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DIGITALISATION AND INTERNATIONAL TRADE TRANSFORMATION: A CROSS-COUNTRY CLUSTER ANALYSIS

The rapid development of digital technologies is reshaping international trade and strengthening the role of digitalisation in countries' competitiveness and global integration. This study aims to identify groups of countries with similar levels of digitalisation and trade transformation in goods and services and to assess the relationship between ICT development, trade transformation, and economic development. The research applies multivariate statistical analysis, including logarithmisation, standardisation, Principal Component Analysis, and K-means clustering. The optimal number of clusters was determined using the Calinski–Harabasz and Duda–Hart criteria based on 2023 data. The findings reveal a four-cluster structure for both merchandise and services trade and confirm a positive relationship between ICT development and international trade. The proposed approach can support cross-country comparisons and evidence-based digital and trade policy development.

Keywords: *digitalization, international trade, information and communication technologies, method of principal components, cluster analysis, digital economy.*

ЦИФРОВІЗАЦІЯ ТА ТРАНСФОРМАЦІЯ МІЖНАРОДНОЇ ТОРГІВЛІ: МІЖКРАЇННИЙ КЛАСТЕРНИЙ АНАЛІЗ

Стрімкий розвиток цифрових технологій суттєво змінює механізми функціонування міжнародної торгівлі, впливаючи на конкурентоспроможність країн та їх інтеграцію у світову економіку. Водночас рівень цифровізації й масштаби трансформації міжнародної торгівлі істотно відрізняються між країнами, що зумовлює необхідність комплексного дослідження взаємозв'язку між цими процесами. Метою дослідження є виявлення груп країн зі схожими характеристиками цифровізації та трансформації міжнародної торгівлі товарами і послугами, а також оцінка взаємозв'язку між розвитком інформаційно-комунікаційних технологій, торговельною трансформацією та рівнем економічного розвитку. Методологічною основою дослідження є багатовимірний статистичний аналіз. Для підготовки даних застосовано логарифмування, стандартизацію та метод головних компонент, що дозволило усунути мультиколінеарність і зменшити розмірність даних. Класифікацію країн здійснено методом K-means, а оптимальну кількість кластерів визначено за критеріями Calinski–Harabasz та Duda–Hart. Інформаційну базу становили інтегральні показники цифровізації та показники трансформації міжнародної торгівлі товарами і послугами за 2023 рік. Результати дослідження показали, що як для торгівлі товарами, так і послугами оптимальною є чотирикластерна структура, яка відображає істотні відмінності між країнами за рівнем цифровізації та торговельної трансформації. Встановлено позитивний зв'язок між розвитком ІКТ та обсягами міжнародної торгівлі. Водночас доведено, що масштаби торговельної діяльності визначаються не лише цифровізацією, а й розміром економіки, рівнем доходів, галузевою структурою та інтеграцією у глобальні ланцюги створення вартості. Високий рівень цифровізації характерний переважно для високодохідних економік. Практична цінність отриманих результатів полягає у можливості використання запропонованого підходу для оцінювання цифрової готовності країн, міжнародних порівнянь та

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обґрунтування державної політики у сфері цифрової трансформації, розвитку міжнародної торгівлі, підвищення конкурентоспроможності економіки й поглиблення інтеграції у світове господарство.

Ключові слова: *цифровізація, міжнародна торгівля, інформаційно-комунікаційні технології, метод головних компонентів, кластерний аналіз, цифрова економіка.*

JEL classification: *F14, O33, C38.*

Problem statement. The rapid expansion of digital technologies has fundamentally changed the conditions under which countries participate in international trade. Digital infrastructure, connectivity, and the adoption of information and communication technologies (ICT) increasingly determine the efficiency of production processes, market access, and the ability of firms to integrate into global value chains. At the same time, countries demonstrate substantial differences not only in the level of digital development but also in the extent to which digitalisation translates into transformations of international trade in goods and services.

These disparities raise an important research problem. Although countries with advanced digital infrastructure are generally expected to achieve higher trade performance, empirical evidence suggests that this relationship is far from uniform. Some highly digitalised economies exhibit relatively modest trade volumes because of their limited market size, whereas several emerging economies maintain substantial exports and imports despite only moderate levels of ICT development. Similarly, the determinants of merchandise trade may differ from those affecting trade in services, where digital capabilities, human capital, and participation in knowledge-intensive activities play a more prominent role.

The increasing heterogeneity of national development trajectories indicates that analysing digitalisation and trade separately is insufficient for understanding contemporary patterns of international economic integration. A comprehensive assessment requires considering both dimensions simultaneously while accounting for differences in countries' levels of economic development. Identifying groups of countries with similar combinations of digitalisation and trade characteristics makes it possible to reveal common development patterns, distinguish structural differences between economies, and assess whether digital transformation is accompanied by corresponding changes in international trade.

Addressing this problem is particularly relevant for designing policies aimed at strengthening countries' international competitiveness. A better understanding of how digitalisation is associated with transformations in merchandise and services trade can provide valuable evidence for developing strategies that promote digital inclusion, structural economic transformation, and more effective integration into the global economy.

Analysis of recent research and publications. In recent years, the impact of digitalisation on international trade has attracted considerable scholarly attention, covering a wide range of factors that shape the competitiveness of countries and businesses. Emphasis has been placed on the macroeconomic determinants of digital transformation. In particular, Wen J., Bibi Z., Gillani S., and Shafiq M. N. demonstrated that financial development, globalisation, economic growth, and international trade are important drivers of digital technology development, although the ability to benefit from digitalisation differs significantly between developed and developing countries [1]. Similar conclusions were reached by Ali Y., Wei L., and Khan H., who identified national digital innovation capacity, particularly digital skills, as a key determinant of digital trade development [2].

Another stream of research focuses on the impact of digitalisation on international trade performance. Zhang W., Tawiah D., Fumey M. P., Asongu S. A., and Adam A. G. found that the positive effect of digitalisation on export growth is realised only under conditions of high institutional quality [3]. Likewise, Ullah Q., Qiu Y., and Sami M. demonstrated that integration into global supply chains, the development of Green FinTech, and sustainable infrastructure promote digital trade while supporting sustainable economic growth [4]. Xiao Y., Liu W., and Ji H. showed that digital economy development stimulates export growth; however, this positive effect weakens as the digital gap between trading partners increases [5].

