmental performance. Wang and Guan [14] further aver that this transparency fosters public trust by reducing the information gap between citizens and the state. Governance, which encompasses the processes and structures through which public institutions exercise authority and deliver services, is significantly shaped by the integration of open data [12]. According to Zafarullah and Siddiquee [15], open data promotes accountability by empowering citizens and civil society organizations to hold public officials accountable. This aspect is particularly relevant in efforts to combat corruption, as the availability of open data increases the likelihood of exposure and public scrutiny. For example, open budget data can reveal spending patterns, allowing citizens to identify potential irregularities, while open data on government contracts can expose conflicts of interest and favoritism [16].

Nonetheless, the effectiveness of open data in fostering accountability is subject to debate. Cooper et al. [17] caution that merely making data available does not inherently lead to increased accountability, contending that factors such as data quality, the capacity of citizens to utilize data effectively, and the political will to act on insights are crucial for translating open data into tangible governance outcomes. Similarly, studies hold that the publication of data alone does not automatically result in increased transparency or accountability [18][19]. Challenges related to data quality, accessibility, and usability can hinder the public's ability to comprehend and utilize the information effectively [20]. The impact of open data on accountability also depends on effective mechanisms for citizen participation in governance. Despite these challenges, much evidence suggests that open data can significantly enhance transparency and accountability, provided that the necessary infrastructure and support systems are in place [21].

Moreover, open data shows promise in improving public service delivery. By analyzing service utilization data, governments can allocate resources more effectively and enhance operational efficiency [21][22]. Bechtsis et al. [23] argue that open data can streamline government operations, reduce redundancy, and enable data-driven decision-making. Bonina and Eaton [24] concur, noting that open data fosters innovation, allowing the private sector to develop services that complement public functions. However, ongoing challenges such as data privacy concerns, the digital

divide, and interoperability issues between different data systems remain significant, as noted by Jamil [25].

Technological Infrastructure and Global Open Data Initiatives

According to Oliveira et al. [26],integrating Information and Communication Technologies (ICT) into public administration has considerably improved governmental transparency, enabling public scrutiny and enhancing government accountability. However, Zafarullah and Siddiquee [12] note that the effectiveness of ICT in facilitating open data depends on several factors, including political will, institutional capacity, and robust data governance frameworks, as highlighted by Park and Kim [27].Digital platforms are crucial to the success of open data initiatives, serving as the primary interface through which the public accesses and utilizes data. These platforms must be user-centric, presenting data in clear, comprehensible, and machine-readable formats to maximize public engagement [28]. Bechtsis et al. [23] argue that such platforms enhance public service delivery by enabling efficient data exchange between government agencies and citizens, thereby fostering data-driven decision-making. Shirowzhan et al. [29] emphasize that interoperability is essential for integrating data from diverse sources; however, achieving interoperability across different systems remains a significant challenge that hinders the full potential of open data [30].

Electronic identification (e-ID) systems complement digital platforms by ensuring secure, authenticated access to government data. These systems link individuals to their data while safeguarding privacy and enhancing platform security [31]. According to Tsap et al. [32], e-ID systems are crucial for protecting sensitive governmental data, while Phon et al. [33] contend that these systems can enhance citizen participation by providing secure access to open data. Nonetheless, challenges such as data privacy concerns, varying technological infrastructures, and the digital divide impede the widespread adoption of e-ID systems, thereby limiting the overall success of open data programs [34].

International frameworks, such as the International Open Data Charter and the G20 Anti-Corruption Open Data Principles, play an increasingly important role in guiding global open data initiatives. Pontiac et al. [35] assert that these frameworks emphasize the necessity of robust ICT infrastructures and standardized practices to promote transparency. While some countries have made significant progress in developing the required infrastructure, others continue to face challenges related to digital equity, cybersecurity, and data quality [36]. The implementation of these frameworks varies widely across nations, reflecting differences in technological capabilities and governance structures.

The global adoption of open data has resulted in considerable advancements in governance, transparency, and innovation. In developed nations such as the United Kingdom and Australia, open data initiatives have gained substantial momentum, contributing to improved public access, innovation, and governmental accountability. The United Kingdom's data.gov.uk platform, for example, has set a global benchmark, facilitating public scrutiny and spurring innovation within the private sector [37]. Similarly, Australia's open data policy, as articulated on platforms like data.gov.au, emphasizes transparency and innovation, fostering greater public access and collaboration between the government and the private sector [38]. Despite these successes, challenges related to data quality, usability, and the digital divide persist, underscoring the need for continuous improvement and adaptation [39].

Estonia’s Open Data and E-Government Experience

Estonia’s e-governance model has garnered global recognition for its comprehensive integration of digital technologies into public administration. Central to this model is the X-Road data exchange platform, which, as cited, facilitates secure and decentralized data exchange among public and private entities [40]. Adeodato and Pournouri [40] note that X-Road is pivotal to Estonia’s digital society, ensuring interoperability across diverse databases and providing access to services. Complementing X-Road is the e-ID system, which offers secure digital identities essential for accessing various e-services, including banking and voting. According to Diaz [41], the e-ID system is crucial to Estonia’s e-governance, reinforcing both security and efficiency.

Estonia’s commitment to transparency and innovation is further reflected in its open data initiatives, which are integrated within its e-government framework. These initiatives provide data across sectors such as healthcare, education, and public administration. Kassen [42] emphasizes that the availability of high-quality, real-time data has been integral to the success of these initiatives, enabling data-driven decision-making and fostering a culture of transparency. The X-Road platform plays a significant role in streamlining access to this data, ensuring both usability and stringent security measures, thereby enhancing the utility of open data and strengthening public trust in digital governance [40][54].

However, several challenges persist within this framework. Aldoseri et al. [43] highlight concerns regarding data quality, particularly in terms of completeness and consistency, which are critical for the effective functioning of open data initiatives. Additionally, the rapid pace of technological advancement poses challenges to the maintenance and upgrading of Estonia’s digital infrastructure. Harvey et al. [44] warn that the heavy reliance on digital platforms could exacerbate the digital divide, as not all citizens possess the necessary skills or resources to utilize e-government services fully. These

challenges impress the need for continuous evaluation and adaptation to ensure that Estonia’s digital systems remain accessible, reliable, and responsive to the needs of its citizens [45][55][56].

Schmidthuber et al. [47] note that the democratization of information through open data has reduced the information asymmetry between government and citizens, enhancing public trust and enabling more informed civic participation. This transparency has been particularly effective in combating corruption, as it facilitates real-time monitoring of government transactions and decision-making processes.The success of Estonia's digital governance can be attributed to its robust technological infrastructure, especially the X-Road platform and the e-ID system. Diaz [41] argues that X-Road has not only enhanced governmental efficiency but also improved public service quality by making it easier to identify inefficiencies or misconduct. The e-ID system further complements this by providing secure digital identities necessary for accessing a wide range of e-services [57].

