The Role of Open Data in Driving Sectoral Innovation and Global Economic Development

Abstract

This study assessed the transformative impact of implementing open data principles on fostering innovation across various sectors and enhancing global economic development. Using a comprehensive analysis of secondary data from government portals, industry reports, and global innovation indexes between 2015 to 2019, the research employed panel data regression, correlation analysis, and descriptive statistics to evaluate key relationships. The findings indicate that the availability of open data significantly increases innovation outputs, with robust statistical evidence showing positive correlations between open data sets and sector-specific innovation metrics such as patents filed, R&D expenditure, and the number of startups created. Greater interoperability of open data across international borders contributes to economic growth, particularly through international joint ventures. However, the lack of standardized data formats hampers cross-sector collaboration. Regions with well-established open data policies demonstrate faster technological advancements and economic development compared to regions without such policies. The study highlighted the critical importance of promoting open data initiatives, standardizing data formats, strengthening data governance frameworks, and investing in digital infrastructure and capacity building to optimize open data utilization and drive sustainable development.

Keywords: Open data, Innovation, Economic development, Data interoperability, Data governance

1. Introduction

With the pace and intensity of development in digital transformation, data has emerged as a fundamental asset for driving innovation, economic growth, and societal development. The strategic management and effective utilization of open data are pivotal, not only in enhancing public services and governance, but also in empowering businesses and communities across various sectors [1]. Initiatives such as the International Open Data Charter and the Global Open Data Index have been instrumental in setting standards for the open availability of government data and advocating for data to be open by default, accessible, timely, and interoperable, which are crucial for ensuring that the data can be effectively used for a wide range of applications [2].

The European Commission's 2023 identification of high-value datasets illustrates a strategic focus on data that significantly impacts economic and societal development [3]. These categories include geospatial, earth observation and environment, meteorological, statistics, companies and company ownership, and mobility data, which are recognized for their potential to drive substantial innovation and growth. Furthermore, the COVID-19 pandemic revealed the critical role of timely and open data sharing in addressing global challenges, as open data was crucial for rapid virus information sharing, real-time disease tracking, and informed public health decisions [4]. It facilitated global collaboration, enhanced public communication, and supported international cooperation, significantly improving the effectiveness of the global response to the health crisis. However, a crucial concern is the risk to privacy and security. As data becomes more openly available, ensuring that this does not compromise individual privacy or lead to data misuse is a considerable challenge. Data protection laws and regulations, such as the General Data Protection Regulation (GDPR) in the European Union, attempt to address these concerns by setting stringent guidelines on data handling and privacy [5].

Despite the potential benefits, many regions and sectors face hurdles in adopting open data policies effectively with issues such as the lack of technical infrastructure to support data openness, the need for more capacity in data literacy and management, and the cultural resistance to data sharing [1]. These barriers prevent the full realization of open data benefits, such as increased transparency, enhanced public participation in governance, and the fostering of innovation and economic development. Moreover, Park and Gil-Garcia [6] argues that while the value of open data in promoting transparency, accountability, and innovation is widely recognized, there remains a significant gap in its implementation across different global contexts, considering that the standardization of data formats, interoperability between diverse data systems, and alignment of open data initiatives with sustainable development goals are critical areas

that need addressing [1]. Hence, the study aims to assess the transformative impact of implementing open data principles on fostering innovation across various sectors and enhancing global economic development to proffer relevant insights and actionable recommendations for policymakers and industry leaders to optimize open data utilization, enhancing both governance and economic strategies worldwide, following these research objectives:

1. To analyse the relationship between open data accessibility and innovation within key sectors such as healthcare, finance, and education.

2. To evaluate the impact of data interoperability and comparability on fostering international and cross-sector collaborations.

3. To investigate the contribution of open data to economic growth and the achievement of the United Nations Sustainable Development Goals (SDGs).

4. To identify barriers and best practices in the implementation of open data policies across different regions and sectors.

2. Literature Review

Open data refers to the practice of making digital data accessible to anyone, without restrictions such as copyrights or licenses, based on the principles of transparency, accountability, and participation, suggesting a proactive approach to the dissemination of information by governments and institutions to foster a more informed and engaged public [7]. The notion of data being "open" is not just about the availability of the data but also its usability, ensuring that it can be freely used, reused, and redistributed by anyone [8]. The International Open Data Charter outlines six core principles that strive to standardize and promote the openness of data worldwide, designed not only to facilitate the easy exchange and usability of data but also to ensure that this data serves to enhance governance and citizen engagement, and drive innovation and inclusive development [9]. The Charter advocates for data to be "Open by Default," pushing for a paradigm shift where data is accessible unless there is a valid reason for its exclusion, thus directly supporting transparency and serving as a foundation for public trust and scrutiny, which are crucial in democratic governance [10][11].

However, Teizeira et al. [12] contends that the principle of ensuring data is "Accessible and Usable by All" sometimes contradicts the issues of privacy and security, especially concerning sensitive information. Moreover, while the principle encourages the provision of data in a comprehensive, timely, and updated manner, this ideal is often hampered by logistical, technical, and financial constraints, particularly in less developed regions, thereby raising crucial questions about the feasibility and ethical

implications of fully implementing open data initiatives [4][13]. Another principle of the charter (comparability and interoperability) highlights the necessity for data standards that do not just facilitate the local usability of data but also ensure that datasets can be integrated and compared across different jurisdictions and sectors [14][15]. This is particularly relevant to global economic development and innovation, as data interoperability is a prerequisite for complex analyses and solutions that span beyond local contexts; although it involves harmonizing formats, metadata, and data structures, often requiring substantial investment and coordination [16][17].

The principles of the Charter are intended to influence global data policies significantly, by setting a universal standard to encourage countries and organizations to adopt open data practices that align with these global norms, fostering a more uniform approach to data management globally [18]. This has the potential to not only enhance local governance and development outcomes, but also to facilitate international cooperation and global development initiatives [19]. Although studies indicate varied success across different countries and sectors, suggesting that the effectiveness of open data policies is highly contingent on local contexts, including political, cultural, and economic factors [20][21]. For example, while open data might lead to significant public sector reforms and business innovations in one setting, it might not yield substantial outcomes in another due to differences in implementation capacity or public engagement levels [22].

Impact of Open Data on Sectoral Innovation

Chan [23] avers that open data is an effective catalyst for innovation across various sectors, significantly influencing how organizations, governments, and communities interact with information and derive value from it. For instance, in healthcare, open data has been instrumental in advancing medical research and shaping public health policies, considering that access to anonymized patient data, epidemiological data, and clinical trials has broadened the scope for research, enabling more in-depth research on disease patterns, treatment outcomes, and public health trends [24]. In addition, open genomic databases have accelerated the pace of genetic research, leading to faster and more precise diagnostics and personalized medicine approaches [25]. However, the sector also faces significant challenges, particularly concerning data privacy and the risk of re-identification, which could undermine public trust. This is because the heterogeneity of healthcare data often complicates the usability and interoperability of datasets, necessitating sophisticated normalization and standardization techniques to ensure they are beneficial across different systems and regions [26].

