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Institutions Matter for the Knowledge Economy: A Panel Data Investigation of Leading Nations (1996–2024)

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Abstract :
The purpose of this research is to examine the role of institutional quality on the knowledge economy in a group of leading economies for the period 1996-2024 using the panel data approach and the PCA. Six countries have been considered in this study, which include Sweden, Switzerland, Denmark, USA, UK, and Norway. A knowledge economy index has been created using five variables namely secondary education, higher education, patents, internet users, and mobile phone users while institutional index has been formed using six variables including governance indicators along with income, foreign direct investments, and trade openness.
From the empirical results of the model, it is found that the value of R^2 of the model is 0.6441 indicating that the model is statistically significant. From the results, it is revealed that there is a positive relationship between institutional quality and the knowledge economy ($\beta = 0.136$). Out of all the factors, the role of trade openness is found to be more important ($\beta = 1.578$) than income ($\beta = 0.746$) while the role of foreign investment is quite insignificant ($\beta = 0.016$).

Keywords: Knowledge economy, Institutions, PANEL models, PCA
Jel classification :O30 ; C38 ; C23 ; P48

1-INTRODUCTION

The global economic landscape has experienced significant change due to the emergence of knowledge, innovation, and rapid developments in the field of information and communication technology (Drucker, 1969; Machlup, 1962). Different from the conventional factors of production such as land, capital, and labor, knowledge is one of the most important assets that can add value to any nation through increased productivity (Stiglitz, 1999). This phenomenon has led to the development of what is termed as the 'knowledge economy' which represents an economic framework where knowledge plays a vital role in value creation based on investments in education, R&D, and digital technology (World 2007) (Dahlman 2006). According to the UNDP (2025), the share of knowledge-intensive industries in GDP is now above 40% in leading economies (UNDP 2025).
This process has led to the increased creation, exchange, and international dissemination of information and heightened global competition for knowledge-based competitiveness. The knowledge economy concept has been operationalized by international organizations, especially the World Bank and UNDP, through the development of an extensive measurement framework. The Knowledge Assessment Methodology (KAM), created by the World Bank in the early 2000s, marked the beginning of knowledge economy readiness assessment of countries. It was succeeded by the advanced Global Knowledge

Index (GKI), which was first presented in 2017, and now includes 195 countries in its 2025 edition. According to the recent results of the GKI, one can observe a remarkable trend that countries with better institutional performance indices tend to perform better than other countries in all knowledge economy aspects, including education, science, innovations, and ICT infrastructure. (UNDP 2025)

Such swift changes call for the emergence of institutional mechanisms in tune with the requirements of the knowledge economy (North 1990) (Schiliro 2012). A successful knowledge economy needs an environment where excellence in education, a competent workforce, good ICT infrastructure and an environment that supports creativity and innovation can flourish (Padash, H; Khodapanah, B; Ebrahimzadeh, M 2017). But, even then, there is no guarantee that success will be attained. The production and diffusion of knowledge are heavily influenced by governmental policies, economic incentives and the institutional environment (Sheehan 1999). Institutions play the role of the 'rules of the game' which decide whether the investments in education and technology lead to any actual production of knowledge (Padash, H; Khodapanah, B; Ebrahimzadeh, M 2017). Recent empirical findings have shown that institutions are one of the main factors behind the conversion of education and ICT investment into knowledge production, using various measures like rule of law, corruption control and governance effectiveness (Zhang 2025). Without institutions, even considerable investments in human capital and infrastructures will not yield the expected results of the knowledge economy.

Despite the growing consensus on the importance of institutions, limited empirical research has examined the institutional determinants of knowledge economy performance specifically among leading developed nations. While studies such as Padash and Khodapanah (2015) and Andrés et al. (2015) have explored this relationship using diverse country samples (Padash and Khodapanah 2015) (Andrés, Asongu and Amavilah 2015), they have not focused exclusively on top-performing economies, nor have they employed advanced econometric techniques combining Principal Component Analysis (PCA) with panel data models over an extended time horizon. Furthermore, most existing studies rely on relatively short time periods and do not adequately address econometric issues such as cross-sectional dependence and serial correlation. This study aims to fill these gaps by investigating the following research question: **To what extent does institutional quality contribute to the development of the knowledge economy in leading nations?** Specifically, we test the hypothesis that higher institutional quality exerts a positive and statistically significant impact on knowledge economy development. To achieve this, we analyze six countries with consistently high Global Knowledge Index scores and robust institutional performance—Sweden, Switzerland, Denmark, the United States, the United Kingdom, and Norway—over the period 1996-2024, employing a combination of PCA and panel data models with Panel-Corrected Standard Errors (PCSE). This approach allows us to provide robust empirical evidence on the institutional determinants of knowledge economy success in developed nations.

Specifically, the objectives of this research are as follows. The first is the construction of composite indicators for both institutional quality and knowledge economy through PCA, which addresses the inadequacies of single-indicator methods. The second objective is the estimation of the effect size and significance of institutional quality on the development of knowledge economy taking into consideration other economic variables such as per capita income, foreign direct investment, and trade. The third objective is the provision of policy recommendations for both advanced economies, which need to sustain their knowledge economies, and for emerging economies, which aim at developing their knowledge economies.

2 THEORETICAL FRAMEWORK

2.1 The Knowledge Economy: Theoretical Underpinning and Tools for Its Measurement

The knowledge economy constitutes a qualitative change in the structure of economies throughout the world since knowledge and innovations have replaced physical resources as key factors of production and value-adding activity. Such concepts were developed in several groundbreaking theories including Machlup's (1962) innovative research in quantifying knowledge intensive activities, Drucker's (1969) introduction of the notion of 'knowledge society' and Stiglitz's (1999) research into policy changes in relation to such economy. The World Bank (2007) defines the knowledge economy as an economy which 'has knowledge as its main engine of growth via strategic investment in education, innovation, information and communication technologies (ICT) and institutions (World 2007).' The same term is defined by the OECD (1996) as an economy where 'the production, distribution, and use of knowledge are the main drivers of growth, wealth creation, and employment.' (Peters 2003) Further developing these ideas, Dahlman (2006) formulated a four-dimensional concept of the knowledge economy as follows: (1) The institutional and economic system that motivates knowledge creation and knowledge utilization (2) Educational and training systems that help to build human capital (3) Innovation and research and development systems that create knowledge (4) Information and communication technology systems that facilitate knowledge dissemination (Dahlman 2006).