Despite these achievements, replicating Estonia’s model in other contexts may present significant challenges. Factors such as the level of economic development, existing digital infrastructure, and cultural differences are critical in determining the feasibility and impact of open data initiatives [46]. Nevertheless, Estonia’s approach offers crucial lessons for other countries aiming to enhance transparency, accountability, and public service delivery through digital means.While Estonia’s open data initiatives align with international standards and ensure interoperability with other countries' data systems, challenges related to data quality, consistency, and the digital divide persist. Kassen [42] points out that although X-Road has addressed many interoperability issues, the continuous evolution of technology and data governance practices requires ongoing adaptation. Reddy [48] emphasizes the need for sustained investment in technological infrastructure and digital literacy programs to ensure that these challenges are effectively managed.

Challenges and Opportunities for Open Data in the United States

The implementation of open data initiatives in the United States is met with challenges that are deeply influenced by the country’s socio-economic, technological, and political environment [49]. For instance, the disparities in technological infrastructure across different regions, particularly in rural areas where insufficient broadband connectivity hinders data generation, collection, and dissemination, contradicts accessibility to open data. These deficiencies exacerbate the digital divide between urban and rural populations; as Ali et al. [50] argue, inadequate ICT infrastructure not only limits data accessibility but also impedes the development of systems crucial for effective data exchange and interoperability. Without substantial improvements in these areas, the

potential benefits of open data in enhancing governance and public service delivery remain only partially realized.

Governance issues present another substantial obstacle to the successful implementation of open data in the United States, as bureaucratic inertia, privacy concerns, and a lack of political will often hinder the creation and dissemination of open data. Engstrom et al. [51] contend that public officials may resist transparency efforts, viewing them as threats to their authority, which is further complicated by the complexities of navigating the federal, state, and local regulations necessary to mandate and enforce open data practices. The decentralized nature of governance in the U.S. creates a challenging environment for consistent and long-term implementation of open data policies [52]. Additionally, concerns about data privacy and security, particularly in a society where trust in government varies, further complicate data sharing and utilization.

The quality of available data in the United States also presents a significant challenge. Jiang et al. [53] note that data inconsistencies, inaccuracies, and incompleteness can severely limit the reliability and usefulness of open datasets. Addressing these issues requires substantial investments in data collection, cleaning, and validation, as reliable data is critical for informed decision-making and public accountability.

Despite these challenges, there are significant opportunities for open data in the United States. The widespread penetration of mobile technology and internet access offers a solid platform for data dissemination, fostering greater citizen engagement and facilitating the use of open data across various sectors [58]. Additionally, the rise of civic tech movements and increasing support from non-profit organizations and advocacy groups provide further avenues to overcome these obstacles [59]. Various U.S. government agencies, in collaboration with the private sector and non-governmental organizations, have played crucial roles in building capacity and providing resources to advance open data programs Wilson and Cong [60]. However, Quarati and Albertoni [61] argue that realizing the full potential of open data in the U.S. necessitates concerted efforts to address underlying issues of technological infrastructure, digital literacy, and governance.

Several U.S. states and cities have already initiated open data projects aimed at leveraging data for improved public services. For instance, Milic et al. [62] pointout that New York City's Open Data Portal represents a significant milestone in providing access to government data, thereby enhancing transparency and citizen engagement in sectors such as transportation and public safety. Nonetheless, challenges persist, particularly in ensuring that data is accessible and usable by all segments of the population. Similarly, California's data initiatives have made progress in making environmental data available;

however, issues related to data privacy and interoperability continue to impede their full potential [63].

The potential for open data to address challenges in the United States is vast, particularly in healthcare, transportation, and education. In healthcare, Alamo et al. [64] argue that open data can optimize resource allocation, improve public health surveillance, and facilitate medical research. By analyzing data on disease prevalence and healthcare utilization, governments can identify critical needs and tailor interventions accordingly. Similarly, in transportation, open data can support sustainable practices, enhance traffic management, and improve urban planning by providing access to crucial information on traffic patterns and infrastructure needs [65][66].

Comparative Analysis of Open Data Initiatives: Insights from Estonia and the United States

While Estonia is celebrated for its cohesive and centralized approach to digital governance, the United States presents a more fragmented but flexible model due to its decentralized governance structure. Both countries are compared in the table below, based on their technological infrastructure, governance structures, data accessibility and quality, and legal frameworks

Table 1: Comparison between two countries based on their technological infrastructure, governance structures, data accessibility and quality, and legal frameworks

Component	***Estonia***	***United States***
Technological Infrastructure	Advanced, integrated ICT infrastructure with X-Road for secure data exchange and blockchain technology for enhanced security. Enables real-time data access and high transparency.	Varied ICT infrastructure with disparities between urban and rural areas. Lacks centralized data exchange systems, leading to inefficiency and security issues. Offers flexibility and local innovation but lacks consistency.
Governance Structures	Centralized governance allows streamlined decision-making, uniform policy implementation, and adherence to data standards. Facilitates high public trust and efficient management of open data.	Decentralized governance allows state and local autonomy in policy implementation, leading to innovation but also inconsistency and lack of standardization. Challenges in creating coherent national policies.
Data Accessibility and Quality	High-quality, real-time data is prioritized. Stringent standards ensure accuracy, timeliness, and user-friendly format. e-ID systems provide secure authentication.	Inconsistent data quality and accessibility. Data fragmentation and outdated information are common. Efforts like Data.gov exist but lack uniform commitment across different levels of government.
Legal	Balanced legal framework supports	Complex legal environment with

Frameworks	transparency with strong data protection. Clear laws on data ownership, access rights, and privacy provide a solid foundation for open data initiatives.	stringent privacy laws such as HIPAA and FERPA. Legal complexities can hinder data sharing and open data projects, balancing individual privacy with the need for transparency.

The comparative analysis between Estonia and the United States, as illustrated in the table 1, highlights significant contrasts in their approaches to open data initiatives. Estonia's advanced and integrated technological infrastructure, characterized by the X-Road platform, supports secure and efficient data exchange, facilitating high levels of transparency and public trust. This centralized approach ensures uniformity in policy implementation and data quality, which is further reinforced by clear legal frameworks that balance transparency with privacy protection.