International trade digitalisation has also attracted attention among Ukrainian researchers. Hetmanenko O. O. and Fizheshi Y. Y. emphasised that digital transformation is a key driver of changes in international trade, and the digital divide affects countries' competitiveness and integration into global trade processes [6]. Shlapak A., Yatsenko O., Ivashchenko O., and others identified the digital divide, digital infrastructure, and the regulatory framework as the main determinants of international e-commerce development and countries' competitiveness [7]. Kharenko V. and Skrypnyk N. demonstrated that digitalisation enhances the efficiency of international trade and integration into global value chains but requires stronger digital infrastructure, cybersecurity, and regulation [8]. Duna N. G. argued that digitalisation creates new opportunities for international economic development while intensifying socio-economic disparities and global risks, requiring a comprehensive approach to digital transformation management [9]. Similarly, Prokhorova M. and Babiar showed that digital technologies improve foreign trade management and expand international business opportunities while underscoring the need to strengthen digital infrastructure, legal regulation, and cybersecurity [10].

Despite the significant number of studies devoted to the impact of digitalization on international trade, the results of existing scientific works are mainly focused on the analysis of individual aspects of this process, in particular the impact of digital technologies on exports, the development of digital trade, the introduction of individual digital tools in the activities of enterprises, cybersecurity or individual components of the digital economy. At the same time, a comprehensive assessment of the relationship between the level of digitalization of countries and the transformation

of international trade in goods and services at the global level remains insufficiently studied. There is no generalized typology of countries formed based on simultaneous consideration of indicators of digital development and transformation of international trade, which makes it difficult to identify groups of countries with similar characteristics and patterns of their development. It is the solution of this scientific problem that determines the purpose of this study.

Research objective. The objective of this study is to identify groups of countries with similar levels of digitalisation and transformations in international trade in goods and services using Principal Component Analysis (PCA) and K-means cluster analysis, and to examine the relationship between ICT development, trade transformation, and countries' levels of economic development.

Research methods. To achieve the research objective, a set of general scientific and special methods of economic and statistical analysis was used. Methods of analysis and synthesis were used to study the theoretical foundations of the digitalization of international trade, generalize the results of modern scientific research and form the conceptual basis of the study. The systematic approach was used to consider digitalization and transformation of international trade as interrelated processes that are formed under the influence of technological, economic and institutional factors. The comparative method was used to compare the digitalization levels, international trade and economic development indicators for different countries. Statistical data processing methods (logarithmization and standardization) were used to prepare the data for multidimensional analysis, eliminate the influence of different scales of measurement of indicators and ensure their comparability. The Principal Component Analysis (PCA) method was used to reduce the dimensionality of the data, eliminate multicollinearity between digitalization indicators and form independent components suitable for cluster analysis. The cluster analysis using the K-means method was used to group countries by a set of indicators of digitalization and transformation of international trade in goods and services, which contributed to the identification of countries with similar development characteristics. The Calinski–Harabasz and Duda–Hart criteria were used to determine the optimal number of clusters and check the quality of the classification. Generalization and graphical visualization methods were used to interpret the results of cluster analysis, assess the relationship, and present the results in tabular and graphical forms.

Presentation of the main research results. The economic diversity of the studied countries may indicate a discrepancy between the level of transformation in trade in goods and services and the overall level of digitalisation. To test this hypothesis, a cluster analysis is conducted using five indicators: three digitalisation indicators and two indicators reflecting economic transformations in trade in goods and services. The K-means clustering method is applied, consisting of three sequential stages, each with a clear mathematical and substantive justification: logarithmisation of variables whose distributions deviate from normality; standardisation of all variables; dimensionality reduction using Principal Component Analysis (PCA). All calculations are performed in Stata SE19.

The dataset comprises composite indicators of merchandise exports and imports constructed using data from the World Trade Organization (WTO) [11], composite indicators of services exports and imports based on the United Nations Conference on Trade and Development (UNCTAD) database [12], and three integral digitalisation indicators developed by the International Telecommunication Union (ITU) [13]: the Universal Connectivity Pillar (UCP), the Meaningful Connectivity Pillar (MCP), and the ICT Development Index (IDI). Owing to data availability, the analysis covers 128–131 countries, excluding Antigua and Barbuda, Belize, Burundi, Fiji, Guyana, India, Nepal, New Caledonia, Niger, and Yemen. The analysis is based on 2023 data for both merchandise and services trade.

Because the sample includes countries with substantially different levels of economic development, the distributions of export and import transformation indicators are strongly right-skewed, unlike the ICT Development Index, which is close to a normal distribution. Therefore, the trade transformation variables are logarithmised. This transformation preserves the ranking of countries while reducing the scale differences to improve clustering performance.

The variables are then standardised using Z-scores, which is required for both PCA and K-means. Since the variables are measured on different scales, standardisation prevents trade indicators from dominating the Euclidean distance used by the clustering algorithm.

At the third stage, PCA addresses multicollinearity. The correlations among UCP, MCP, and ICT range from 0.89 to 0.98, indicating that they largely measure the same phenomenon. Including them directly in clustering would overestimate the contribution of digitalisation relative to trade. PCA resolves this issue by transforming the five original variables into uncorrelated principal components.

Thus, logarithmisation, standardisation, and PCA jointly ensure reliable clustering by eliminating scale effects, equalising the contribution of variables, and removing information redundancy caused by multicollinearity.

To determine the optimal number of principal components, the eigenvalues and explained variance are analysed. The PCA results are presented in Table 1.

Table 1

PCA results: eigenvalues and component variance

Component	Eigenvalue	Difference	Dispersion	Cumulative dispersion
Comp1	3.88	2.91	0.78	0.78
Comp2	0.97	0.86	0.19	0.97
Comp3	0.11	0.08	0.02	0.99
Comp4	0.03	0.03	0.00	1.00
Comp5	0.01	0.00	0.00	1.00

Source: developed by the authors.