Diagram 1: knowledge economy measurement framework - core indicators

Pillar 1	Pillar 2	Pillar 3	Pillar 4
Institutional & economic regime	Education & training	Innovation & r&d	Ict infrastructure
-rule of law -government effectiveness -regulatory quality -control of corruption -political stability -voice & accountability	-secondary enrollment -tertiary enrollment -education expenditure -quality of education -adult literacy	-r&d expenditure (% of gdp) -patent applications -scientific publications -researchers per capita	-internet users (% of population) -mobile subscriptions (per 100 people) -fixed broadband subscriptions -ict exports (% of total) -telephone lines (per 100 people) -personal computers (per 100 people)

Source: Adapted from (Dahlman 2006)

Measurement methods of knowledge economies have seen significant evolution in the last two decades. The Knowledge Assessment Methodology (KAM) developed by the World Bank in the early 2000s offered the first benchmarking tool based on four indicators: economic incentives and institutional regime; education and human resources; innovation system and ICT infrastructure. Based on the previous experience of the development of such frameworks, in 2017, UNDP in collaboration with the Mohammed bin Rashid Al Maktoum Knowledge Foundation published the Global Knowledge Index (GKI). The new assessment framework offers much more sophisticated analysis and includes six sub-indices: pre-university education; technical and higher education; R&D and innovation; ICT; economic and environmental factors; governance and social factors (UNDP, 2025). The 2025 version of the Global Knowledge Index includes 195 countries and is currently the most advanced and comprehensive assessment method of the state of the knowledge economy of different countries. It is particularly worth mentioning the 'enabling environment' dimension which includes governance and institutional factors because of the recognition that institutions are not just one of several pillars of the knowledge economy, but its basic infrastructure that enables all other processes (UNDP 2025).

Endogenous growth theory, introduced by Romer (1990) and Lucas (1988), forms the basis of theoretical explanations of the knowledge economy. While Romer's pioneering work refuted the diminishing returns assumption of the neoclassical growth theory by highlighting increasing returns to scale associated with the knowledge production – knowledge is non-rival (consumed jointly) and partially excludable (patents and copyrights), Romer model emphasizes the importance of intentional investments into R&D, human capital accumulation, and knowledge spillovers in explaining economic growth. The theoretical framework implies that more developed countries (with higher knowledge stock and R&D investment rate) will grow faster than less developed countries, forming positive feedback loop of knowledge creation and economic growth (Romer 1990) (Lucas 1988).

Nevertheless, there are certain limitations of endogenous growth models. First of all, Jones (1995) claims that scale effects postulated by Romer model (larger populations imply faster growth) lack empirical support and proposes semi-endogenous growth models which account for diminishing returns to R&D (Jones 1995). Second, Aghion and Howitt (1998) introduce 'creative destruction' approach and suggest another model of economic growth which stems from constant process of innovating old technologies. Finally, from the point of view of this paper, it is necessary to mention critique of North (1990) and other institutional theorists who believe that endogenous growth models ignore the existence of certain institutional requirements for knowledge generation and dissemination. In the absence of proper institutions (property rights, contracts, regulations) R&D investments will not generate economic growth (Aghion and Howitt 1998).

This paper takes advantage of the merger between institutional and endogenous growth theories and suggests that institutions are the underlying factors which affect efficiency of the knowledge production function. Institutional quality serves as a moderator of the relationship between knowledge investment (education, R&D, ICT) and knowledge economy output.

Recent empirical researches prove the existence of the relationship between the level of knowledge economy and economic growth of the countries of the Middle East and North Africa region. Barkhordari et al. (2019) proved that institutions, human capital, scientific research and infrastructure are the major pillars positively affecting economic growth in these countries. Therefore, it is necessary to adopt an integrated knowledge economy policy (Barkhordari 2019).

2.2 Institutions as a Framework for the Knowledge Economy

According to North (1990), institutions refer to the "rules of the game in society"—the formal and informal constraints that define the framework within which people interact, lower uncertainties, and exchange goods or services. Institutions include formal rules (such as constitutions, laws, and regulations) and informal constraints (social norms, conventions, and codes of conduct). All these contribute towards forming the incentive structure that influences economic, political, and social activities of people. The quality of institutions has been traditionally assessed based on governance indicators covering six aspects: control of corruption, rule of law, government effectiveness, regulatory quality, political stability and absence of violence, and voice and accountability (Kaufmann, Kraay and Mastruzzi 2010). In respect of the knowledge economy, institutions are especially important as they establish the security of property rights, enforcement of contract, knowledge diffusion system, and incentives for innovation and risk-taking. Schiliro (2012) posits that institutions of good quality decrease transaction costs and provide predictability of the environment that facilitates knowledge creation (Schiliro 2012).

The significance of institutions in terms of developing knowledge economy is associated with three interconnected functions. First, the stimulating function: institutions create incentives for investments in knowledge and innovation, creating a well-established system of intellectual property rights protection, competition, and effective patent systems (Andrés, Asongu and Amavilah 2015). The US Bayh-Dole Act (1980) and strong protection of patents in Sweden show how institutional conditions may contribute to efficient transfer of knowledge between universities and companies and innovation processes. Secondly, the enabling function: institutions provide and regulate infrastructures of education and technologies making sure that there is high-quality human capital and knowledge production (Padash, H; Khodapanah, B; Ebrahimzadeh, M 2017). Switzerland's dual education system and Denmark's high level of R&D expenditures (3% of GDP) are good illustrations of the importance of investments in education and research for success of knowledge economy. Thirdly, the facilitating function: institutions facilitate international knowledge and technology transfers, build trust in economic relationships and create stability in the business environment (Schiliro 2012). Such examples as openness of Norway for international research collaborations and UK's developed contract enforcement regime are illustrative of this function. Thus, these three functions are interconnected in such a way that creates a virtuous circle of attracting investments and further development of institutions, as well as knowledge economy development.