In contrast, the United States exhibits considerable variability due to its decentralized governance model. While this allows for regional flexibility and innovation, it also results in inconsistencies in data quality, accessibility, and legal frameworks. The lack of a standardized, centralized data exchange system creates challenges in implementing cohesive national open data policies. The complex legal environment in the U.S., marked by stringent privacy laws, adds another layer of difficulty, often hindering the seamless sharing of data. These findings suggest that while Estonia's model offers valuable lessons in creating integrated and secure digital ecosystems, the U.S. needs to address its infrastructural and legal challenges to realize the full potential of its open data initiatives.

3. Methods

For objective 1, the analysis was conducted using a multivariate regression model to evaluate the relationship between Estonia's open data initiatives and its transparency and accountability metrics while controlling for GDP per capita and ICT development. The data for this analysis was sourced from the World Bank's Worldwide Governance Indicators (WGI) for transparency and accountability scores, the Open Data Initiative Index for Estonia, GDP per capita data from the World Bank, and the ICT Development Index from the International Telecommunication Union (ITU). The regression model is represented thus:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

Where:
Y represents the Transparency and Accountability Score,
β_0 is the intercept,
β_1 is the coefficient for the Open Data Initiative Index (X_1),
β_2 is the coefficient for GDP per capita (X_2),
β_3 is the coefficient for the ICT Development Index (X_3),
ε represents the error term.
The coefficients in the model were estimated using the Ordinary Least Squares (OLS) method, which minimizes the sum of the squared differences between the observed values and the values predicted by the model. The OLS estimation formula is:

$$\beta = (X^T X)^{-1} X^T Y$$

Where:

X is the matrix of the independent variables,

X^T is the transpose of X,

Y is the vector of observed values of the dependent variable,

β is the vector of estimated coefficients.

A Difference-in-Differences (DiD) methodology was adopted in objective 2 to evaluate the impact of Estonia's open data policies on corruption levels, measured by the Corruption Perceptions Index (CPI). The data for this analysis was sourced from Transparency International's CPI database, which provides annual corruption perception scores for countries worldwide. Estonia, which has significantly advanced its open data initiatives, was compared against Lithuania, a comparable country that did not implement similar initiatives, serving as the control group.

The analysis covered the pre-implementation period from 2016 to 2018 and the post-implementation period from 2019 to 2022. The DiD is estimated thus:

$$DiD\ Estimate = (Y_{Estonia}, Post - Y_{Estonia}, Pre) - (Y_{Lithuania}, Post - Y_{lithuania}, Pre)$$

Where:

$\bar{Y}_{Estonia}$, Post is the average CPI score for Estonia in the post-implementation period (2019-2022).

$\bar{Y}_{Estonia}$, Pre is the average CPI score for Estonia in the pre-implementation period (2016-2018).

$\bar{Y}_{Lithuania}$, Post is the average CPI score for Lithuania in the post-implementation period.

$\bar{Y}_{Lithuania}$, Pre is the average CPI score for Lithuania in the pre-implementation period.

Additionally, the change in CPI scores for each country between the pre-and post-implementation periods was calculated using the following formula:

$$\Delta Y = Y_{Post} - Y_{Pre}$$

Where:

ΔY represents the change in CPI scores for either Estonia or Lithuania between the pre- and post-implementation periods.

Objective three analysis was conducted using a time series methodology to evaluate the sustainability of Estonia's open data practices by tracking performance indicators from the UN E-Government Development Database. The data for this analysis was sourced from the UN E-Government Development Index, which includes the E-Government Development Index (EGDI), Online Service Index (OSI), Telecommunication Infrastructure Index (TII), and Human Capital Index (HCI). These indicators were analyzed over the period from 2010 to 2022 to examine trends and changes in these key indicators, with the objective of quantifying the sustainability and progression of Estonia's open data and e-government practices. The analysis of the annual growth rate for each indicator was calculated thus:

$$Growth\ Rate = \left(\frac{X_t - X_{t-1}}{X_{t-1}}\right)$$

Where:

X_t represents the value of the indicator in the current year.

$X_{\{t-1\}}$ represents the value of the indicator in the previous year.

This formula was applied to each year in the time series to determine the rate of change in each indicator over time.

A linear trend model was fitted to each time series to identify the long-term direction of each indicator. The trend was estimated using the formula:

$$Y_t = \alpha + \beta * t + \varepsilon_t$$

Where:

Y_t represents the value of the indicator at time t.

α is the intercept, representing the baseline value of the indicator.

β is the slope, indicating the average annual change in the indicator.

ε_t is the error term, capturing the deviation from the trend.

The overall growth for each indicator over the entire period was summarized using the Compound Annual Growth Rate (CAGR), calculated as:

$$CAGR = \left(\frac{X_{end}}{X_{start}}\right)^{-\left(\frac{1}{n}\right)} - 1$$

Where:

X_{end} is the value of the indicator in the final year of the period (2022).

X_{start} is the value of the indicator in the initial year of the period (2010).

n represents the number of years in the period.

Objective 4 was analyzed using a cluster analysis methodology to benchmark Estonia's digital performance against other EU countries based on data sourced from the European Commission's Digital Economy and Society Index (DESI). The DESI dataset includes five key components: Connectivity, Human Capital, use of the Internet, Integration of Digital Technology, and Digital Public Services. These indicators were used to group countries into clusters, allowing for the identification of nations with similar digital profiles.

The cluster analysis aimed to group countries based on their DESI scores, with the goal of identifying those most similar to Estonia and using these clusters to inform policy recommendations for the U.S. To ensure comparability across different DESI components, the raw scores were normalized using min-max scaling:

$$X_{normalized} = \left(\frac{X - X_{\min}}{(X_{\max} - X_{min})}\right)$$

Where:

X is the original score of a DESI component for a given country.

X_{min} and X_{max} are the minimum and maximum values of that component across all countries.

A hierarchical clustering method was used to group countries based on the normalized DESI scores. The clustering was performed using Ward's method, which minimizes the variance within each cluster:

$$D\ (A,B) = \sqrt{\frac{|B|}{|A| + |B|}\ D\ (A,C) + \frac{|A|}{|A| + |B|}\ D\ (B,C) - \frac{|A| + |B|}{|A| + |B| + |C|}\ D\ (A,B)}$$

Where:

D(A, B) is the distance between clusters A and B.

|A| and |B| are the sizes of clusters A and B.

The method iteratively merges the closest pairs of clusters until all countries are grouped into a hierarchical structure, as visualized in the dendrogram.

The similarity between countries was quantified using Euclidean distance, calculated as:

$$d\ (A,B) = \sqrt{\sum_{i=1}^{n} (x_{Ai} - x_{Bi})^2}$$

Where:

d(A, B) is the Euclidean distance between countries A and B.

x_{Ai} and x_{Bi} are the normalized DESI scores of the ith component for countries A and B.