The first two principal components explain 97.1% of the total variance (Table 1). The first component (78%) reflects the overall level of national development, as all five variables have similar positive loadings (0.40–0.48). The second component (19.4%) differentiates countries with high trade volumes and moderate digitalisation from those with advanced digitalisation but relatively lower trade volumes. Consequently, the first two components are retained for clustering. This choice is also supported by the scree plot and the Kaiser criterion (Fig. 1).

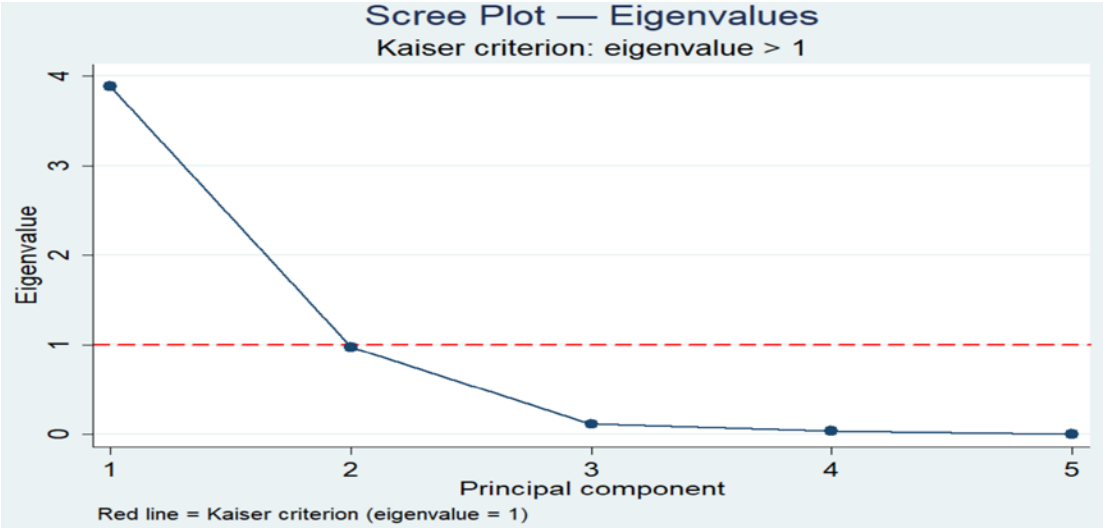

Fig. 1. Scree plot for digitalisation indicators and transformations of exports and imports of goods

Source: developed by the authors.

Because K-means requires a predefined number of clusters, the optimal solution is assessed using the Calinski–Harabasz (CH) and Duda–Hart criteria (Table 2).

Table 2

Calinski–Harabasz (CH) and Duda–Hart criteria

Number of clusters	Criterion CH	Duda-Hart
k=1	-	0.55
k=2	168.32	0.45
k=3	222.85	0.85
k=4	214.03	0.93
k=5	214.32	0.41
k=6	212.61	0.52
k=7	217.69	0.49
k=8	212.46	0.49
k=9	211.39	0.76
k=10	178.24	0.69

Source: developed by the authors.

Although the Calinski–Harabasz criterion reaches its maximum at three clusters, the Duda–Hart criterion indicates a four-cluster solution. The latter was selected because it provides better statistical validation and greater economic interpretability. As shown in Table 3, all variables significantly contribute to cluster formation ($p < 0.05$), confirming the robustness of the four-cluster solution, whereas the three-cluster alternative showed weaker discriminatory performance. Therefore, the four-cluster solution was considered the most appropriate for subsequent analysis.

Table 3

Statistical significance of variables in cluster formation

Variable	F-criterion	p-value
UCP	170.88	0.00
MCP	176.99	0.00
ICT	235.94	0.00
Transform_ExpProd	210.05	0.00
Transform_ImpProd	120.97	0.00

Source: developed by the authors

The average values of the variables within each cluster are presented in Table 4. Cluster 4 exhibits the highest average values for all five variables, indicating the strongest combination of digitalisation and trade transformation. It is followed by Cluster 1, while Clusters 2 and 3 demonstrate progressively lower levels across both dimensions.

Table 4

Average values of variables by cluster

Cluster	UCP	MCP	ICT	Transform_ExpProd	Transform_ImpProd
1	82.26	90.72	86.49	1199.69	3123.70
2	67.35	80.58	73.96	100.58	676.07
3	30.27	49.47	39.88	88.34	647.57
4	86.84	92.08	89.45	27795.89	36202.50
Total	69.85	80.73	75.29	7654.53	10658.97

Source: developed by the authors.

A visual representation of the distribution of countries across the four clusters is presented in Figure 2.

Cluster 1 (37 countries) is the most homogeneous in terms of income structure, consisting predominantly of high-income (22 countries) and upper-middle-income (9 countries) economies, with only six lower-middle-income countries and no low-income countries. It mainly includes the Baltic states, developed European economies, the Middle East, and several upper-middle-income countries in Latin America and Eastern Europe.