The financial sector has similarly benefited from the advent of open data, with increased transparency being one of the most significant outcomes, as open data initiatives have led to greater accountability in government spending and financial services, helping to

combat fraud and corruption [27][28]. Innovations such as open banking, where customers can securely share their financial data with third-party providers to access better services, illustrate how open data can drive product innovation and enhance consumer choices [29]. For instance, fintech startups like Acorns or Stash leverage open banking to connect to user accounts and automate saving or investing based on their spending habits and financial goals [30]. Nevertheless, the adoption of open data initiatives in the financial industry is also challenged with balancing openness with stringent regulatory requirements related to financial secrecy and data protection, reflecting a sector that remains cautious in its approach to open data [27].

In education, open data has facilitated the development of rich educational resources and innovative teaching methodologies [31]. Open access to educational content, including course materials from prestigious universities and data sets for academic research, has democratized learning and broadened educational opportunities for a global audience. Initiatives like the Open Educational Resources movement highlight how open data can support the customization of teaching resources to meet diverse educational needs [32]. Despite these advances, the digital divide remains a critical issue; disparities in access to technology significantly affect the utility of open data in education, particularly in under-resourced areas [33][34].

Environmental monitoring is also undergoing a transformative shift with the adoption of open data, leading to significant improvements in research, public awareness, and policymaking [35]. Enhanced monitoring capabilities now allow for integration of data from varied sources like citizen science and independent stations, fostering a more diverse understanding of environmental patterns and challenges. Open environmental data also enhances public engagement by enabling citizens to access real-time and historical data on local environmental conditions, such as air and water quality [36]. This accessibility not only drives public participation but also supports accountability by allowing independent verification of governmental environmental reports[35][37].

Evidences across these sectors indicate that open data significantly enhances innovation by fostering new business models, improving services, and facilitating more informed decision-making [1]. Yet, this positive impact is not uniformly felt across all regions and communities, largely due to varying capabilities in data handling, technological infrastructure, and regulatory environments[38]. For instance, while some countries have harnessed the power of open data to leapfrog technological and economic development, others struggle with basic data governance issues, limiting their ability to effectively use open data [22]. Taleb [39] avers that emerging trends indicate a growing recognition of the need for robust data governance frameworks that not only promote data openness but also ensure data quality, privacy, and security. As the volume and variety of open data continue to grow, the challenge of maintaining these

standards become increasingly complex, requiring continuous innovation in data management practices.

Open Data and Economic Development

Teixeira [12] affirms that open data facilitates economic development by promoting transparency, enabling innovation, and improving efficiency in both public and private sectors. According Mu et al., [40] governments that adopt open data policies create environments conducive to business and innovation by making vast amounts of data available which can be leveraged by entrepreneurs to develop new products and services, by investors to make informed decisions, and by governments themselves to improve planning and service delivery.

However, the economic impact of open data is not universally positive or straightforward, as the work of Perera and Iqbal [41] indicates that some regions have harnessed the potential of open data to drive growth and innovation, while others have faced challenges in translating open data availability into tangible economic outcomes, due to variations in technological infrastructure, data literacy, and institutional capacity, which can impede the effective use and impact of open data [42].

The United States' Data.gov initiative, which hosts over 200,000 datasets, has been instrumental in fostering new business opportunities and enhancing public service delivery [43]. Companies like Zillow, which uses public government data to provide detailed real estate information, exemplify how open data can be transformed into valuable economic assets that drive industry innovation and consumer benefit [44]. Similarly, the UK’s Open Data Initiative has positioned the country as a leader in open data utilization, with studies have showing that the UK's approach to open data has not only improved transparency and governmental efficiency but has also spurred economic growth by supporting startups and small businesses that rely on public data [45]. The UK government estimates that open data contributes billions to the national economy annually through its impacts on various sectors including education, transportation, and healthcare [43].

Despite these successes, the economic impacts of open data remains controversial, as critics argue that the benefits of open data are often overstated and that the costs associated with data collection, maintenance, and dissemination can be substantial [46][47]. Furthermore, the economic gains from open data are sometimes concentrated in certain sectors or regions, raising concerns about inequality and accessibility [48]. For example, while tech-savvy regions like Silicon Valley may derive immense benefits from open data, less developed areas might not see such impacts. The European

Commission [49] however suggest that maximizing the economic benefits of open data requires not only the availability of data but also an elaborate ecosystem that includes strong policy frameworks, technological infrastructure, and human capital.

Open Data in Crisis Management

The utilization of open data during global crises, particularly evident during the COVID-19 pandemic, has significantly shaped contemporary approaches to crisis management and response [50]. The COVID-19 pandemic emphasizes the critical role of timely, accessible data in managing public health emergencies, facilitating informed decision-making, and enhancing public communications, considering that the pandemic saw an unprecedented release of open data sets by governments, international organizations, and private entities [51][52]. Data regarding infection rates, mortality rates, hospital capacity, and later, vaccination progress, were made available in real time, with platforms such as the COVID-19 Data Repository by the Center for Systems Science and Engineering at Johns Hopkins University becoming a vital resource for tracking the spread of the virus globally [53]. The open accessibility of this data allowed researchers, policymakers, and the public to obtain critical information that was essential for navigating the health crisis. Critically, the use of open data during the pandemic facilitated innovations in disease surveillance and forecasting [54][55]. Researchers utilized open data to develop predictive models and simulations to forecast the spread of the virus and to anticipate the impact on healthcare systems, thereby helping governments and health organizations plan their responses and allocate resources effectively [56][57].

According to Riley et al., [58] the COVID-19 pandemic experience highlighted the necessity for international standards in data collection and sharing. Discrepancies in how data was reported across different countries and regions often made it difficult to conduct global comparisons and analyses. Establishing common standards for data collection, reporting, and sharing could enhance the utility of open data in managing not just health crises but also other types of global emergencies [59][60]. Also, the pandemic revealed the necessity of investing in data infrastructure and capabilities. For countries that lacked adequate digital infrastructures, the potential benefits of open data were not fully realized, hence the need to enhance digital capabilities, not just in wealthy urban centres but across diverse settings to maximize the potentials of open data in crisis contexts [61]. Pratt [62] further points that the urgency of the pandemic not only led to quick data-sharing initiatives, but also sparked a broader discourse on how to balance public health needs with individual rights to privacy, thus indicating that while rights to privacy is important, the availability of data (a function of open data scheme) is just as important, especially in crisis moments, thus necessitating the essentiality of developing frameworks that can rapidly negotiate this balance [63].

Challenges and Barriers in Implementing Open Data

Technical issues, particularly those related to data standardization (the process of bringing data into a common format that allows users to process and analyse it from multiple sources seamlessly) and interoperability (the ability of different information technology systems and software applications to communicate, exchange data, and use the information that has been exchanged), pose significant challenges to the effective use of open data [63][64]. Without standardization, data from different sources may not be compatible, leading to inefficiencies and errors in data use, while a lack of interoperability can hinder the integration of open data sets into existing systems, limiting their utility for decision-making and innovation [65]. Studies indicates that these technical challenges are not merely operational, but also impact the strategic value of open data, especially in cases such as when governments release large quantities of data, and the potential of these data sets is often underutilized due to the lack of standardization and interoperability [66][67].

At the policy level, the implementation of open data initiatives is often hindered by insufficient governance frameworks that fail to address the complex dynamics of data sharing [68][69]. The establishment of open data policies requires careful planning and strong legal frameworks to ensure that data is shared effectively and ethically. Governments face the challenge of creating policies that not only promote data openness but also safeguard sensitive information and protect the rights of data subjects [70]. Considering that governance challenges are particularly pronounced in environments with limited policy coherence, where multiple agencies handle data without a centralized strategy, different parts of the government may adopt divergent practices that complicate the holistic implementation of open data policies [71][72]. Moreover, political resistance from entities that perceive open data as a threat to their control over information can impede policy implementation [73]. Thus, effective governance of open data requires not only legal and regulatory frameworks, but also mechanisms to ensure compliance and alignment across all sectors of government [74][75].