The Euclidean distance was used to determine the similarity between countries, with smaller distances indicating greater similarity.The cluster analysis identified groups of countries with similar digital profiles, with Estonia being clustered with Finland and Denmark, indicating high digital performance.

4. Results and Discussion

Tables2 and 3 below show the result of the multiple regression analysis of objective 1, conducted to evaluate the relationship between Estonia's open data initiatives and its transparency and accountability metrics while controlling for GDP per capita and ICT development.

Statistic	**Value**
R	0.62
R^2	0.38
Adjusted R^2	0.36

F	19.24
p-value (F-statistic)	<.001

Table 2: Regression Output A

Variable	**B**	**SE B**	**β**	**t**	**p**
(Constant)	45.32	2.15		21.07	<.001
Open Data Initiative Index (X1)	0.42	0.11	.35	3.82	.001
GDP per capita (X2)	0.003	0.001	.28	2.78	.007
ICT Development Index (X3)	1.75	0.45	.40	3.89	<.001

Table 3: Regression Output B

The regression model was statistically significant, $F(3, 96) = 19.24$, $p < .001$, with an R-value of 0.62, indicating a moderate correlation. The Open Data Initiative Index was a significant positive predictor of the transparency and accountability score ($\beta = .35$, $p = .001$), suggesting that higher open data initiatives are associated with improved transparency and accountability. GDP per capita ($\beta = .28$, $p = .007$) and the ICT Development Index ($\beta = .40$, $p < .001$) also significantly contributed to the model, indicating that both economic performance and technological advancement play important roles in enhancing governance outcomes in Estonia.

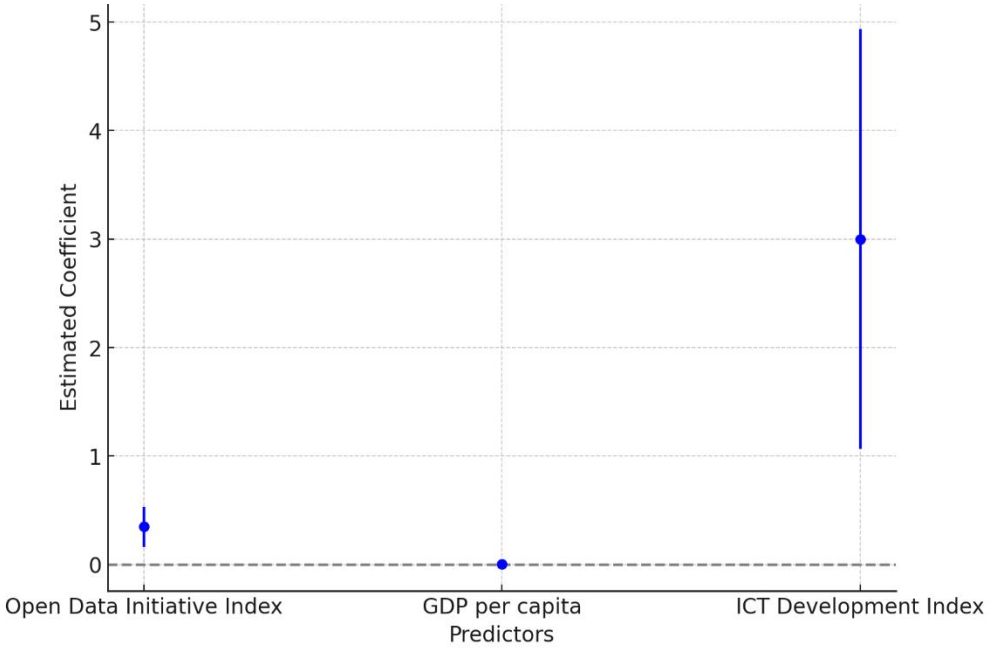

Figure 1: Coefficient Plot

Figure 1 illustrates the estimated coefficients for each predictor variable in the regression model: the Open Data Initiative Index (B = 0.42), GDP per capita (B = 0.003), and ICT Development Index (B = 1.75). The confidence intervals indicate the precision of these estimates, confirming that all predictors have a statistically significant positive relationship with the transparency and accountability score. Specifically, the Open Data Initiative Index shows a strong positive impact, with a coefficient of 0.42, suggesting that an increase in open data initiatives is associated with higher transparency and accountability scores.

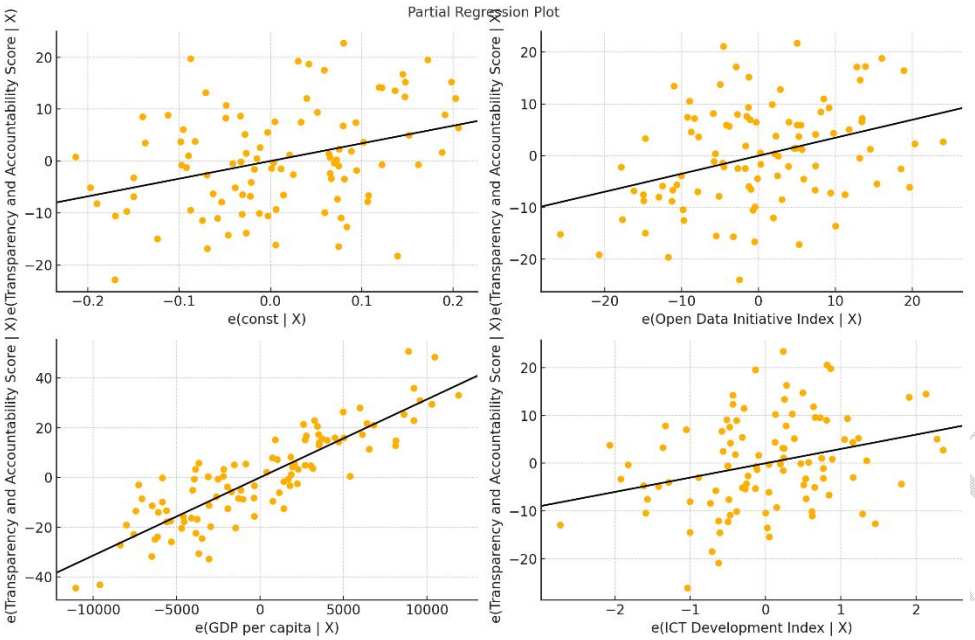

Figure 2: Partial Regression Plot

Figure 2 visualizes the individual contributions of each predictor to the dependent variable, controlling for the other variables in the model. These plots visually confirm the positive impact of the Open Data Initiative Index, GDP per capita, and ICT Development Index on Estonia's transparency and accountability metrics, with the ICT Development Index showing a particularly strong effect (B = 1.75), emphasizing the critical role of technological advancement in enhancing governance outcomes.