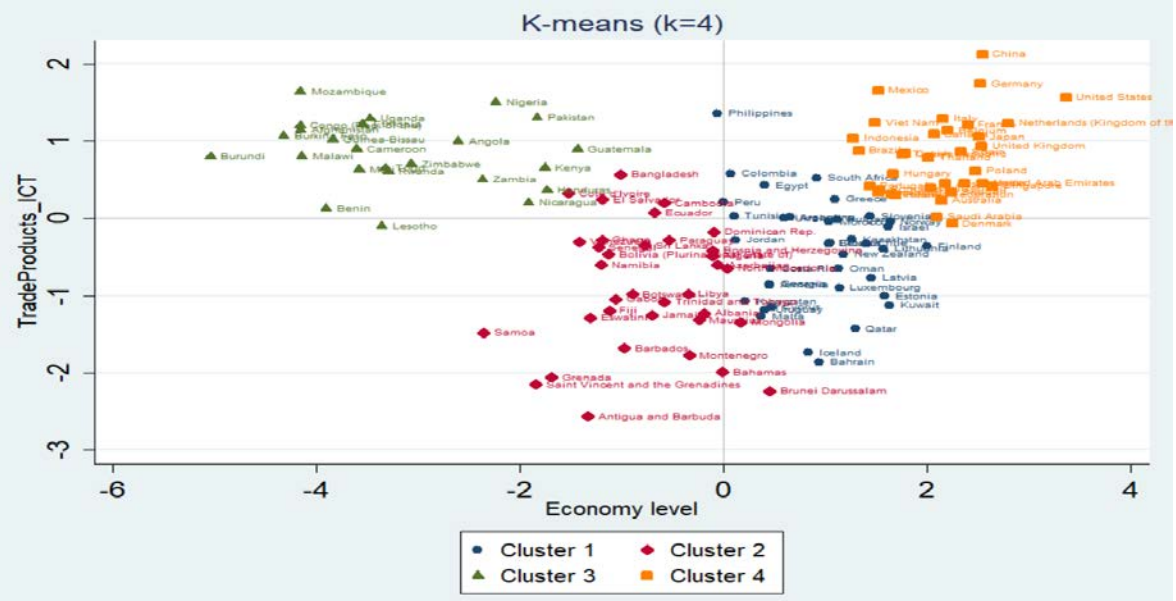

Fig. 2. Distribution of countries across four clusters based on digitalisation indicators and transformations in merchandise exports and imports

Source: developed by the authors.

Cluster 2 (36 countries) is the most economically diverse, although it is dominated by upper-middle-income economies (21 countries). It also includes ten lower-middle-income and five high-income countries, while low-income economies are absent. This cluster is characterised by moderate digitalisation and relatively low trade transformation indicators.

Cluster 3 (24 countries) represents the least developed economies. It comprises ten low-income and twelve lower-middle-income countries, with only two upper-middle-income economies and no high-income countries. This cluster reflects the lowest levels of both digitalisation and trade transformation.

Cluster 4 (34 countries) includes the world's most advanced economies and is dominated by high-income countries (25 of 34). It encompasses the leading economies of Western Europe, North America, and the Asia-Pacific region, together with several large upper-middle-income economies, including China, Brazil, Mexico, Indonesia, Türkiye, and Malaysia. Viet Nam is the only lower-middle-income country in this cluster.

Overall, the clustering reveals a clear relationship between ICT development, trade transformation, and income level. Cluster 4 concentrates predominantly high-income economies (74%), Cluster 1 combines developed and several middle-income countries (59% high-income), Cluster 2 is dominated by upper-middle-income countries (58%), while Cluster 3 consists almost entirely of low- and lower-middle-income economies (92%).

Figures 3 and 4 present scatter plots illustrating the relationship between ICT development (ICT Development Index, IDI) and the volumes of merchandise exports and imports across the four identified clusters.

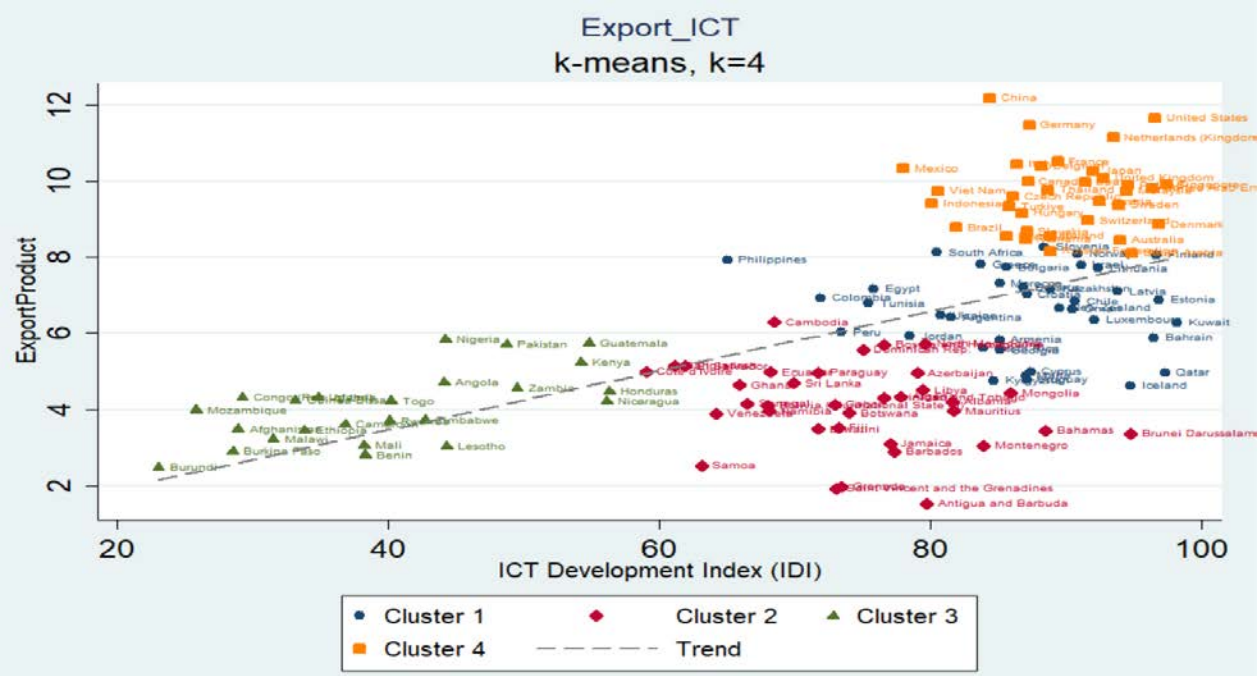

Fig. 3. Relationship between ICT development and merchandise exports by cluster
Source: developed by the authors.