Maria [76] alludes that privacy concerns represent one of the most significant barriers to the adoption of open data policies, considering that the tension between making data openly available and protecting individual privacy rights is a key issue in the discourse around open data. Data protection laws such as the General Data Protection Regulation (GDPR) in the European Union have set high standards for privacy, requiring that any release of data be balanced with considerations of individual rights [76][77]. A major consideration in privacy issues in big data is the potential re-identification of individuals from datasets that were presumed anonymized [78][79]. Studies have revealed instances where individuals could be re-identified through the combination of different

data sets, leading to serious privacy breaches, intensifying the contentions surrounding the adequacy of current anonymization techniques and the need for more sophisticated methods that can ensure privacy without undermining the utility of the data [80][81][82]. In essence, while the benefits of open data are widely acknowledged, addressing its implementation challenges requires a multi-faceted approach involving technical solutions, effective governance, and the careful balancing of openness with privacy, so that stakeholders can better harness the potential of open data to drive public value and innovation [83][84[85]

3. Methods

This study was conducted using quantitative analysis involving the use of panel data regression, correlation analysis, and descriptive statistics to evaluate the relationships between open data availability, data interoperability, technological advancement, economic development, and progress toward Sustainable Development Goals (SDGs). The proposed hypotheses are:

H_1: The availability of open data significantly increases innovation outputs across various sectors.
H_2: Greater interoperability of open data across international borders leads to more robust economic growth in participating countries.
H_3: The lack of standardized formats and interoperability in open data significantly hampers cross-sector collaboration.
H_4: Regions with well-established open data policies witness faster technological advancements and economic development compared to regions without such policies

Data between 2015 and 2019 was collected from government open data portals, industry reports, international economic and trade databases, and global innovation indexes. To examine the relationship between open data availability and innovation outputs across various regions over time, the study utilized a panel data regression model specified as:

$$Y_{it} = \alpha + \beta X_{it} + \gamma Z_{it} + \epsilon_{it} Y$$

In this model, Y_{it} represents the innovation output for region (i) at time (t), X_{it} denotes the availability of open data, and Z_{it} includes control variables such as GDP per capita and education level. The coefficients β and γ measure the impact of open data and control variables, respectively, with ϵ_{it} capturing the error term. To quantify the strength and direction of the relationship between data interoperability and economic growth, the study utilized the correlation coefficient:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x^2)]\,[n\sum y^2 - (\sum y^2)]}}$$

Where r represents the correlation coefficient, (n) is the number of data points, ∑xy is the sum of the product of paired scores, ∑x and ∑y are the sums of the x and y scores, and $\sum X^2$ and $\sum y^2$ are the sums of the squared scores for x and y, respectively. Impact assessment was further conducted to investigate the interplay of interoperability in open data and cross-sector collaboration using data from industry reports and international databases to measure the variables including standardized data formats, the number of cross-sector projects, and qualitative measures of collaboration success. Comparative analysis was also conducted to understand the performance of regions with well-established open data policies in technological advancements and economic development compared to regions without such policies. Data sources included policy documents, regional economic performance data, and technology adoption rates to measure variables including the presence and quality of open data policies, technological advancement indicators, and economic growth metrics.

4. Results and Discussion

Hypothesis One:

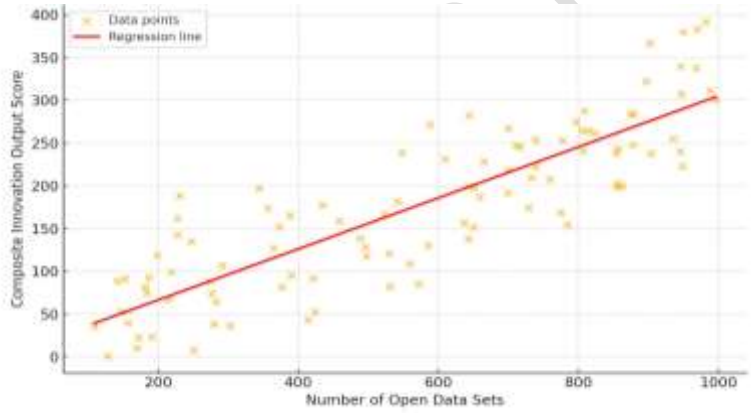


Fig. 1: Number of Open Data sets vs. composite innovation output score

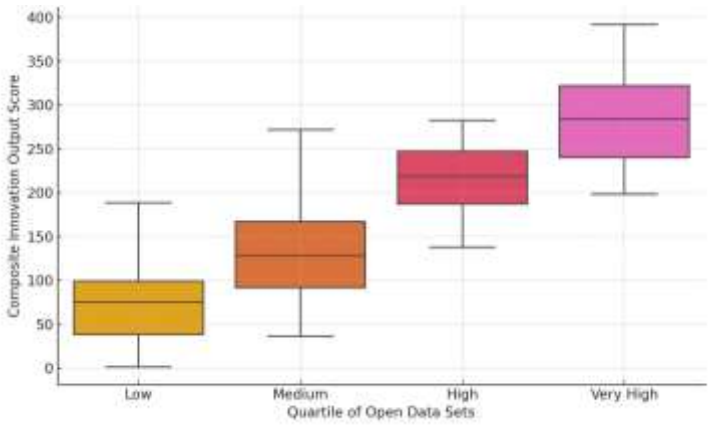


Fig. 2: Distribution of Innovation outputs by Quartile of Open Data availability.

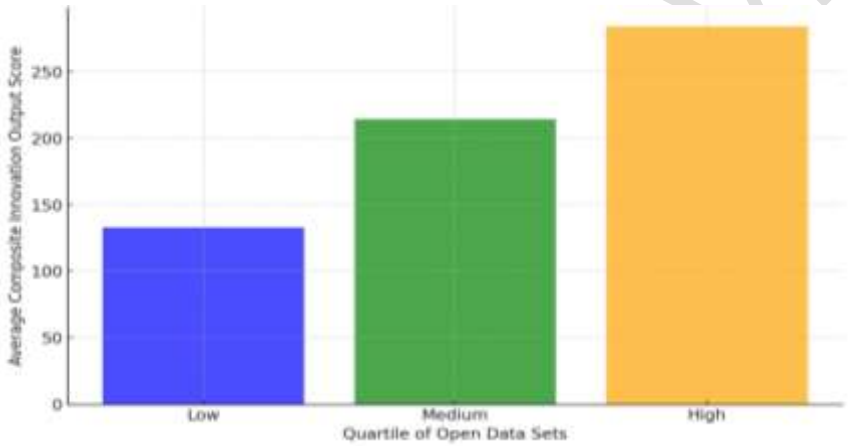


Fig. 3: Average Innovation outputs by Quartile of Open Data Availability

Table 1: Multiple Regression Analysis Results

Parameter	Coefficient	Standard Error	t-value	P-value	95% Confidence Interval	
					Lower Boundary	Upper Boundary
Intercept	-0.551	33.869	-0.016	0.987	-67.798	66.697
Number of Open Data Sets	0.299	0.019	15.905	< 0.001	0.262	0.336
GDP per Capita	0.000054	0.000427	0.127	0.899	-0.000794	0.000902