According to Sheehan (1999), the emergence of knowledge economy needs not only the presence of institutions but credible institutions as well since they are crucial for creating a secure and stable environment for knowledge and economic interactions (Sheehan 1999). According to Schiliro (2012), the creation and diffusion of knowledge depend on the governmental policies which in their turn emerge due to economic incentives and institutions and cannot be guaranteed by market mechanisms alone (Schiliro 2012).

2.4 Recent Empirical Evidence on the Importance of Institutions

Recent empirical evidence has emphasized the central role played by institutions in promoting a knowledge-based economy. In particular, Padash and Khodapanah (2015) found a significant positive influence of good governance on the knowledge economy index among the sample of 33 countries, underlining the importance of the rule of law, political stability, and anti-corruption actions. Their results showed that these components have more influence than others (Padash and Khodapanah 2015). In the similar Iranian case, Padash et al. (2017) revealed that the index of general institutional environment has a significant influence on the knowledge economy index, where the legal and political environment has a more influential role than business environment (Padash, H; Khodapanah, B; Ebrahimzadeh, M 2017).

Andrés et al. (2015) argued that despite the necessity of the protection of intellectual property rights, these rights alone cannot promote the development of a knowledge economy in the Middle East, North Africa, and Sub-Saharan Africa. Institutional quality plays a more significant role in determining success. In turn (Andrés, Asongu and Amavilah 2015), Boussetta et al. (2022) highlighted major problems faced by developing countries of the Middle East and North Africa in the process of the transition to a knowledge-based economy, emphasizing the importance of the quality of institutions in catching up with developed countries (Boussetta, Aissaoui and Sellaouti 2022).

According to Zhang et al. (2025), industrial change in emerging countries requires the collaboration of both innovation in institutions and technology because failure to cooperate between institutions and technology hinders knowledge creation. (Zhang 2025).

2.5 Integration of Governance Dimensions with Macroeconomic Variables to Foster a Knowledge-Based Economy

Quality of institutions involves more than just the six dimensions of governance such as rule of law, government effectiveness, regulatory quality, control of corruption, political stability, and voice and accountability. It includes a macroeconomic environment that is favorable to growth. Such a favorable macroeconomic environment entails factors like trade openness and GDP per capita. These two factors help determine how well the country can absorb, diffuse, and use knowledge and technology, as well as provide the necessary means for investments in education, research and development, and ICT.Following the institutional economics theory, trade openness promotes the diffusion of applied knowledge and technology through means like import and export of goods, foreign direct investment, and international collaboration. As such, trade openness helps the institutions adapt the rules and legislation in accordance with international standards (World 2007).

Current literature supports the fact that strong institutional setting encourages FDI, and quality institutions help in the strengthening of FDI in transferring technology and knowledge. The present literature from the MENA region shows that the government effectiveness directly and positively affects the performance of the knowledge economy ($\beta=0.089$, $p = 0.025$), which is an indicator of the importance of institutional setting in achieving knowledge results (Boumediene et Elamine 2026). On the contrary, the per capita GDP level is positively associated with the ability of a country to invest in knowledge infrastructure, innovate and attract talent, thus ensuring better policy implementation through institutions for a knowledge-based economy (Schiliro 2012). In recent times, there has been a finding that institutional quality enhances economic growth and welfare. For instance, a study conducted for 52 African countries has revealed that political stability, anti-corruption, regulatory quality, rule of law and government effectiveness act as critical determinants of economic growth and welfare (Kunawotor 2026).

Therefore, the interrelationship among the six indices with respect to openness of trade and per capita income forms an institutional framework that goes beyond mere formal institutions and includes the economic factors that make the institutions more adaptive to the demands of the knowledge-based economy. Recent research shows that the institutional pillar plays a more prominent role in promoting economic complexity compared to the other pillars of the knowledge economy. The analysis of 36 African countries shows that there exists a positive and significant correlation between the institutional index and economic complexity across all dimensions, while the correlation with technology is insignificant (Velamva 2024). It explains the reason why the developed countries lead the Global Knowledge Index in terms of not only having good governance but also having an open and prosperous economy (UNDP 2025).

3 ECONOMETRIC STUDY

This paper aims at explaining the role of institutions in the knowledge economy. The data set used for this research involves six top economies of the knowledge economy, namely, Sweden, Switzerland, Denmark, the USA, the UK, and Norway, between 1996 and 2024. The dependent variable is an index that represents several variables of the knowledge economy. The independent institutional variable is an index that is based on six variables of governance according to World Bank data. Per capita GDP, foreign direct investment, and trade openness are the independent variables. The analysis will be conducted using panel regression models and PCA in Stata 17.

3.1 Model Specification and Variable Measurement

Following the theoretical framework discussed above, we specify the following panel data model to examine the relationship between institutional quality and knowledge economy development:

$$LnKE = β\_0 + β\_1LnINST + β\_2LnGDPP + β\_3LnFDI + β\_4LnTO + ε \quad ....(01)$$

where i denotes country (i=1,...,6) and t denotes year (t=1996,...,2024).

The dependent variable, KE, represents the Knowledge Economy Index, a composite measure constructed from five indicators: secondary school enrollment (EDUs), higher education enrollment (EDUh), total patent applications (RD), internet users per 100 people (INT), and mobile phone subscriptions per 100 people (MT). These indicators were selected based on the World Bank's Knowledge Assessment Methodology framework, which identifies education, innovation, and ICT infrastructure as core knowledge economy pillars (Dahlman 2006). We employ Principal Component Analysis (PCA) to construct this composite index, using the first principal component that captures the maximum variance in the underlying indicators.