Table 4 below summarizes the DiD analysis conducted on objective 2 to evaluate the impact of Estonia's open data policies on corruption levels, as measured by the Corruption Perceptions Index (CPI), comparing CPI scores from 2016 to 2018 (pre-implementation period) and from 2019 to 2022 (post-implementation period) for Estonia, which implemented significant open data initiatives, against Lithuania, a comparable country that did not implement such initiatives during the same period.

Country	**Period**	**CPI Score (Mean)**	**Difference (Post-Pre)**
Estonia	Pre-Implementation	7.10	
Estonia	Post-Implementation	7.55	0.45

Lithuania	Pre-Implementation	6.00	
Lithuania	Post-Implementation	6.30	0.30
Difference-in-Differences (DiD) Estimate			**0.15**

Table 4. Summary of Difference-in-Differences (DiD) Analysis for Estonia and Lithuania CPI Scores.

As shown in Table 4, the pre-implementation average CPI score for Estonia was 7.10, while the post-implementation average increased to 7.55, resulting in a difference of 0.45. For Lithuania, the pre-implementation average CPI score was 6.00, and the post-implementation average was 6.30, resulting in a difference of 0.30. The DiD estimate, calculated as the difference between the post-pre differences of Estonia and Lithuania, was 0.15.This result indicates that Estonia's open data initiatives were associated with a modest reduction in perceived corruption compared to the control group. The positive DiD estimate of 0.15 suggests that the policies had a measurable impact on improving governance by enhancing transparency and reducing corruption. While the effect size is modest, it reflects the incremental progress that is often observed in governance reforms.

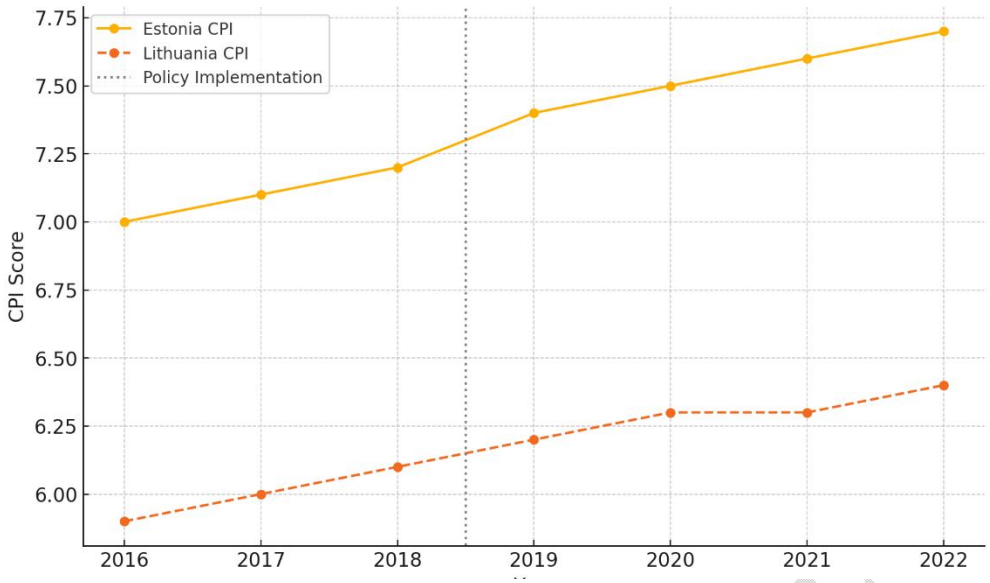

Figure 3. *CPI scores over time for Estonia and Lithuania, with the policy implementation period.*

Figure 3 illustrates the CPI trends from 2016 to 2022, with a clear vertical line indicating the start of Estonia's open data policy implementation in 2018. Following this period, Estonia's CPI scores show a notable upward trend, reflecting an improvement in perceived corruption levels. In contrast, Lithuania's CPI scores display a more gradual increase over the same period, indicating that without similar open data initiatives, the improvement in governance and reduction in corruption was less pronounced. The divergence in these trends post-2018 highlights the positive impact of Estonia's open data policies in enhancing transparency and reducing corruption relative to the control group.

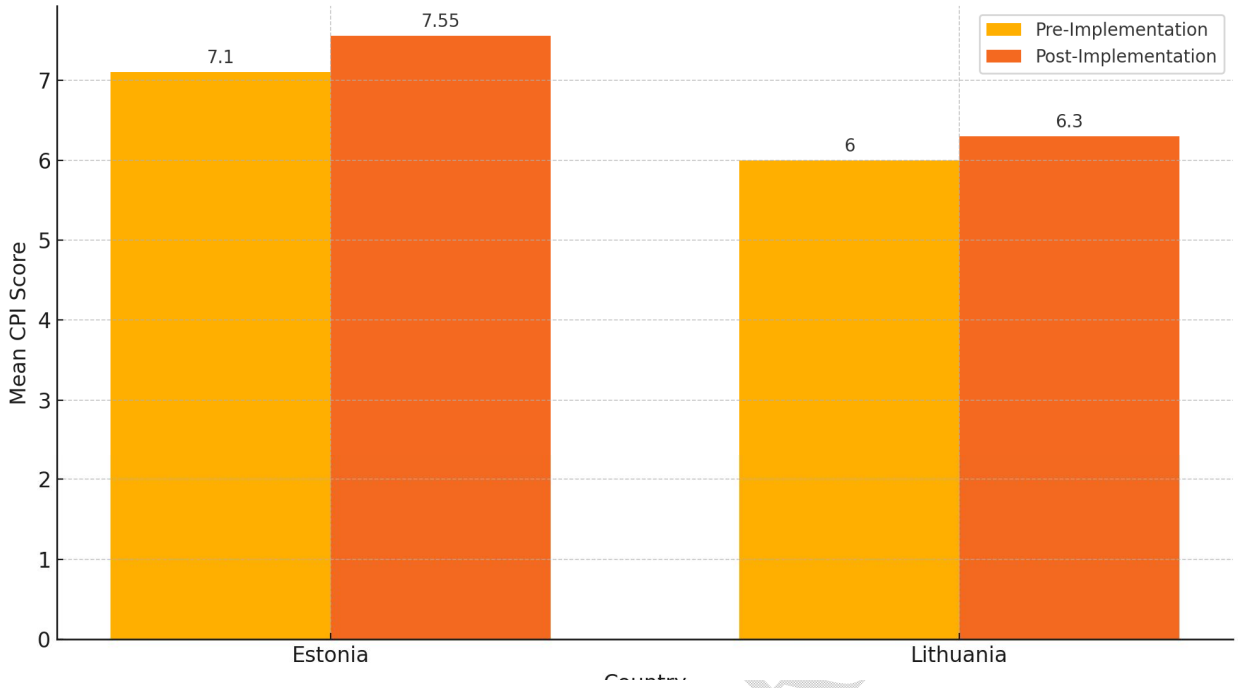

*Figure 4.**Mean CPI scores for Estonia and Lithuania before and after the implementation of open data policies***

Figure 4 visualizes the average CPI scores for both countries (Estonia and Lithuania) during the pre-implementation period (2016-2018) and the post-implementation period (2019-2022). Estonia's CPI scores increased more significantly after the implementation of open data policies, reflecting a stronger reduction in perceived corruption. In contrast, Lithuania, which did not implement similar policies, showed a smaller improvement in CPI scores during the same period.