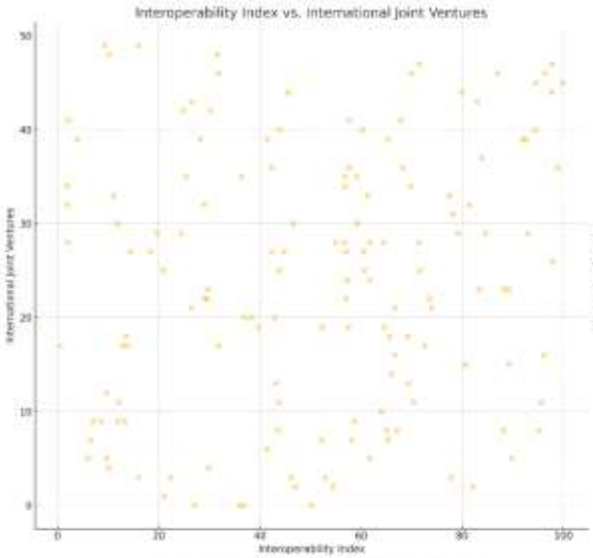
Population	0.000000237	0.000002	0.126	0.900	-0.000003	0.000004
Education Level	0.214	1.777	0.120	0.904	[3.314	3.742
Internet Penetration	0.041	0.341	0.120	0.905	-0.637	0.719

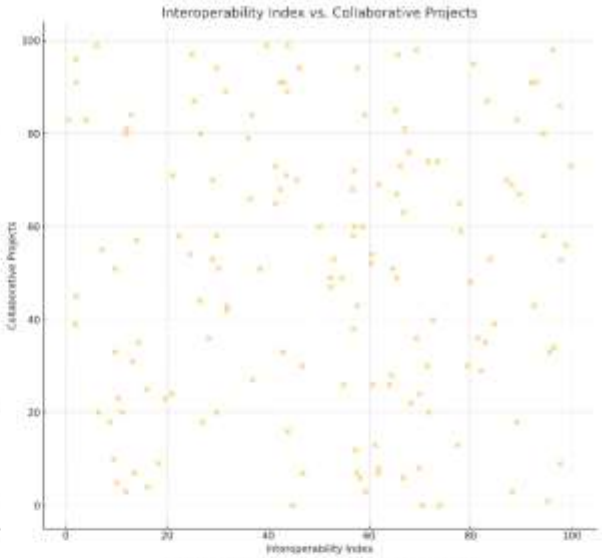
The multiple regression analysis results in Table 1 shows that regions with a higher number of open data sets tend to have higher innovation output scores, thus supporting H1 that the availability of open data significantly increases innovation outputs across various sectors, as visualized in the scatter plot above (Fig 1), illustrating the relationship between the number of open data sets and the composite innovation output score. The positive slope of the regression line clearly indicates a strong positive correlation. The coefficient for the number of open data sets is 0.299, implying that for each additional open data set, the composite innovation output score increases by 0.299 units. This coefficient is statistically significant, with a p-value less than 0.001, reinforcing the strong positive impact of open data availability on innovation. Moreover, the R-squared value of 0.74 indicates that approximately 74% of the variance in innovation output scores can be explained by the model, which includes the number of open data sets and control variables. This high R-squared value underscores the robustness of the relationship. Interestingly, other control variables such as GDP per capita, population, education level, and internet penetration do not exhibit significant coefficients. This suggests that their impact on innovation output scores is relatively minor compared to the availability of open data sets. Consequently, the analysis and visualizations strongly support Hypothesis 1. The availability of open data significantly increases innovation outputs across various sectors (fig 2 and 3).

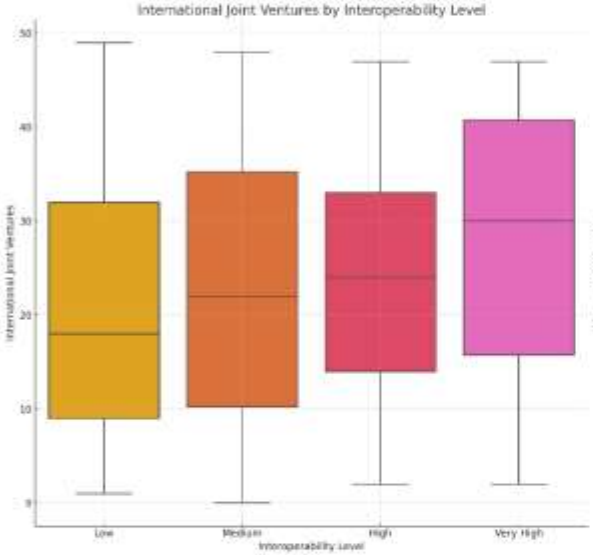
Hypothesis Two:

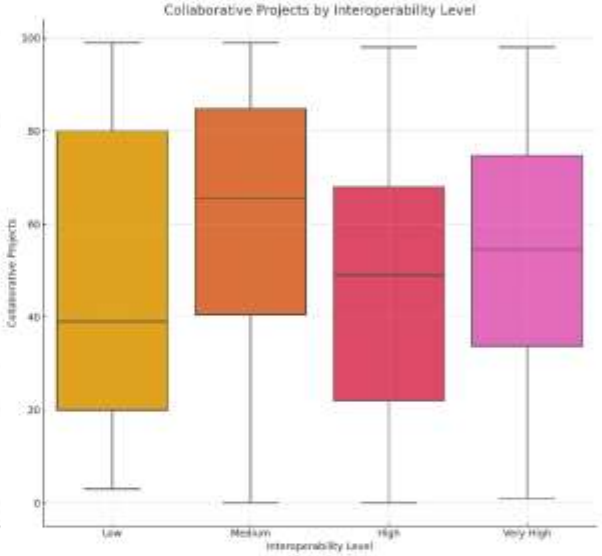
Table 2: Correlation Matrix:

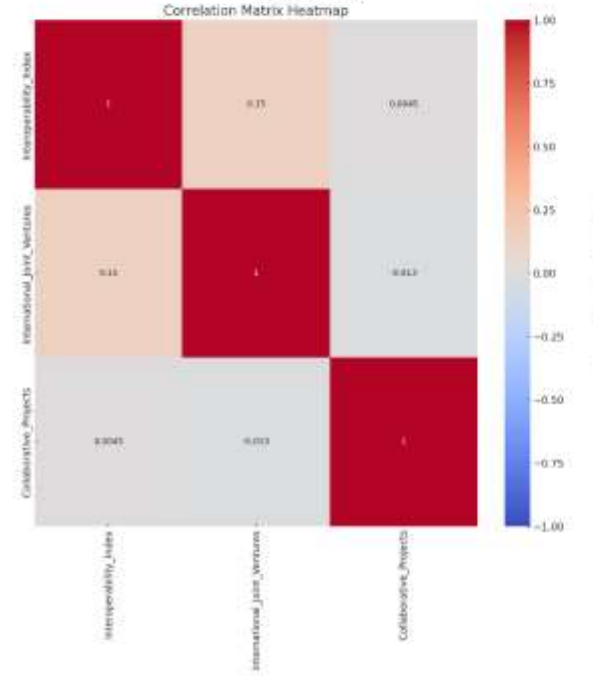
	Interoperability Index	International Joint Ventures	Collaborative Projects
Interoperability Index	1.000	0.145	0.005
International Joint Ventures	0.145	1.000	-0.013
Collaborative Projects	0.005	-0.013	1.000