The independent variable of primary interest, INST, represents the Institutional Quality Index, also constructed via PCA from six World Bank Worldwide Governance Indicators: control of corruption (CC), rule of law (RL), government effectiveness (GE), political stability (PS), regulatory quality (RQ), and voice and accountability (VA) (Kaufmann, Kraay and Mastruzzi 2010). These six indicators collectively capture the multidimensional nature of institutional quality, encompassing both the formal rules and their enforcement.

Control variables include: GDP per capita (GDPP), measured in constant 2015 US dollars; Foreign Direct Investment (FDI), measured as net inflows as a percentage of GDP; and Trade Openness (TO), calculated as the sum of exports and imports divided by GDP. All variables are transformed using natural logarithms to address skewness in the data, improve model fit, and enable interpretation of coefficients as elasticities (Wooldridge 2010).

3.2 Principal Component Analysis (PCA) for Knowledge Economy Index Construction

Given the lack of direct access to the Knowledge Economy Index throughout the entire time range under investigation (1996–2024), the composite index will be created based on the Principal Component Analysis (PCA). PCA is a mathematical technique of reducing the number of variables by transforming them into the smaller number of uncorrelated principal components while retaining the greatest amount of information contained in the original variables (Jolliffe 2002). This technique is especially suitable for the development of composite indices as it is based on the empirical determination of the weights of the elements rather than assigning equal weights to them arbitrarily.

Five variables were chosen in accordance with the KAM World Bank framework and available data: secondary education enrollment (EDUs), higher education enrollment (EDUh), total patents (RD), internet users per 100 persons (INT), and mobile phone subscription per 100 persons (MT). Before conducting PCA, the suitability of data is checked using the following criteria: (1) correlation matrix check for sufficient correlation among the variables; (2) Kaiser-Meyer-Olkin (KMO) test of sampling adequacy; and (3) Bartlett's test of sphericity for checking if the variables are sufficiently correlated to conduct PCA. According to Kaiser (1974), the KMO value >0.5 indicates that the data is acceptable for PCA, >0.7 is good, and >0.9 is excellent. The selection of the number of principal components to retain is made using the Kaiser criterion (eigenvalues > 1) and the scree plot technique (Cattell 1966). The first principal component (Comp1) will be used as the Knowledge Economy Index as it accounts for the largest variance.

Table 1: Correlation Matrix for Variables

	INT	**MT**	**RD**	**EDUs**	**EDUh**
INT	1				
MT	0.9384	1			
RD	0.0002	-0.1299	1		
EDUs	0.136	0.1703	-0.4259	1	
EDUh	0.6168	0.464	0.3248	0.2515	1

Source: Prepared by researchers using STATA 17 software

Table 2: KMO test for variables

Variable	**kmo**
INT	0.6165
MT	0.5300
RD	0.4486
EDUs	0.5262
EDUh	0.5636
Overall	**0.5369**

Source: Prepared by researchers using STATA 17 software

It can be seen from the correlation matrix that most variables have correlation. Moreover, the value of the KMO test statistic exceeds 0.50, hence fulfilling the criteria for applying principal component analysis (PCA).

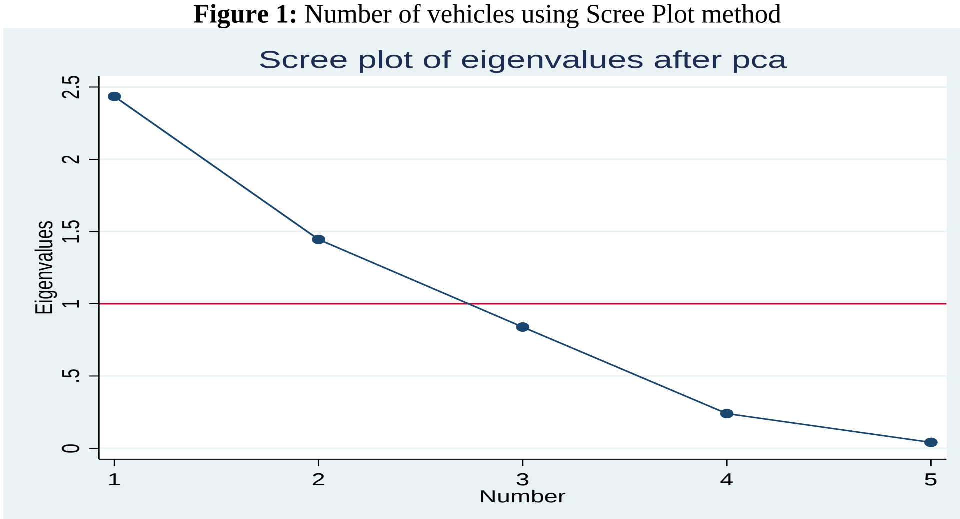
Table 3: Variance Matrix

Component	**Eigenvalue**	**Difference**	**Proportion**	**Cumulative**
Comp1	2.43513	0.989817	0.487	0.487
Comp2	1.44531	0.606418	0.2891	0.7761

Comp3	0.838891	0.598932	0.1678	0.9439
Comp4	0.239958	0.199241	0.048	0.9919
Comp5	0.0407174	.	0.0081	1

Source: Prepared by researchers using STATA 17 software

Figure 1: Number of vehicles using Scree Plot method



Source: Prepared by researchers using STATA 17 software

Table 04: Determining the number of components using the Kassiar method

Component	Variance	Difference	Proportion	Cumulative
Comp1	2.42392	0.967416	0.4848	0.4848
Comp2	1.45651	.	0.2913	0.7761

Source: Prepared by researchers using STATA 17 software

Table 05: Component matrix of variables after rotation

Variable	Comp1	Comp2	Unexplained
INT	0.6151	-0.0041	0.08249
MT	0.5751	-0.1149	0.1654
RD	0.0753	0.7598	0.1574
EDUs	0.1509	-0.6075	0.3881
EDUh	0.5124	0.2011	0.3262

Source: Prepared by researchers using STATA 17 software

By employing the rock curve and Kaiser's rule, the five variables, namely, the percentage of mobile phones used, internet usage, patents filed, secondary school enrollments, and tertiary education, can be summarized through two principal components called Comp1 and Comp2. The paper will employ Comp1 because it has the highest proportion of variance at 61.51%.