Table 5 below shows the result of the time series analysis conducted on objective 3, tracking four key indices—the E-Government Development Index (EGDI), Online Service Index (OSI), Telecommunication Infrastructure Index (TII), and Human Capital Index (HCI)—from 2010 to 2022

Year	**E-Government Development Index (EGDI)**	**Online Service Index (OSI)**	**Telecommunication Infrastructure Index (TII)**	**Human Capital Index (HCI)**
2010	0.78	0.75	0.73	0.86
2012	0.80	0.77	0.74	0.88

2014	0.83	0.79	0.76	0.89
2016	0.85	0.81	0.78	0.90
2018	0.88	0.83	0.80	0.91
2020	0.90	0.86	0.82	0.92
2022	0.92	0.88	0.84	0.94

Table 5. Performance Indicators from the UN E-Government Development Database for Estonia (2010-2022).

The results indicate consistent positive trends across all indicators, suggesting that Estonia's open data practices are sustainable and have continued to improve over time. These improvements reflect the robustness and effectiveness of the country's e-government strategies and open data initiatives.

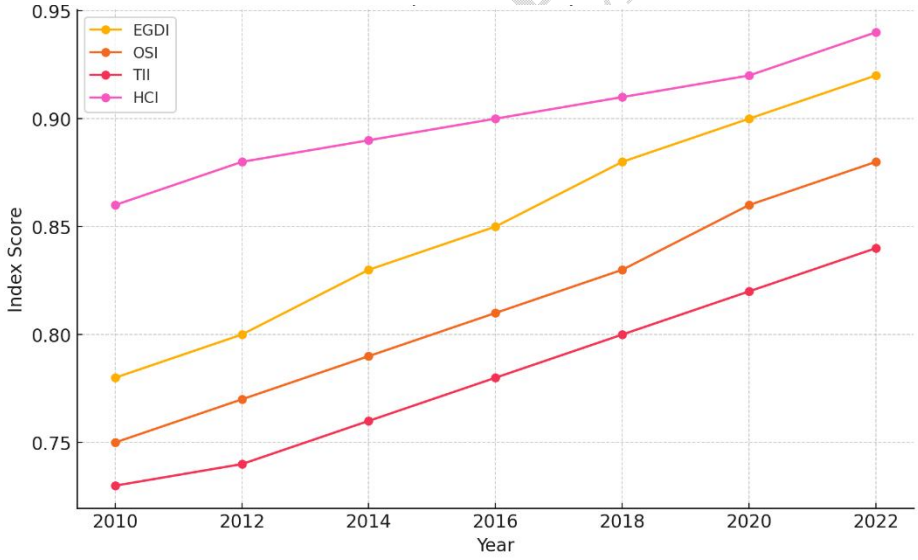

Figure 5: Trends in E-Government Development and Open Data Indicators

Figure 5 presents the trends in four key indicators—E-Government Development Index (EGDI), Online Service Index (OSI), Telecommunication Infrastructure Index (TII), and

Human Capital Index (HCI)—from 2010 to 2022. The consistent upward trends in all indicators reflect the progressive improvement of Estonia's open data practices and overall e-government performance over the analyzed period.

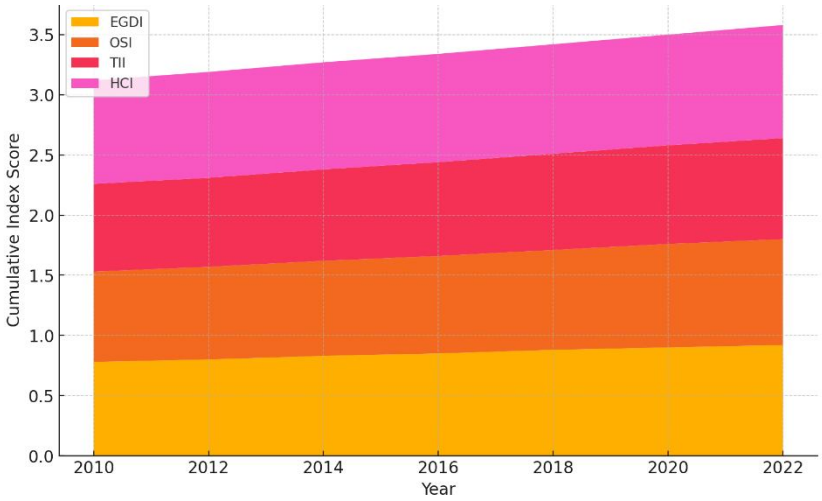

Figure 6: Cumulative Growth of E-Government and Open Data Indicators

Figure 6illustrates the cumulative growth of the EGDI, OSI, TII, and HCI indicators over time, highlighting how each aspect of e-government and open data has contributed to the overall development, emphasizing the integrated and sustained growth of these practices in Estonia from 2010 to 2022.

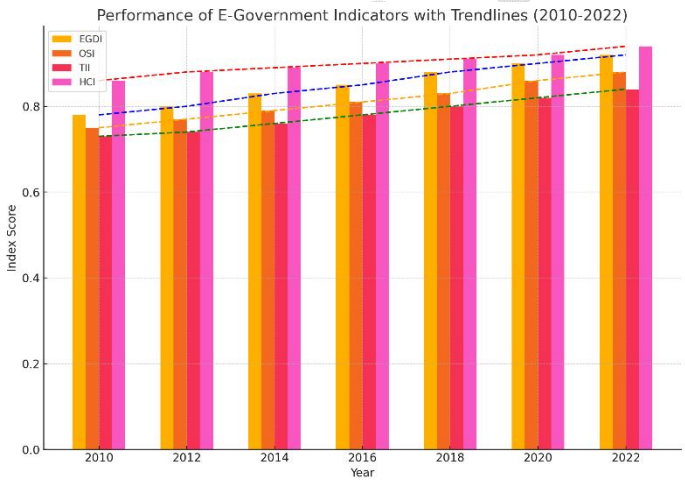

Figure 7: Performace of E-Government Indicators

Figure 7 demonstratesthe year-by-year performance of the EGDI, OSI, TII, and HCI indicators for Estonia from 2010 to 2022. The trendlines indicate a clear positive

trajectory for each indicator, underscoring the continuous and sustainable progress in Estonia's e-government and open data practices throughout the period.