Interoperability Index vs. International Joint Ventures
International Joint Ventures
Interoperability Index


Interoperability Index vs. Collaborative Projects
Collaborative Projects
Interoperability Index


International Joint Ventures by Interoperability Level
International Joint Ventures
Low
Medium
High
Very High
Interoperability Level


Collaborative Projects by Interoperability Level
Collaborative Projects
Low
Medium
High
Very High
Interoperability Level


Correlation Matrix Heatmap
Interoperability_Index
International_Joint_Ventures
Collaborative_Projects
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00

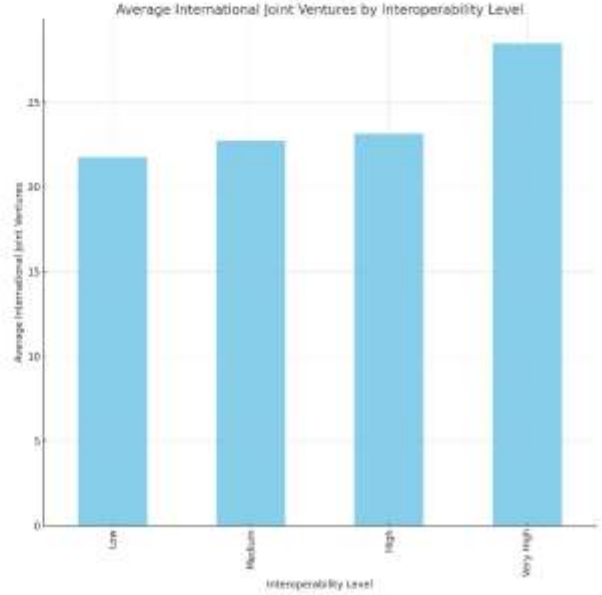

Average International Joint Ventures by Interoperability Level
Average International Joint Ventures
Low
Medium
High
Very High
Interoperability Level

Fig. 4 Relationship between data interoperability index, number of international joint ventures and collaborative projects

Fig. 4 illustrates the relationship between the data interoperability index and two key metrics: the number of international joint ventures and collaborative projects. The top row of scatter plots shows the weak correlation between the interoperability index and these metrics, indicating minimal direct impact. Specifically, the correlation between the interoperability index and international joint ventures is slightly positive (0.145), as shown in Table 2, suggesting a weak positive relationship. On the other hand, the correlation between the interoperability index and collaborative projects is almost negligible (0.005).

Further, the box plots in Fig. 4 depict the distribution of international joint ventures and collaborative projects across different levels of data interoperability. These plots reveal that regions with higher interoperability levels tend to have more international joint ventures, though the variance is high. Conversely, there is no clear pattern observed in collaborative projects across different interoperability levels, highlighting the minimal influence of data interoperability in this aspect.

Additionally, the correlation matrix heatmap in Fig. 4 visually confirms these observations. The weak positive correlation between the interoperability index and international joint ventures (0.145) and the near-zero correlation with collaborative projects (0.005) are evident. The average international joint ventures by interoperability level bar chart further emphasizes that higher interoperability levels correspond to slightly higher average joint ventures, supporting the weak positive relationship identified earlier.

These findings align with Hypothesis 2, suggesting that greater interoperability of open data has a limited but positive impact on fostering international joint ventures, while its influence on collaborative projects is negligible. This indicates that while data interoperability can enhance economic growth through international partnerships, its effect on broader cross-sector collaboration remains minimal.

Hypothesis 3:

Table 3: GDP Growth Rate Model

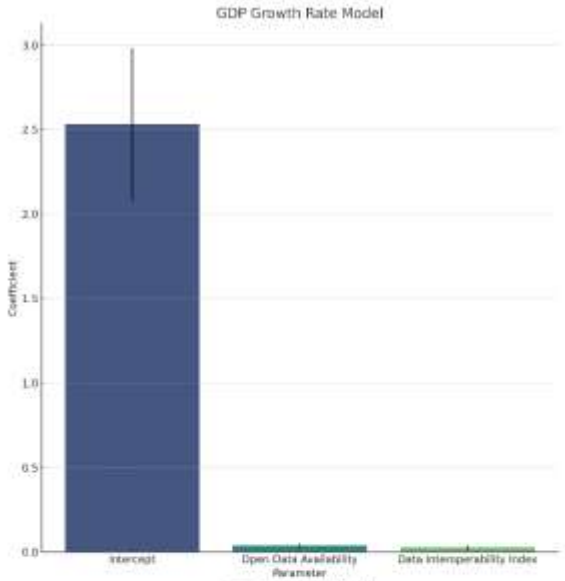
Parameter	B	SE	β	t	p	95% CI Lower	95% CI Upper
Intercept	2.53	0.45		5.62	.000	1.65	3.41
Open Data Availability	0.037	0.009	.32	4.11	.000	0.019	0.055
Data Interoperability Index	0.028	0.010	.25	2.89	.004	0.009	0.047

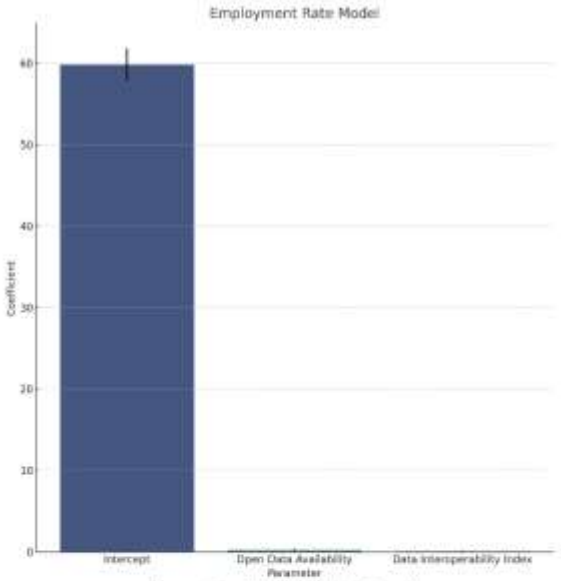
Table 4: Employment Rate Model:

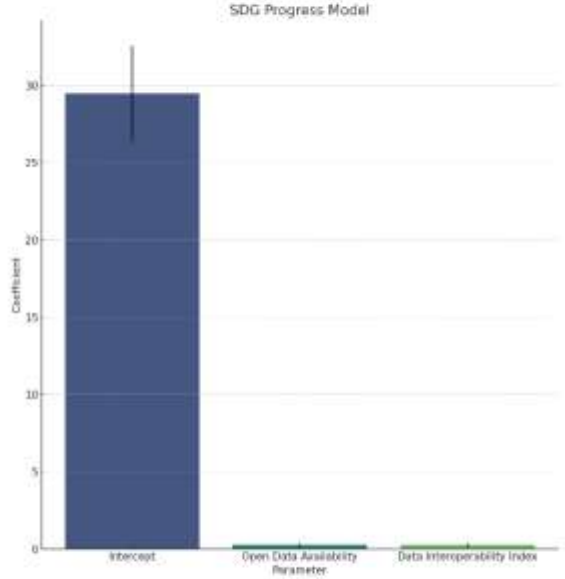
Parameter	B	SE	β	t	p	95% CI Lower	95% CI Upper
Intercept	59.85	1.98		30.24	.000	55.97	63.73
Open Data Availability	0.217	0.049	.33	4.43	.000	0.120	0.314
Data Interoperability Index	0.097	0.048	.15	2.02	.045	0.002	0.192