3.3 Principal Component Analysis (PCA) of Institutional Variables:

Table 06: Correlation Matrix for Institutional Variables

	CC	GE	PS	RQ	RL	VA
CC	1.0000					
GE	0.8004	1.0000				
PS	0.7093	0.7048	1.0000			
RQ	0.3786	0.3037	0.0349	1.0000		
RL	0.8055	0.7792	0.7400	0.2892	1.0000	
VA	0.8560	0.7305	0.6701	0.2612	0.7763	1.0000

Source: Prepared by researchers using STATA 17 software

Table 07: KMO Test for Institutional Variables

Variable	kmo
CC	0.8283
GE	0.9203
PS	0.8508
RQ	0.5746
RL	0.9048
VA	0.8640
Overall	**0.8581**

Source: Prepared by researchers using STATA 17 software

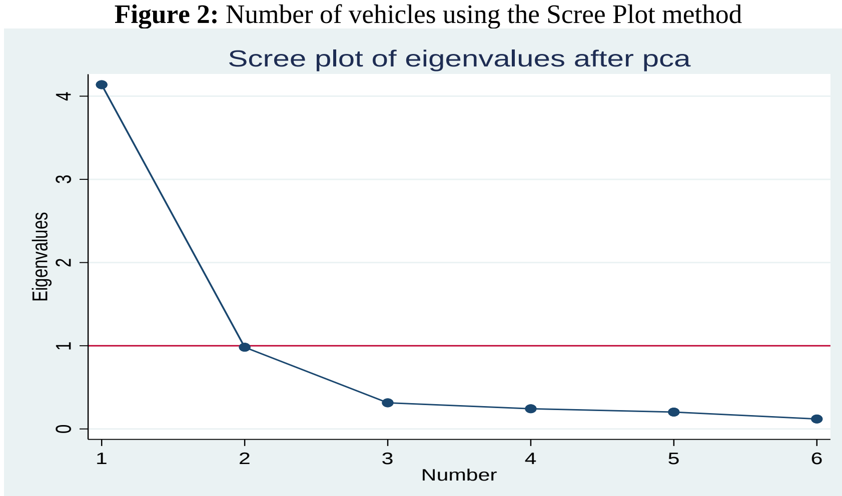
It can be seen from the correlation matrix that all the variables are positively correlated. The value of the Kaiser-Meyer-Olkin (KMO) test is found to be around 0.85, which meets the requirements of using the principal component analysis (PCA) approach.

Table 8: Variance Matrix

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	4,13814	3,15610	0,68970	0,68970
Comp2	0,98203	0,66784	0,16370	0,85340
Comp3	0,31420	0,07148	0,05240	0,90570
Comp4	0,24272	0,03980	0,04050	0,94620
Comp5	0,20292	0,08291	0,03380	0,98000
Comp6	0,12000	,	0,02000	1,00000

Source: Prepared by researchers using STATA 17 software

Figure 2: Number of vehicles using the Scree Plot method



Source: Prepared by researchers using STATA 17 software

Table 9: Determining the number of components using the Kassiar method

Component	Variance	Difference	Proportion	Cumulative
Comp1	4.13814	.	0.6897	0.6897

Source: Prepared by researchers using STATA 17 software

Table 10: Component matrix of variables after rotation

Variable	Comp1	Unexplained
CC	0,46140	0,11920
GE	0,44040	0,19740
PS	0,40530	0,32030
RQ	0,18090	0,86460
RL	0,44910	0,16530
VA	0,44110	0,19500

Source: Prepared by researchers using STATA 17 software

From the rock plot and Kaiser method, it can be seen that the six variables; anti-corruption, government effectiveness, regulatory quality, rule of law, political stability, and voice and accountability, can be shown to be contained in one single principal component which explains the most variance amounting to 68.97%.

3.4 Panel Unit Root Tests

In order to find out whether there is the presence of unit roots in the time series data for the variables under consideration, there are various tests that can be conducted. In the current research, only two such tests have been conducted; namely the LLC and IPS tests. The findings are given in the table below.

Table 11: Results of the LLC and IPS time series stability tests

IPS		LLC		
1st Difference	Level	1st Difference	Level	
/	-7.03684 (0.0000)	/	-5.52475 (0.0000)	**LnKE**
-4.78637 (0.0000)	0.85746 (0.8044)	-8.56330 (0.0076)	0.25616 (0.6011)	**LnINST**
-5.11167 (0.0000)	0.79308 (0.7861)	-4.44767 (0.0000)	0.58482 (0.7207)	**LnGDPP**
-4.2477 (0.0000)	-0.38822 (0.3489)	-2.56686 (0.0051)	2.05307 (0.9800)	**LnFDI**
/	-1.38185 (0.0835)	/	-2.08607 (0.0185)	**LnTO**

Source: Prepared by researchers using STATA 17 software

The probability is shown by the value enclosed in brackets, while the statistic is indicated by the value shown above the bracketed value. The series is said to be stationary if the probabilities of all the statistics are less than 5%. This shows that the series LnKE and LnTO are stationary at the level while the series LnINST, LnGDPP, and LnFDI are stationary at first difference.

3.5 **Panel Data Estimation Methods**

We estimate the aforementioned model using three different approaches to estimating panel data models: pooled ordinary least squares (POLS), fixed effects (FE), and random effects (RE). The assumptions and consequences of each approach are as follows:

- Pooled OLS: Assumption of identical intercepts and slopes for all countries. Hence, there is no consideration of country heterogeneity. Neglect of such heterogeneity may result in omitted variable bias in case the unobserved country heterogeneity is related to the explanatory variables.
- Fixed effects (FE): Country specific intercepts allow control of time-invariant country heterogeneity. FE should be used in case the country heterogeneity is related to the explanatory variables but does not permit the estimation of the effects of time-invariant variables.
- Random effects (RE): The country-specific effects are assumed to be random draws from the distribution, thus allowing estimation of the within and between variation. RE is more efficient than FE, but assumes that the country-specific effects are uncorrelated with the explanatory variables.