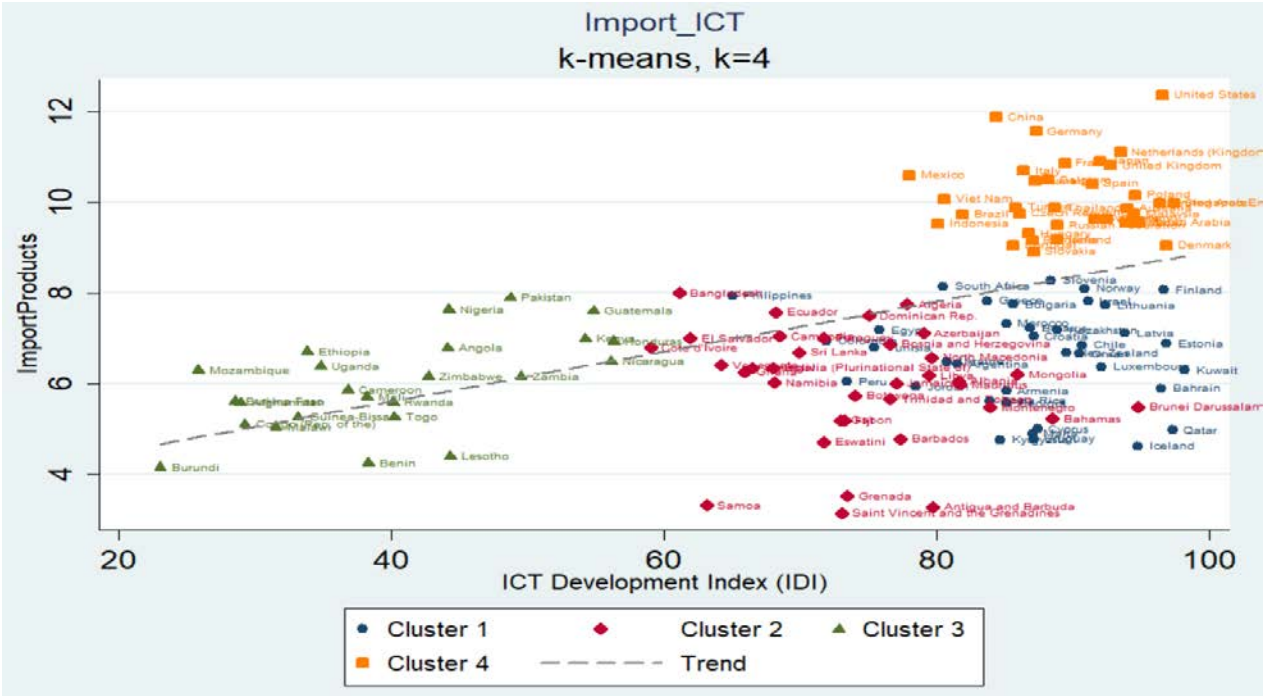

Fig. 4. Relationship between ICT development and merchandise imports by cluster
Source: developed by the authors.

Figure 3 demonstrates clear differences between the identified clusters. Cluster 1 is concentrated in the high-IDI range (approximately 65–95) with medium-to-high export volumes. Several countries, such as the Philippines, exhibit export levels substantially above the cluster average, whereas highly digitalised small economies (e.g., Bahrain, Qatar, and Iceland) maintain relatively modest merchandise exports, reflecting the limited size of their domestic economies.

Cluster 2 forms the broadest horizontal distribution, with countries exhibiting moderate-to-high ICT development but consistently low export volumes. This pattern is particularly evident among small island economies and other countries whose limited economic scale constrains merchandise exports despite relatively advanced digitalisation.

Cluster 3 occupies the lower-left section of the figure, combining low ICT development with generally low export volumes. Nevertheless, several large economies, including Nigeria and Pakistan, deviate from the overall

trend by recording comparatively high merchandise exports despite modest levels of digitalisation, largely reflecting their resource or manufacturing specialisation.

Cluster 4 dominates the upper-right quadrant and combines the highest ICT development with the largest merchandise export volumes. China and the United States clearly stand out as global leaders, followed by the major European economies and Japan. Large upper-middle-income countries such as Brazil, Indonesia, Mexico, and Viet Nam also demonstrate substantial export volumes despite lower ICT levels than the most advanced economies.

The fitted trend line in Figure 3 confirms a statistically significant positive relationship between ICT development and merchandise exports. However, the considerable dispersion around the regression line indicates that digitalisation alone does not determine export performance, with economic size remaining an important explanatory factor.

A similar pattern is observed in Figure 4 for merchandise imports. Cluster 1 includes highly digitalised countries with moderate-to-high import volumes, while several small high-income economies combine excellent ICT performance with relatively limited imports because of their market size. Cluster 2 again displays the greatest dispersion, with countries characterised by moderate ICT development but relatively low import volumes. Large developing economies, including Bangladesh and the Philippines, constitute the main positive deviations from the cluster average because of their substantial domestic demand.

Cluster 3 remains concentrated at low ICT levels but exhibits considerable variation in import volumes. Countries such as Pakistan, Nigeria, Ethiopia, and Angola import significantly more than other economies with comparable digitalisation, reflecting the influence of population size and domestic market demand. Cluster 4 again occupies the upper-right part of the figure, with the United States representing the largest importer, followed by China and the major European economies. Smaller developed countries, despite having some of the highest ICT levels, record more moderate import volumes because of their limited economic scale.

Overall, Figure 4 confirms the positive relationship between ICT development and merchandise imports. Together with the export analysis, these results demonstrate that countries with higher levels of digitalisation generally participate more actively in international merchandise trade. Nevertheless, the absolute scale of trade is also strongly determined by the size of the economy, allowing large countries with only moderate ICT development to outperform smaller but highly digitalised economies in absolute trade volumes.

A similar cluster analysis was conducted using digitalisation indicators together with the transformations of services exports and imports. Owing to data availability, the analysis was performed for the selected sample of countries using 2023 data. As with merchandise trade, the distributions of services export and import indicators are right-skewed, whereas the ICT indicator is much closer to a normal distribution. Therefore, the service trade variables were logarithmised before clustering. The high correlations among the digitalisation indicators were addressed using PCA. The PCA results are presented in Table 5.

Table 5

PCA results: eigenvalues and component variance

Component	Eigenvalue	Difference	Dispersion	Cumulative dispersion
Comp1	4.01	3.26	0.80	0.80
Comp2	0.74	0.58	0.15	0.95
Comp3	0.16	0.06	0.03	0.98
Comp4	0.09	0.09	0.02	1.00
Comp5	0.01	0.00	0.00	1.00

Source: developed by the authors.