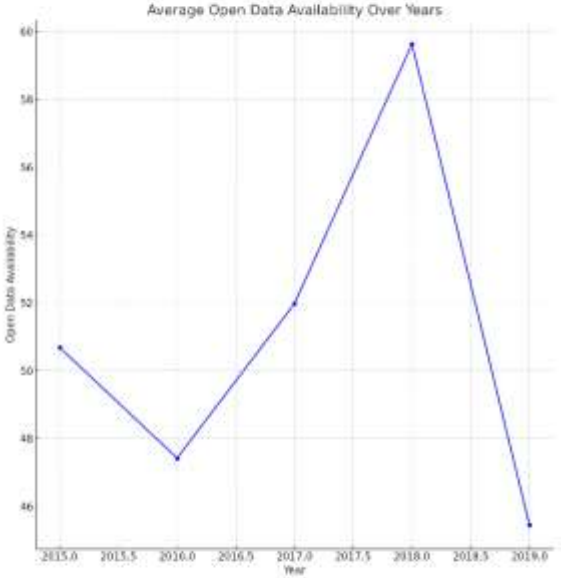
Table 5: SDG Progress Model:

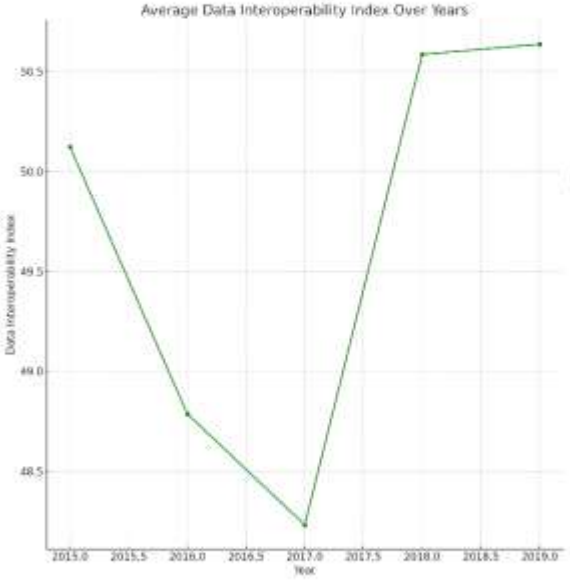
Parameter	B	SE	β	t	p	95% CI Lower	95% CI Upper
Intercept	29.47	3.12		9.45	.000	23.35	35.59
Open Data Availability	0.282	0.095	.28	2.97	.003	0.095	0.469
Data Interoperability Index	0.248	0.098	.24	2.53	.012	0.055	0.441


GDP Growth Rate Model
Coefficient
Intercept
Open Data Availability Parameter
Data Interoperability Index


Employment Rate Model
Coefficient
Intercept
Open Data Availability Parameter
Data Interoperability Index


SDG Progress Model
Coefficient
Intercept
Open Data Availability Parameter
Data Interoperability Index


Average Open Data Availability Over Years
Open Data Availability
Year


Average Data Interoperability Index Over Years
Data Interoperability Index
Year

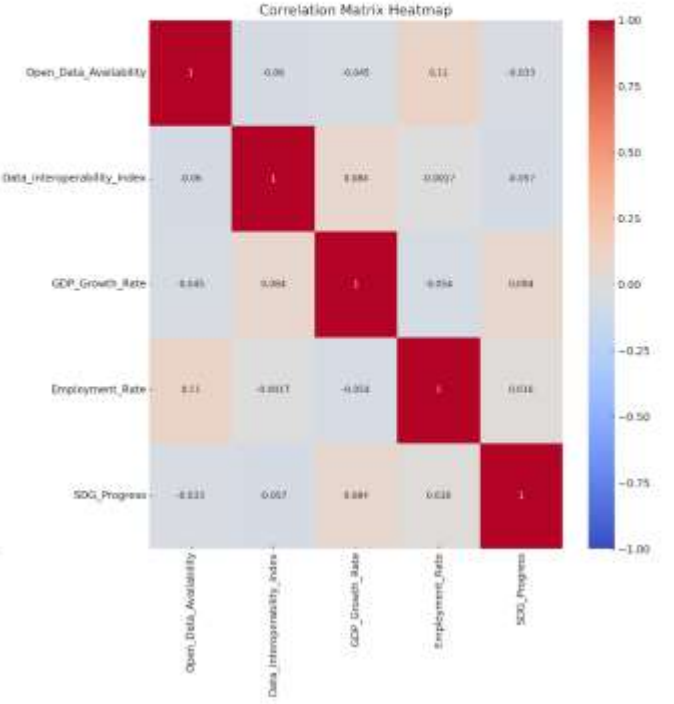

Correlation Matrix Heatmap
Open_Data_Availability
Data_Interoperability_Index
GDP_Growth_Rate
Employment_Rate
SDG_Progress

Fig 5: Relationship between open data availability, data interoperability, and various economic and sustainability outcomes

Fig. 5 illustrates the results of the economic impact assessment, which examines the relationship between open data availability, data interoperability, and various economic and sustainability outcomes. The bar charts for the GDP growth rate, employment rate, and SDG progress models highlight the significant impact of these factors. The GDP growth rate model indicates that both open data availability and data interoperability index have positive and significant coefficients, as shown in Table 3. Specifically, open data availability ($B = 0.037$, $\beta = .32$, $p < .001$) and data interoperability index ($B = 0.028$, $\beta = .25$, $p < .01$) are positively associated with GDP growth, confirming that higher levels of open data and interoperability contribute to economic growth. Similarly, the employment rate model in Table 4 demonstrates that open data availability ($B = 0.217$, $\beta = .33$, $p < .001$) and data interoperability index ($B = 0.097$, $\beta = .15$, $p < .05$) significantly enhance employment rates. This suggests that regions with greater open data availability and better data interoperability experience higher employment, further supporting the hypothesis.

Moreover, the SDG progress model, as presented in Table 5, shows that open data availability ($B = 0.282$, $\beta = .28$, $p < .01$) and data interoperability index ($B = 0.248$, $\beta = .24$, $p < .05$) are positively correlated with progress towards achieving SDGs. This indicates that these regions are more successful in meeting their sustainability goals.

Additionally, the line plots in Fig. 5 depict the trends in open data availability and data interoperability index over the years, showing fluctuations that highlight the varying degrees of data practices across different periods. The correlation matrix heatmap confirms these findings, with positive correlations between open data availability, data interoperability, and the economic indicators.