In order to choose the appropriate estimation approach, we undertake three formal tests of specification (Table 13). First, the F-test for fixed effects compares POLS and FE under the null hypothesis that all country-specific intercepts are equal. Second, the Breusch-Pagan Lagrange Multiplier (LM) test compares POLS and RE with the null hypothesis of zero variance of country-specific effects. Third, the Hausman test compares FE and RE under the null hypothesis that the country-specific effects are uncorrelated with the explanatory variables and, thus, supports RE. Based on these tests, we chose the most appropriate model and conducted tests for autocorrelation and heteroskedasticity.

Table 12: Results of the estimation of the pooled regression model and the fixed and random effects model

Number of countries: 6				(Dependent variable: KE (Knowledge Economy		
Total views: 154				(Study period: (1996-2024		
Random Effects Model		**Static Effects Model**		**cumulative regression**		**explanatory variables**
P-value	**Coef**	**P-value**	**Coef**	**P-value**	**Coef**	
0.030	0.26358	0.214	0.13662	0.013	0.32659	**LnINST**
0.000	0.95194	0.000	0.74627	0.000	0.74875	**LnGDPP**
0.470	0.02207	0.534	0.01656	0.892	-0.00486	**LnFDI**
0.029	0.32731	0.000	1.57899	0.101	0.18872	**LnTO**
0.000	-9.72205	0.000	-12.93108	0.000	-6.78195	**Constant**
0.5764		0.6441		0.3590		**R-squared**
				0.3418		**Adj R-squared**
157.29		65.15		20.86		**F-test**

0.0000	0.0000	0.0000	**Prob> F**

Source: Prepared by researchers using STATA 17 software

Table 13: Tests for selecting the appropriate model

Test	Probability	calculated value	suitable model
Ficher	29.69	0.0000	Fixed effects
Breusch and Pagan	138.49	0.0000	Random effects
Hausman	32.15	0.0000	Fixed effects

Source: Prepared by researchers using STATA 17 software

In order to determine which model should be used in our analysis, the comparison will begin with the comparison between the pooled regression model and the fixed-effects regression model. According to the Fisher test, the probability of the fixed effects statistic is less than 5%, thus, the fixed-effects regression model can be used. Further on, the comparison of the pooled model and the random effects model is done by applying the Breusch-Pagan test; the probability of the random effects statistic is also lower than 5%, therefore, the latter is preferred in our case. The distinction between the two models mentioned above is made with the help of the Hausman test, where the probability is less than 5% once again. The findings are illustrated in Table 13.

3.6 Model Validity Testing

In order to determine whether the model is valid or not, the following series of tests were conducted, providing the following outcomes:

1) Wooldridge test for autocorrelation: The p-value corresponding to this test is less than 5%, thus demonstrating the existence of autocorrelation (see Appendix 6).

2) Heteroskedasticity test: The p-value corresponding to this test is less than 5%, which means that there is heteroskedasticity (see Appendix 7).

3) Pesaran test for cross-sectional independence: The p-value corresponding to this test is greater than 5%, which means that there is no cross-sectional dependence (see Appendix 8).

3.7 Panel-Corrected Errors

Based on the previous analysis, the model (fixed effect model) being estimated is found to have auto-correlation and heteroskedasticity problems. Therefore, the problems are taken care of by correcting the errors using the method of Panel-Corrected Standard Errors (PCSE). The method takes care of inhomogeneous variance and modifies the standard errors of the parameters. The end model thus becomes:

$$LnKE = -12.931 + 0.136\ LnINST + 0.746\ LnGDPP + 0.016\ LnFDI + 1.578TO\ldots\ldots(02)$$

As seen from Appendix No. (09), which gives an error correction model, the value of p of Fisher statistic is 0.0008, which is less than 5%, and thus indicates significance of the model. Further, the coefficient of determination, R^2, is 0.6441, suggesting that the independent variables explain 64.41% of the variability of the dependent variable, while the rest 35.59% variability comes from other sources not considered in the model. The p-value of Fisher statistic in case of regressors is less than 5%, indicating that all the variables except foreign direct investment are significant.

3.9 Interpretation of results:

The model generated (Equation No. 02) produces the following findings:

First: Explaining the impact of the Institutions Index (INST) on the knowledge economy

The study results show a positive relationship between the Institutions Index and the Knowledge Economy Index such that a unit increase in the value of the Institutions Index is related to a 0.136 unit increase in the value of the Knowledge Economy Index. This implies that institutional quality is crucial in creating an environment that facilitates the knowledge economy. According to North (1990), good institutions minimize uncertainty and create the necessary legal structures for protecting intellectual property rights, thus encouraging investments in research and development (Schiliro 2012). Also, good governance and regulation improve efficiency in public service delivery, including education and digital infrastructure (Kaufmann, Kraay and Mastruzzi 2010). This finding is supported by the existing empirical literature. For example, according to Padash and Khodapanah (2015), the rule of law, political stability, and anti-corruption measures have more impact on the knowledge economy. Also, Andrés et al. (2015) found out that the quality of public institutions is the most important factor for success. The analysis shows that the six countries that have high rankings in the Institutional index have used their institutional superiority to create knowledge superiority, ranking highest in the Global Knowledge Index in consecutive years (UNDP 2025).

Secondly, explaining the impact of GDP per capita

The results show the presence of a very high positive correlation between the GDP per capita and the knowledge economy index, implying that an increase in the GDP per capita by 1 unit leads to the corresponding increase in the knowledge economy by 0.746 units. This influence is explained by the complementary nature of income and investments in the knowledge economy pillars (education, research and development, digital infrastructure) (Dahlman 2006). The results correspond to human capital theory (Becker 1964) and the literature on endogenous growth (P. Romer 1990) emphasizing that high income implies more investment in education and innovations. High individual income implies better opportunities for acquiring skills and, thus, contributes to higher productivity and innovations (World 2007). The result shows that leadership in the knowledge economy among the considered countries is determined by the higher income and the investments in highly developed education, research, and digital systems making this variable the most influential in the model.