The first two principal components explain 95% of the total variance (Table 5). The first component (80%) reflects the overall level of national development, with all five variables exhibiting similar positive loadings (0.41–0.48). The second component (15%) distinguishes countries with relatively high trade volumes but moderate digitalisation from those with advanced digitalisation and comparatively lower trade volumes. Consequently, the first two components were retained for further analysis.

The scree plot (Fig. 5) indicates that the first principal component satisfies the Kaiser criterion. Nevertheless, retaining the first two components provides a more representative basis for clustering. The corresponding Calinski–Harabasz (CH) and Duda–Hart statistics are reported in Table 6.

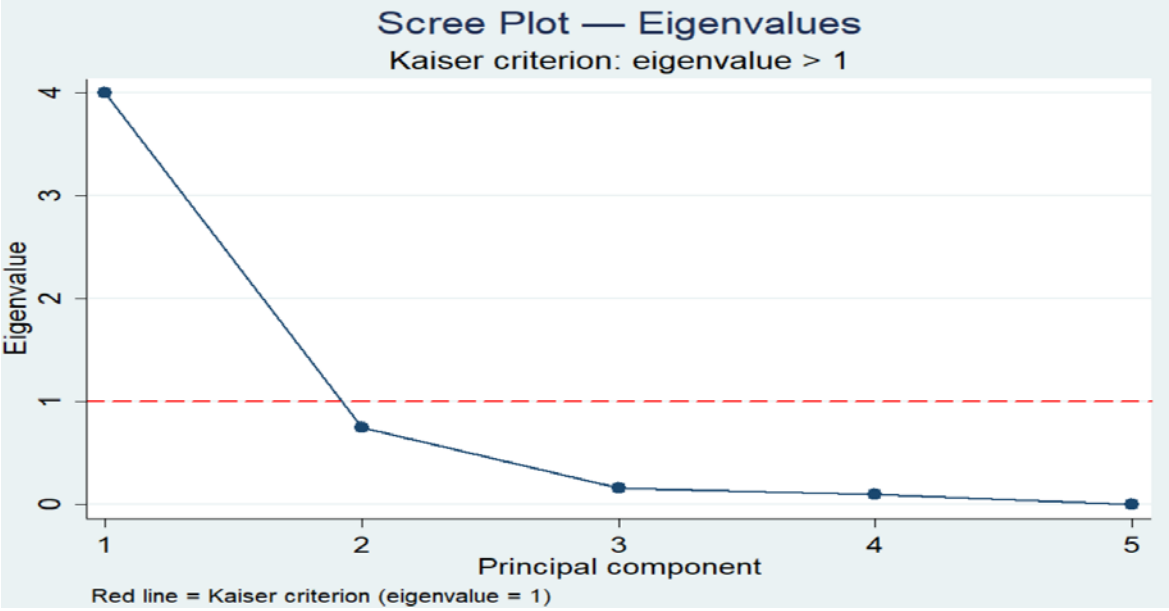

Fig. 5. Scree plot for digitalisation indicators and transformations of services exports and imports

Source: developed by the authors.

Table 6

Calinski–Harabasz (CH) and Duda–Hart criteria

Number of clusters	Criterion CH	Duda-Hart
k=1	-	0.455
k=2	189.66	0.742
k=3	215.23	0.434
k=4	229.72	0.855
k=5	199.89	0.427
k=6	202.39	0.442
k=7	211.20	0.629
k=8	166.25	0.820
k=9	190.71	0.598
k=10	174.99	0.855

Source: developed by the authors.

Both the Calinski–Harabasz and Duda–Hart criteria indicate that a four-cluster solution is optimal. Accordingly, K-means clustering was performed using four clusters. The statistical significance of all five variables is confirmed by the F-statistics and p-values below 0.05 (Table 7), demonstrating that each variable contributes significantly to cluster formation.

Table 7

Statistical significance of variables in cluster formation

Variable	F-criterion	p-value
UCP	199.29	0.00
MCP	280.38	0.00
ICT	329.04	0.00
Transform_ExpServ	102.22	0.00
Transform_ImpServ	115.67	0.00

Source: developed by the authors.

The average values of the variables for each cluster are presented in Table 8.

Table 8

Average values of variables by cluster

Cluster	UCP	MCP	ICT	Transform_ExpServ	Transform_ImpServ
1	61.02	77.78	69.40	136.42	125.84
2	80.96	90.47	85.71	638.09	539.21
3	88.8	92.54	90.67	7552.89	7948.78
4	28.7	45.68	37.2	73.86	68.95
Total	70.2	81.11	75.65	2352.47	2428.78

Source: developed by the authors.

Cluster 3 records the highest average values across all five variables, indicating the strongest combination of digitalisation and services trade transformation. It is followed by Clusters 2 and 1, whereas Cluster 4 exhibits the lowest average values. The composition of each cluster is presented in Table 8, while the distribution of countries across the four clusters is illustrated in Figure 6.

Cluster 1 (34 countries) consists mainly of upper-middle- and lower-middle-income economies, with only three high-income Caribbean island states (Antigua and Barbuda, Barbados, and Trinidad and Tobago). Geographically, it is highly diverse, covering Latin America, North Africa, the Middle East, Southeast Asia, Sub-Saharan Africa, and the Balkans. The cluster is characterised by a medium level of ICT development combined with relatively modest services trade, reflecting a transitional stage of economic development.