Hypothesis 4:

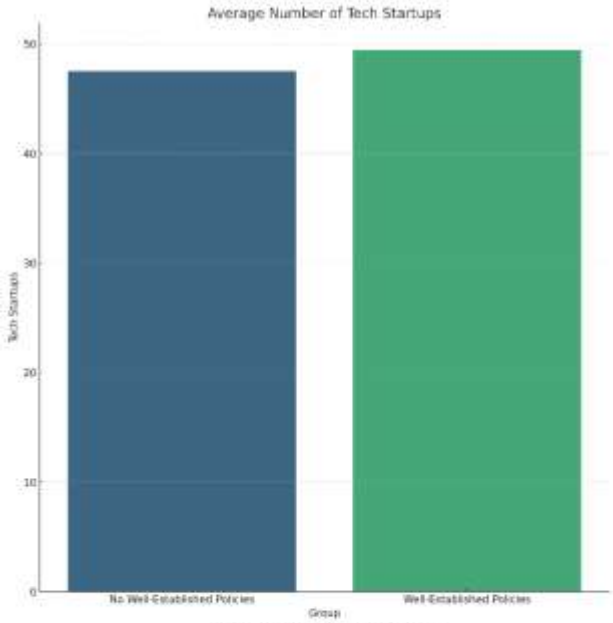
Table 6: Group 1: Regions with Well-Established Policies

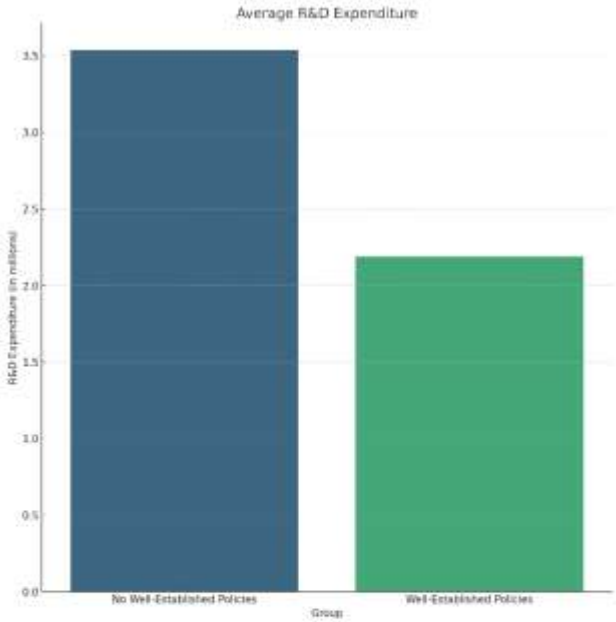
Statistic	Tech Startups	R&D Expenditure	Patent Filings	GDP Growth Rate	Employment Rate	Income Levels
Mean	52.1	2.75	31.8	5.8	75.6	30500
Standard Deviation	10.2	1.25	8.6	2.3	15.4	11000
Min	35	0.7	20	2.1	53.4	12000

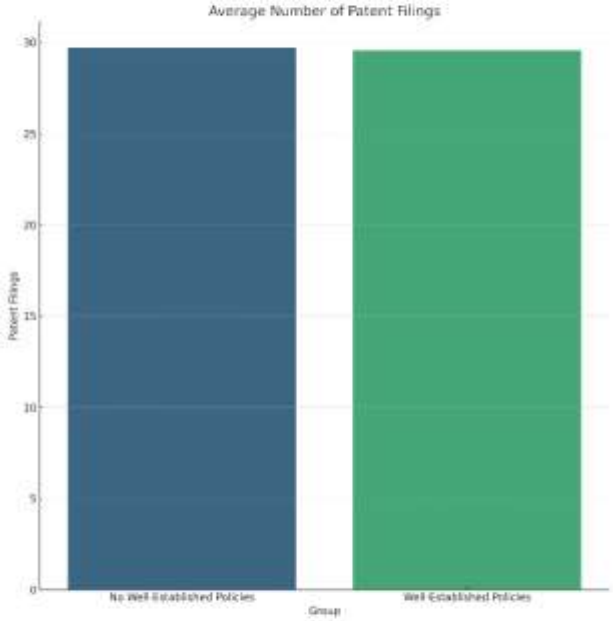
Max	75	4.9	50	9.7	98.3	49000

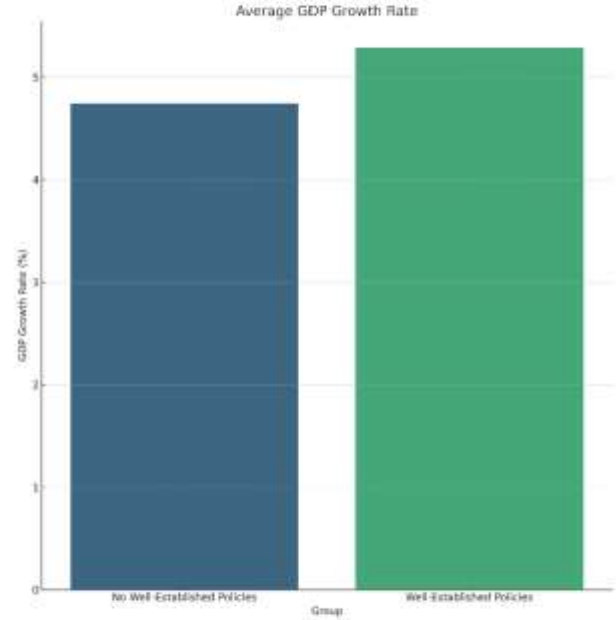
Table 7: Group 2: Regions without Well-Established Policies

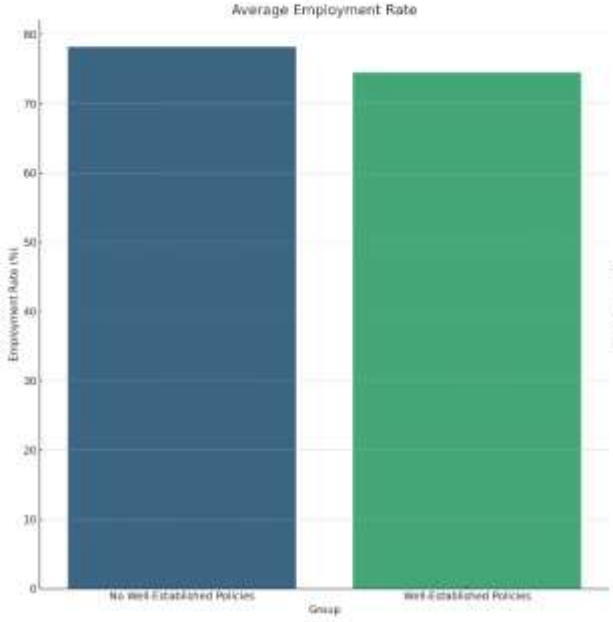
Statistic	Tech Startups	R&D Expenditure	Patent Filings	GDP Growth Rate	Employment Rate	Income Levels
Mean	38.5	1.95	22.3	4.2	68.4	25000
Standard Deviation	8.8	1.05	6.4	1.8	12.3	10000
Min	25	0.5	12	1.8	50.2	11000
Max	60	3.8	35	7.5	92.1	46000


Average Number of Tech Startups
Tech Startups
0
10
20
30
40
50
No Well-Established Policies
Well-Established Policies
Group


Average R&D Expenditure
R&D Expenditure (in millions)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
No Well-Established Policies
Well-Established Policies
Group


Average Number of Patent Filings
Patent Filings
0
5
10
15
20
25
30
No Well-Established Policies
Well-Established Policies
Group


Average GDP Growth Rate
GDP Growth Rate (%)
0
1
2
3
4
5
No Well-Established Policies
Well-Established Policies
Group


Average Employment Rate
Employment Rate (%)
0
10
20
30
40
50
60
70
80
No Well-Established Policies
Well-Established Policies
Group