Third, interpreting the impact of foreign direct investment (FDI)

The findings suggest a positive relationship between FDI and the knowledge economy index, where one unit of FDI increases the knowledge economy by 0.016 units. However, the effect is small and insignificant. This result supports the idea that the studied countries are developed economies exporting rather than importing technology investments (Borensztein 1998). Also, FDI may have its effect on knowledge economy via indirect channels that require a long-term horizon (Schiliro 2012). Knowledge accumulation in the advanced economies is more dependent on innovations created domestically rather than technologies introduced from outside (Coe 1995). According to the literature, the impact of FDI also depends on the quality of institutions in the host country (Hamid 2024). Altogether, the results show that FDI does not play an important role in shaping the knowledge economy in the developed countries; instead, they depend on investments in research and development and high-quality education.

Fourth, interpreting the effect of trade openness (TO)

Fourth, concerning the influence of trade openness (TO): the findings show a high positive relationship between trade openness and Knowledge Economy Index. In particular, a one unit increase in the TO index leads to 1.578 units increase in the Knowledge Economy, which is the highest coefficient in the model. Thus, it shows how important it is for a country to be integrated in the world economy to facilitate knowledge and technology transfer. International trade is an important channel through which knowledge and technology are transferred (Grossman 1991). Knowledge embodied in capital goods is transferred through imports, while exports promote innovation because of international competition. Trade openness makes domestic competition higher and, therefore, forces the firm to enhance its productivity (Frankel 1999). Recent studies suggest that the influence of trade openness is greater for countries with well-developed institutions (Boumediene et Elamine 2026). The TO index has made possible development of the knowledge economy due to technology transfer, knowledge sharing, and creation of a good investment environment. These countries are among the most open in the world, thus facilitating knowledge transfers and attracting skilled workers and, hence, making trade openness the most effective tool to create knowledge economy in them.

Fifth: Integrated analysis of results

variable	coefficient	Significance	relative importance	Theoretical interpretation
Trade openness (TO)	1.578	Significant	First	Primary channel through which technology and knowledge are transferred across borders.
GDP per capita	0.746	Significant	Second	Government's ability to invest in the basic building blocks of the knowledge economy.
Institutions (INST)	0.136	Significant	Third	Offering an environment and incentive for innovation.
Foreign Direct Investment (FDI)	0.016	Insignificant	Fourth	Less Impact in Developed Nations Compared to Internal Factors

3.8 The significance of the result for the countries under study:

All countries included in this study have been found to be characterized by openness in terms of trade. The reason for this is that foreign trade constitutes a considerable portion of their gross domestic product. Through openness in their trade practices, these countries have been able to benefit from the transfer of knowledge, recruit skilled labor from other countries, and develop and conduct research and development through cooperation with their trade partners. Furthermore, they are members of international organizations including the World Trade Organization (WTO), as well as regional organizations such as the European Union.

4 CONCLUSION

This paper concludes that institutional quality serves as both the foundation and precondition for the creation of sustainable knowledge-based economy. Using panel models and PCA analysis of a sample of leading countries over the period of 1996-2024, the results reveal that strong and effective institutions positively affect the knowledge economy (β = 0.136). This effect is even more pronounced when institutions work in combination with trade openness (β = 1.578) and high income levels (β = 0.746). Trade openness appears to be the most critical factor influencing technology and knowledge transfer across borders, whereas per capita GDP becomes an important determinant due to its ability to provide resources required for investments in education, research, and development. Foreign direct investments have a limited impact (β = 0.016) in these developed countries and indicate a move towards the use of endogenous capabilities as the driver for innovation and creativity.

These results prove that the leading positions of the analyzed countries in the Global Knowledge Index were achieved due to consistent efforts rather than temporary factors. The results are achieved as a result of years of development of strong and effective institutions, open economies incorporated into the international economic environment, and highly-developed infrastructure of education and research. The results of this research indicate the need to integrate institutional, economic, and trade aspects while developing a strategy for knowledge development, since none of the dimensions is effective without integration with the other two.

4.1 The following policy recommendations can be formulated based on the study findings:

1. Institutional Quality Improvement: Countries striving to transform into a knowledge economy must focus on improving indicators related to governance, paying special attention to the rule of law, anti-corruption, and government effectiveness. All these variables are the cornerstone on which all other pillars should be built. The findings of the study reveal that good institutions are not only contributing to the process but are an essential precondition to making investments in education and technologies pay off by actually leading to knowledge creation.
2. Increasing Investments in Education, Research & Development: Per capita GDP proves to be a very influential indicator (β = 0.746), emphasizing the importance of growing income levels through sustainable economic development and allocating a sufficient part of resources to education, R&D, and ICT infrastructure.
3. Support of Trade Openness: Trade openness is the most effective means of transferring knowledge and technologies (β = 1.578). Thus, it is necessary to adopt a liberal trade policy, sign trade agreements that allow the transfer of technology and protection of intellectual property rights, as well as increasing the economy's absorptive capacity to absorb imported knowledge and turn it into its own capabilities.
4. Creation of Favorable Environment for Knowledge-Related Investments: Even though the effect of FDI is relatively weak in the current sample (β = 0.016, not statistically significant), FDI can be still quite important for developing countries as an indirect channel of technology transfer in combination with improvements in the institutional quality of the economy. It is wise to use FDI in industries with intensive technological component.
5. Integration of Policies: The standard model shows that it is the interaction between institutions, trade openness, and income, and not any of these factors independently, that creates a knowledge economy. This fact makes it clear that policy formulation must be comprehensive and holistic, taking these variables into account as an organic whole.