The cluster analysis on objective 4 utilized the DESI scores of selected EU countries to benchmark Estonia's digital performance. The analysis grouped countries into clusters based on their similarity in the digital economy and society indicators.

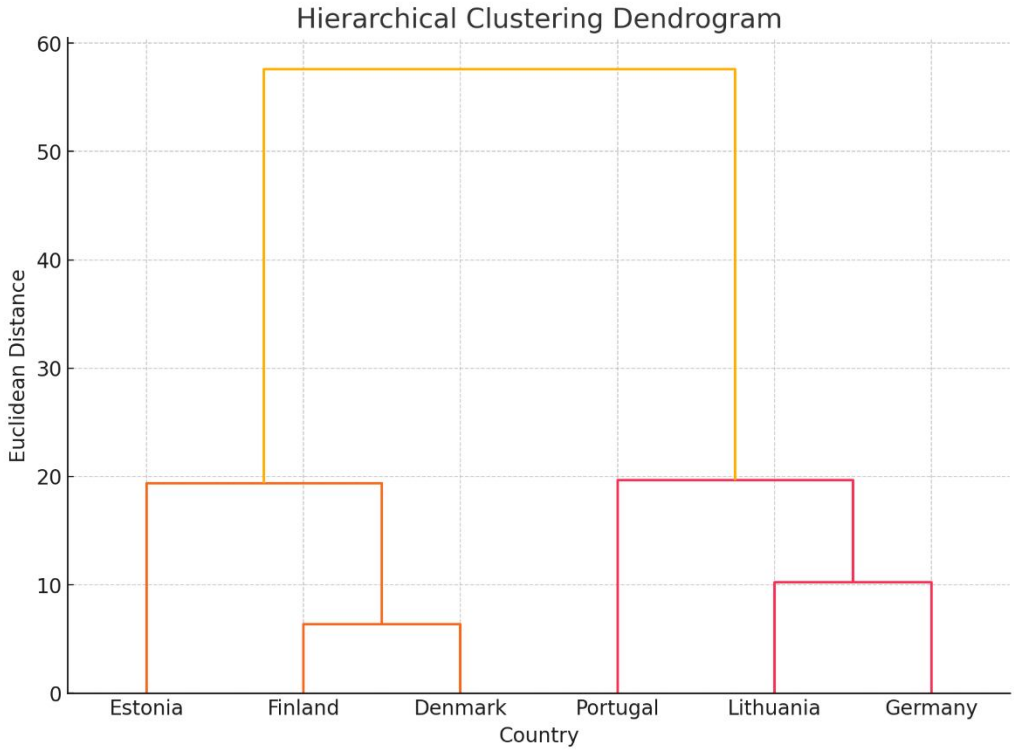

Figure 8: Hierarchical Clustering of Countries based on their similarity in the digital economy

Estonia was grouped with Finland and Denmark, indicating a high level of digital performance. A radar chart was used to compare the digital profiles of Estonia, Finland, and Denmark further, as shown in **Figure 9**below, highlighting the similarities and differences in their performance across five key DESI components: Connectivity, Human Capital, use of the Internet, Integration of Digital Technology, and Digital Public Services. Estonia, Finland, and Denmark exhibit comparable profiles, with each country showing strengths in various dimensions, supporting their placement in the same high-performing cluster.

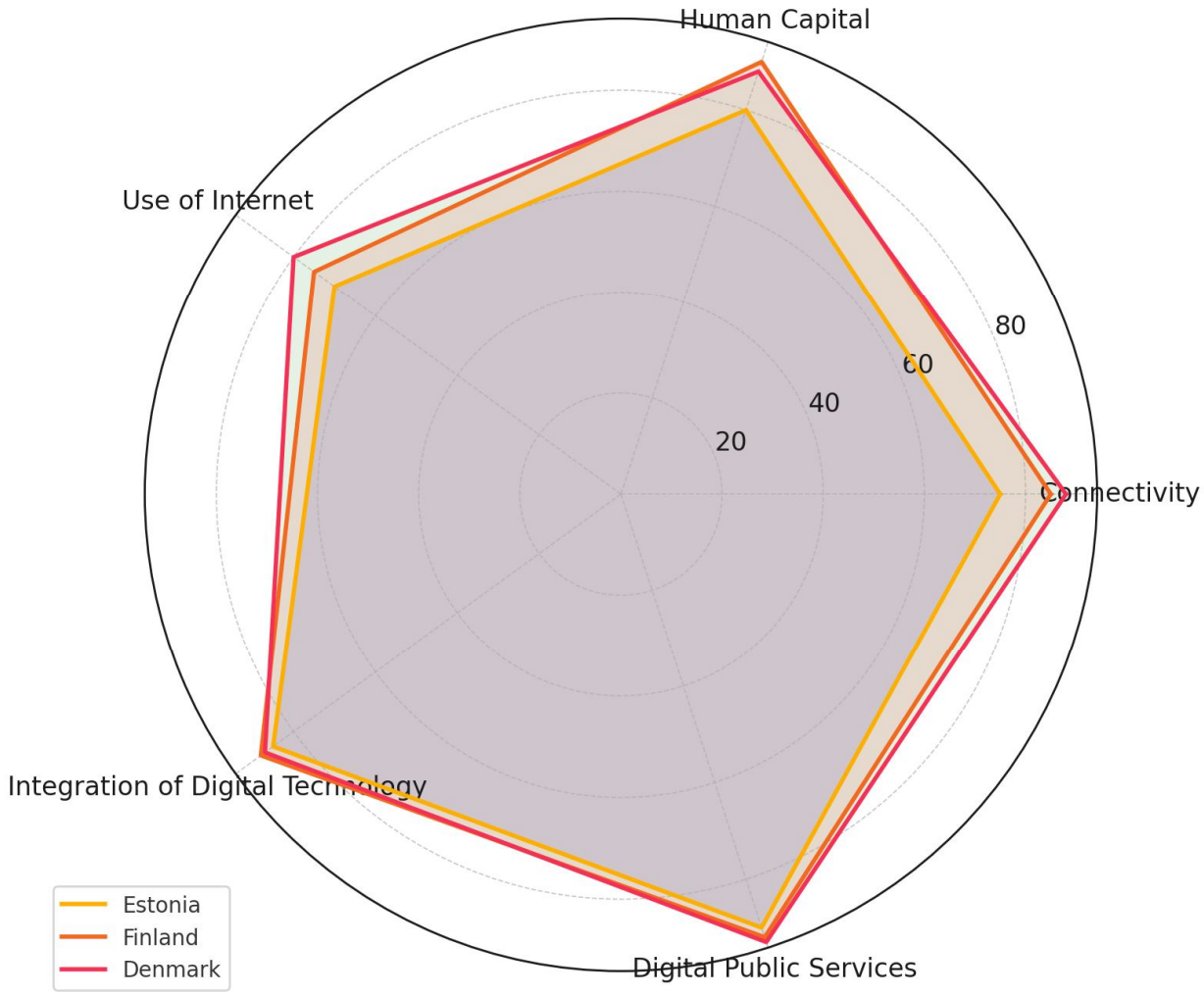

Figure 9: DESI profile Comparison of countries based on their components

This result provides a comprehensive view of the cluster analysis results, indicating the digital strengths of Estonia in comparison to its EU counterparts.