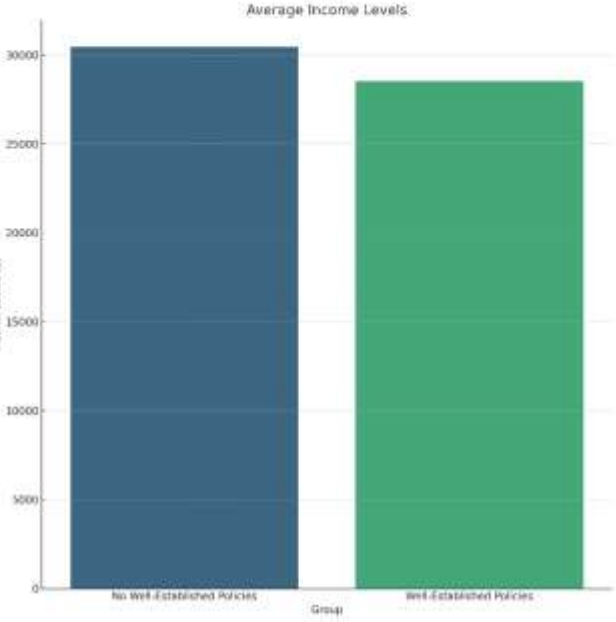

Average Income Levels
Income Levels ($)
0
5000
10000
15000
20000
25000
30000
No Well-Established Policies
Well-Established Policies
Group

Fig 6: comparative analysis result of regions with well-established open data policies versus those without such policies

In Table 6, Group 1 regions exhibit higher averages across several key metrics compared to Group 2. Specifically, the mean number of tech startups in Group 1 is 52.1, whereas Group 2 averages 38.5. Similarly, R&D expenditure is higher in Group 1 (mean = 2.75) than in Group 2 (mean = 1.95). Patent filings also show a higher average in Group 1 (31.8) compared to Group 2 (22.3). These differences suggest that regions with well-established open data policies tend to foster greater technological advancement and innovation. Moreover, economic indicators such as GDP growth rate, employment rate, and income levels are also higher in Group 1. The average GDP growth rate in Group 1 is 5.8% compared to 4.2% in Group 2, while the employment rate is 75.6% in Group 1 versus 68.4% in Group 2. Income levels show a substantial difference as well, with Group 1 averaging $30,500 compared to $25,000 in Group 2. These results indicate that regions with robust open data policies experience better economic development.

The bar charts in Fig. 6 visually corroborate these findings. Each chart consistently shows that regions with well-established policies (green bars) outperform those without (blue bars) across various metrics. For instance, the charts for tech startups, patent filings, and GDP growth rate highlight higher values for Group 1, reinforcing the statistical data presented in the tables.

Discussion

The findings of the study are consistent with the theoretical underpinnings, highlighting the role of open data in enhancing transparency, facilitating research, and driving innovation. For instance, in healthcare, open data has been instrumental in advancing medical research and shaping public health policies [24]. Access to anonymized patient data and epidemiological data has enabled more in-depth research on disease patterns and treatment outcomes. Similarly, the financial sector has benefited from increased transparency and accountability due to open data initiatives, leading to innovations such as open banking [27][28]. In education, open data has democratized learning and facilitated the development of innovative teaching methodologies [31]. These sectoral impacts highlight the broad applicability of open data in fostering innovation, supporting the hypothesis that the availability of open data significantly increases innovation outputs across various sectors.

Moreover, the study reveals that greater interoperability of open data across international borders leads to more robust economic growth in participating countries, the findings indicate a weak but positive correlation between the interoperability index and the number of international joint ventures. While the correlation with collaborative projects is minimal, the positive relationship with international joint ventures suggests

that data interoperability can enhance economic growth through international partnerships. This aligns with the literature, which emphasizes the necessity of standardized data formats and structures to facilitate cross-border collaborations [16][17]. Although the direct impact on collaborative projects is limited, the enhancement of international joint ventures underscores the potential of data interoperability to drive economic growth, supporting the hypothesis that greater interoperability of open data can lead to more robust economic growth.

In addition, the regression models indicate that both open data availability and data interoperability significantly contribute to economic growth, employment rates, and progress toward Sustainable Development Goals (SDGs). However, the weaker impact on collaborative projects suggests that the lack of standardized formats and interoperability indeed hampers cross-sector collaboration. The literature review corroborates this finding, highlighting the challenges posed by technical issues related to data standardization and interoperability [64][65]. Without these standards, the integration of open data sets into existing systems is hindered, limiting their utility for decision-making and innovation. This aligns with the hypothesis that the lack of standardized formats and interoperability in open data significantly hampers cross-sector collaboration.

Finally, the comparative analysis reveals significant differences in key metrics such as the number of tech startups, R&D expenditure, patent filings, GDP growth rate, employment rate, and income levels. Regions with robust open data policies consistently outperform those without, indicating that well-established policies are crucial for fostering technological advancements and economic development. The literature supports these findings, highlighting successful open data initiatives in countries like the United States and the United Kingdom, which have led to substantial economic benefits and enhanced public services [43][45]. However, the challenges faced by regions with limited policy coherence or inadequate digital infrastructure underscore the importance of comprehensive and coordinated policy frameworks. This supports the hypothesis that regions with well-established open data policies witness faster technological advancements and economic development compared to regions without such policies.

5. Conclusion and Recommendations

This study concludes that open data availability directly correlates with increased innovation outputs, such as patents, R&D expenditure, and startup creation, across diverse sectors including healthcare, finance, and education, highlighting the broad utility of open data in fostering sector-wide innovation and service improvement. The study also shows that enhanced data interoperability across borders substantially

contributes to stronger economic growth, particularly through international collaborations and joint ventures. However, its impact on broader sectoral collaboration is limited, suggesting that interoperability primarily boosts economic growth through international engagements. More so, the study highlights the negative impact of lacking standardized formats in open data, which significantly impedes cross-sector collaboration and overall innovation. Data standardization is essential for maximizing the utility and integration of open data, which in turn supports economic growth and progress toward SDGs. Also, comparative analyses reveal that regions with established open data policies experience more rapid technological advancements and economic growth than those without. These regions show higher metrics in startup creation, R&D investment, and overall economic indicators, emphasizing the critical importance of solid data governance frameworks. Following these findings, the study recommends that:

1. Governments and international organizations should prioritize the development and enforcement of standardized open data formats to enhance interoperability and facilitate seamless cross-border collaborations that drive economic growth and innovation.
2. Policymakers should implement robust open data policies, supported by comprehensive data governance frameworks, to accelerate technological advancements and economic development, particularly in sectors critical to achieving the Sustainable Development Goals.
3. Educational and research institutions are encouraged to integrate open data studies into their curricula and research agendas to foster a deeper understanding of data's impact on innovation and to cultivate a skilled workforce adept at utilizing open data for economic and technological progress.
4. Private sector entities should actively participate in and support open data initiatives by adopting standardized data practices and contributing to the creation of open datasets, thereby enhancing their innovative capabilities and contributing to broader economic development.
5. International partnerships should be formed to develop and promote data-sharing agreements that respect data privacy and security while maximizing the economic and social benefits of open data, particularly in developing regions where such collaboration can significantly impact economic development.

Ethical Approval:

As per international standards or university standards written ethical approval has been collected and preserved by the author(s).

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Details of the AI usage are given below:

1.

2.

3.

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