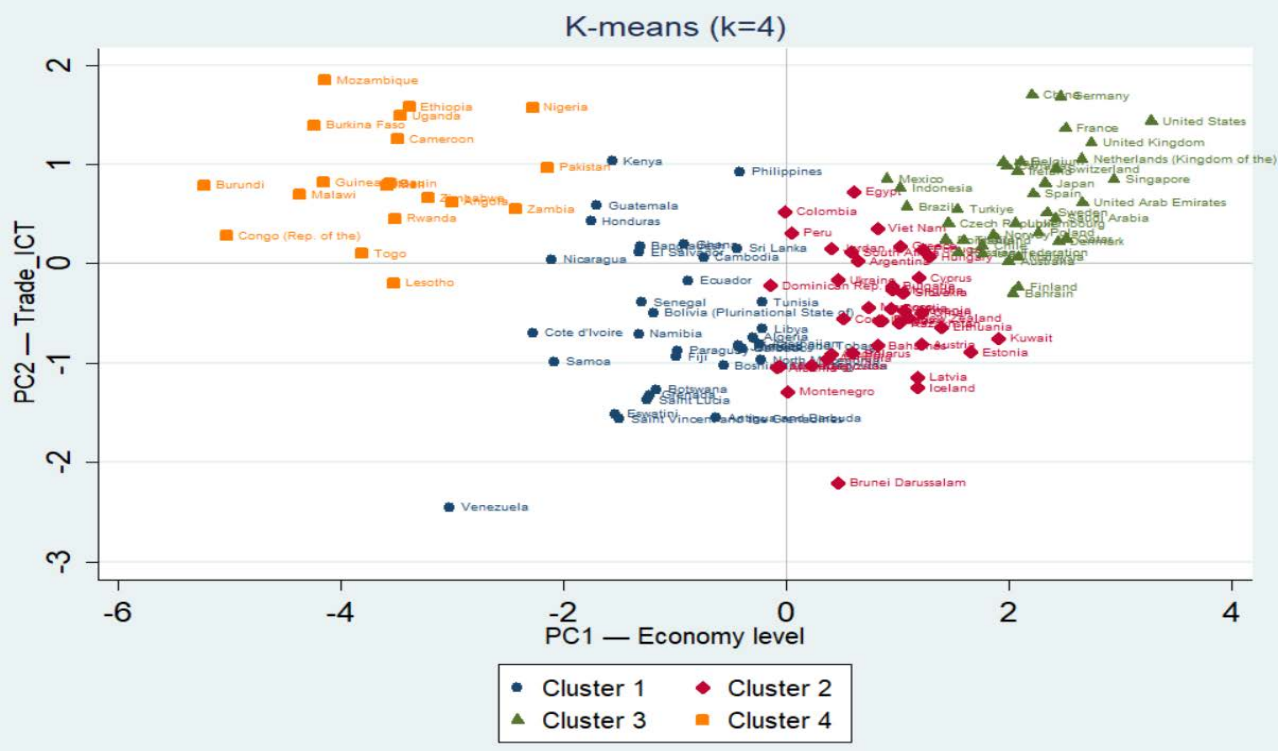

Fig. 6. Distribution of countries across four clusters based on digitalisation indicators and transformations in services exports and imports

Source: developed by the authors.

Cluster 2 (40 countries), the largest cluster, is dominated by high- and upper-middle-income economies. Viet Nam is the only lower-middle-income country, reflecting its rapid expansion of services exports despite its income level. The cluster mainly comprises countries from Central and Eastern Europe, Latin America, the Middle East, Central Asia, and the Pacific region, characterised by relatively high digitalisation and moderate-to-high participation in services trade.

Cluster 3 (36 countries) is the most homogeneous, consisting almost entirely of high-income economies with only a few upper-middle-income countries. It includes most countries of Western Europe, North America, East Asia, the Middle East, and Oceania. This cluster combines the highest ICT development with the largest services trade volumes, illustrating the competitive advantage of advanced digital economies.

Cluster 4 (19 countries) is the smallest and includes the least developed economies, predominantly from Sub-Saharan Africa together with Pakistan and a small number of Asian countries. Although Nigeria and Pakistan have relatively large economies, their low ICT development and structural constraints in the services sector place them in this group. The cluster is characterised by the lowest ICT levels, limited economic diversification, strong dependence on commodity exports, and weak integration into global services trade.

Overall, the four-cluster structure closely reflects the global digital divide. The cluster boundaries largely coincide with the World Bank income classification, confirming the strong relationship between economic development, digitalisation, and participation in international trade in services.

Figures 7 and 8 illustrate the relationship between ICT development (ICT Development Index, IDI) and the volumes of services exports and imports across the four identified clusters.

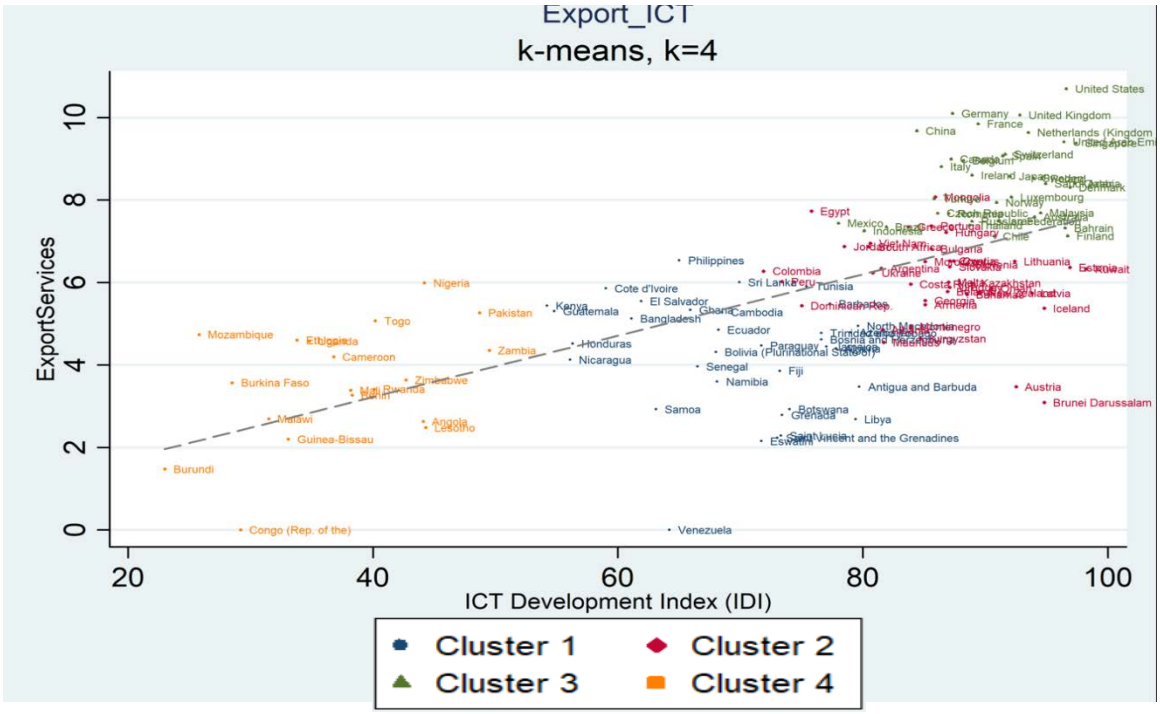

Fig. 7. Relationship between ICT development and services exports by cluster
Source: developed by the authors.