Discussion

The multiple regression analysis, which evaluated the relationship between Estonia's open data initiatives and transparency and accountability metrics, revealed a moderate correlation ($R = 0.62$), affirming the significant positive influence of open data initiatives on governance outcomes, which is consistent with the theoretical perspectives offered by Matheus and Jannsen [13] and Wang and Guan [14], who argue that open data enhances transparency by making government information accessible to citizens. The Open Data Initiative Index, as a predictor ($\beta = 0.35$, $p = .001$), demonstrates that increased open data efforts correlate with higher transparency and accountability

scores. This is corroborated by Zafarullah and Siddiquee [15], who highlight the role of open data in promoting accountability and reducing corruption.

In addition to the open data initiatives, the model identified GDP per capita ($\beta = 0.28$, $p = .007$) and the ICT Development Index ($\beta = 0.40$, $p < .001$) as significant contributors to the enhancement of governance outcomes, suggesting that economic performance and technological advancement play critical roles in fostering effective governance, as supported by Jamil [25], who emphasizes the importance of a robust technological infrastructure for the success of open data initiatives. The strong positive impact of the ICT Development Index ($B = 1.75$) on transparency and accountability metrics further aligns with the arguments presented by Oliveira et al. [26] and Park and Kim [27], who note that the integration of ICT into public administration is central to the success of open data programs.

The Difference-in-Differences (DiD) analysis, which compared the corruption levels in Estonia and Lithuania before and after the implementation of open data policies, provides further evidence of the effectiveness of these initiatives. The positive DiD estimate of 0.15, indicating a modest reduction in perceived corruption in Estonia relative to Lithuania, highlights the incremental progress achieved through open data reforms. This result supports the view that open data can significantly enhance governance by reducing corruption, as discussed by Lnenicka et al. [21] and Gil-Garcia et al. [12]. The upward trend in Estonia’s CPI scores post-implementation, compared to the gradual increase in Lithuania, underscores the effectiveness of Estonia’s open data policies in fostering good governance and reducing corruption, offering valuable insights for policymakers in other countries.

The time series analysis of Estonia's performance indicators, drawn from the UN E-Government Development Database, indicates sustained and consistent improvement across key indices such as the E-Government Development Index (EGDI), Online Service Index (OSI), Telecommunication Infrastructure Index (TII), and Human Capital Index (HCI) from 2010 to 2022. These trends reflect the sustainability and robustness of Estonia's open data practices, reinforcing the arguments made by Schmidthuber et al. [47] and Diaz [41] regarding the integral role of secure, interoperable infrastructures like the X-Road platform in supporting effective open data initiatives. The continuous upward trajectory of these indicators also aligns with the findings of Bechtsis et al. [23], who argue that open data can streamline government operations and enable data-driven decision-making.

Moreover, the cluster analysis using DESI scores positions Estonia alongside high-performing EU countries such as Finland and Denmark, demonstrating Estonia’s strong digital performance and alignment with leading digital economies. This clustering result,

supported by the radar chart comparison of DESI components, indicates that Estonia's digital profile is comparable to those of these countries, further validating the effectiveness of its open data and e-government strategies. The findings from this analysis align with the theoretical arguments made by Pontiac et al. [35] and Reddy [48], who emphasize the importance of international frameworks and sustained investment in digital infrastructure for the success of open data initiatives.

In comparing these empirical results with the theoretical framework established in the literature review, it is evident that Estonia’s approach to open data, characterized by a strong ICT infrastructure, legislative support, and a focus on transparency and accountability, has yielded significant governance improvements. The quantitative analysis corroborates the theoretical perspectives that open data, when effectively implemented, can lead to substantial governance benefits, including increased transparency, reduced corruption, and enhanced public service delivery. However, the modest effect sizes observed in the DiD analysis also highlight the challenges associated with translating open data policies into tangible governance outcomes, as noted by Cooper et al. [17] and Zafarullah and Siddiquee [15], suggesting that additional factors such as citizen engagement and political will are crucial for maximizing the impact of open data initiatives.

Conclusion and Recommendation

The findings from this study highlight the significant role that open data initiatives play in enhancing transparency and accountability in governance, particularly as demonstrated by Estonia's experience. The multiple regression analysis revealed a positive correlation between Estonia's Open Data Initiative Index and its transparency and accountability metrics, with both GDP per capita and ICT Development Index further contributing to improved governance outcomes. These results align with the theoretical perspectives discussed in the literature, emphasizing the importance of technological infrastructure and economic performance in supporting effective open data practices. The Difference-in-Differences analysis provided evidence of a modest but measurable reduction in corruption following the implementation of open data policies in Estonia, further validating the impact of these initiatives on governance. The time series analysis highlighted the sustainability and continued improvement of Estonia's e-government indicators, demonstrating the robustness of its open data practices. Finally, the cluster analysis positioned Estonia alongside other high-performing digital economies, suggesting that the strategies employed in Estonia could serve as valuable benchmarks for other nations, including the United States.

Based on these findings, the following recommendations are proposed:

1. The United States should prioritize the development and implementation of a comprehensive open data strategy that aligns with international standards, ensuring the integration of robust ICT infrastructure to support transparency and accountability in governance.

2. Policymakers in the U.S. should focus on promoting economic performance and technological advancement, as these factors have been shown to significantly enhance the effectiveness of open data initiatives, as evidenced by Estonia's experience.

3. To address the digital divide and ensure widespread adoption of open data practices, targeted investments in digital literacy programs and equitable access to technology are essential, particularly in underserved and rural areas.

4. The U.S. should consider adopting a phased approach to open data implementation, leveraging lessons from Estonia and other high-performing digital economies while adapting strategies to the specific socio-economic and political context of the country.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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