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Appendices:

Appendix 01: Estimating the Combination Model

```
. reg LnKE LnINST LnGDPP LnFDI  LnTO

      Source |       SS           df       MS      Number of obs   =       154
-------------+----------------------------------   F(4, 149)       =     20.86
       Model |  13.6263214         4  3.40658035   Prob > F        =    0.0000
    Residual |  24.3312621       149  .163297061   R-squared       =    0.3590
-------------+----------------------------------   Adj R-squared   =    0.3418
       Total |  37.9575835       153  .248088781   Root MSE        =     .4041

------------------------------------------------------------------------------
        LnKE | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
      LnINST |   .3265928   .1302905     2.51   0.013     .0691371    .5840486
      LnGDPP |   .7487593   .1059757     7.07   0.000     .5393499    .9581686
       LnFDI |  -.0048618   .0357085    -0.14   0.892    -.0754223    .0656986
        LnTO |   .1887236   .1144488     1.65   0.101    -.0374287     .414876
       _cons |  -6.781958    1.06986    -6.34   0.000    -8.896016   -4.667899
------------------------------------------------------------------------------
```

Appendix 02: Estimation of the Fixed Effects Model

```
. xtreg LnKE LnINST LnGDPP LnFDI LnTO, fe

Fixed-effects (within) regression               Number of obs     =        154
Group variable: pays                            Number of groups  =          6

R-squared:                                      Obs per group:
     Within  = 0.6441                                         min =         22
     Between = 0.0511                                         avg =       25.7
     Overall = 0.0774                                         max =         29

                                                F(4,144)          =      65.15
corr(u_i, Xb) = -0.8790                         Prob > F          =     0.0000

------------------------------------------------------------------------------
        LnKE | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
      LnINST |   .1366263   .1095778     1.25   0.214    -.0799624    .3532149
      LnGDPP |   .7462785   .1127308     6.62   0.000     .5234576    .9690994
       LnFDI |   .0165603   .0265375     0.62   0.534    -.0358931    .0690137
        LnTO |   1.578999    .257021     6.14   0.000     1.070977     2.08702
       _cons |  -12.93108   1.064583   -12.15   0.000    -15.03531   -10.82685
-------------+----------------------------------------------------------------
     sigma_u |  .88291484
     sigma_e |  .28845291
         rho |  .90355759   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(5, 144) = 29.69                     Prob > F = 0.0000
```

Appendix 03: Estimating the Random Effects Model

```
. xtreg LnKE LnINST LnGDPP LnFDI LnTO, re

Random-effects GLS regression                   Number of obs     =        154
Group variable: pays                            Number of groups  =          6

R-squared:                                      Obs per group:
     Within  = 0.5764                                         min =         22
     Between = 0.0786                                         avg =       25.7
     Overall = 0.3293                                         max =         29

                                                Wald chi2(4)      =     157.29
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000

------------------------------------------------------------------------------
        LnKE | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
      LnINST |   .2635805   .1216089     2.17   0.030     .0252314    .5019297
      LnGDPP |   .9519443   .1104488     8.62   0.000     .7354686     1.16842
       LnFDI |   .0220763   .0305371     0.72   0.470    -.0377754    .0819279
        LnTO |   .3273152   .1497327     2.19   0.029     .0338445    .6207858
       _cons |  -9.722054   1.090223    -8.92   0.000    -11.85885   -7.585256
-------------+----------------------------------------------------------------
     sigma_u |  .12267247
     sigma_e |  .28845291
         rho |   .1531601   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Appendix 04: Lagrange Multiplier Test

```
Breusch and Pagan Lagrangian multiplier test for random effects

        LnKE[pays,t] = Xb + u[pays] + e[pays,t]

        Estimated results:
                         |       Var     SD = sqrt(Var)
                ---------+-----------------------------
                    LnKE |   .2480888       .4980851
                       e |   .0832051       .2884529
                       u |   .0150485       .1226725

        Test: Var(u) = 0
                             chibar2(01) =   138.49
                          Prob > chibar2 =   0.0000
```

Appendix 05: Hausmann Test

```
. hausman fixed_model random_model

                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             | fixed_model  random_model     Difference       Std. err.
-------------+----------------------------------------------------------------
      LnINST |    .1366263     .2635805       -.1269542               .
      LnGDPP |    .7462785     .9519443       -.2056658        .0225678
       LnFDI |    .0165603     .0220763        -.005516               .
        LnTO |    1.578999     .3273152        1.251684        .2089017
------------------------------------------------------------------------------
                           b = Consistent under H0 and Ha; obtained from xtreg.
            B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

    chi2(4) = (b-B)'[(V_b-V_B)^(-1)](b-B)
            =  32.15
Prob > chi2 = 0.0000
(V_b-V_B is not positive definite)
```

Appendix 06: Self-Attachment Detection Test

```
. xtserial LnKE LnINST LnGDPP LnFDI LnTO

Wooldridge test for autocorrelation in panel data
H0: no first-order autocorrelation
    F(  1,       5) =   2995.265
           Prob > F =      0.0000
```

Appendix 07: Heterogeneity Detection Test

```
Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (6)  =          116.96
Prob > chi2 =          0.0000
```

Appendix 08: Test for detecting correlation between sections

```
. xtcsd, pesaran abs


Pesaran's test of cross sectional independence =    15.592, Pr = 0.0000

Average absolute value of the off-diagonal elements =    0.841
```

Appendix 09: Error Correction Form

```
. xtreg LnKE LnINST LnGDPP LnFDI  LnTO, fe vce(robust)

Fixed-effects (within) regression               Number of obs     =        154
Group variable: pays                            Number of groups  =          6

R-squared:                                      Obs per group:
     Within  = 0.6441                                         min =         22
     Between = 0.0511                                         avg =       25.7
     Overall = 0.0774                                         max =         29

                                                F(4,5)            =      34.84
corr(u_i, Xb) = -0.8790                         Prob > F          =     0.0008

                                  (Std. err. adjusted for 6 clusters in pays)
```

LnKE	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
LnINST	.1366263	.0626339	2.18	0.081	-.0243793	.2976318
LnGDPP	.7462785	.0967125	7.72	0.001	.4976711	.9948859
LnFDI	.0165603	.0174883	0.95	0.387	-.0283947	.0615153
LnTO	1.578999	.4407497	3.58	0.016	.4460156	2.711982
_cons	-12.93108	1.770493	-7.30	0.001	-17.48228	-8.379883
sigma_u	.88291484					
sigma_e	.28845291					
rho	.90355759	(fraction of variance due to u_i)				