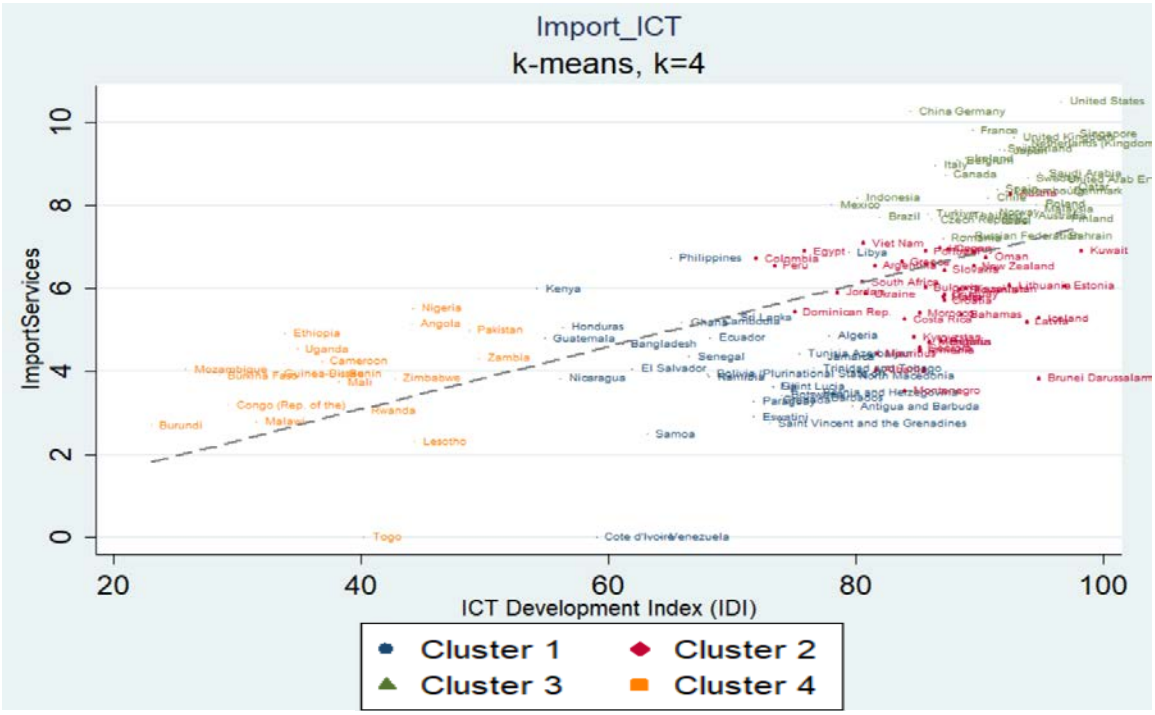

Fig. 8. Relationship between ICT development and services imports by cluster
Source: developed by the authors.

Figure 7 demonstrates clear differentiation between the clusters. Cluster 1 occupies the central part of the distribution, combining medium ICT development with moderate services exports. Most observations lie below the regression line, although the Philippines stands out with exceptionally high services exports driven by its business process outsourcing (BPO) sector, while Venezuela records unusually low exports because of its prolonged economic crisis. Cluster 2 exhibits the greatest dispersion, spanning a broad range of ICT levels and export volumes. Besides developed European economies, it includes several middle-income countries, such as Egypt and Mongolia, whose comparatively high services exports indicate successful integration into outsourcing and ICT-enabled services. Kuwait represents a high-income economy with moderate export performance.

Cluster 3 dominates the upper-right quadrant, combining the highest ICT levels with the largest services exports.

The United States is the clear leader, followed by Germany, the United Kingdom, France, the Netherlands, China, Singapore, Switzerland, Ireland, and Japan. Several large upper-middle-income economies, including Brazil, Indonesia, Mexico, Thailand, Türkiye, and China, also achieve substantial services exports despite lower income levels than the most advanced economies. Cluster 4 is concentrated in the lower-left part of the graph, reflecting both low ICT development and limited services exports. Countries such as Nigeria and Pakistan exceed the general trend because of the size of their economies, whereas most other countries remain close to the lower end of both indicators.

The regression line confirms a positive relationship between ICT development and services exports. However, the substantially larger dispersion compared with merchandise exports suggests that digitalisation alone does not determine services trade. Other factors - including economic structure, financial and tourism development, workforce skills, and participation in global outsourcing networks—also play an important role. This explains the strong performance of countries such as the Philippines and Egypt, as well as the comparatively weak performance of Venezuela despite its moderate ICT level.

Figure 8 reveals a similar pattern. Cluster 1 occupies the central part of the distribution with moderate ICT development and services imports, while Kenya and the Philippines record the highest import volumes within the cluster. Cluster 2 again displays the greatest dispersion. Several middle-income economies, including Viet Nam, Colombia, Egypt, Libya, and Peru, record relatively high services imports, whereas Brunei Darussalam represents a notable outlier with exceptionally low imports despite one of the highest ICT levels.

Cluster 3 dominates the upper-right quadrant, led by the United States and followed by China, Germany, France, the United Kingdom, Singapore, the Netherlands, Japan, and other advanced economies. These countries combine very high ICT development with the largest services import volumes. Cluster 4 remains concentrated at low ICT levels. Nigeria, Angola, Ethiopia, Pakistan, and Uganda import substantially more services than countries with similar digitalisation levels, largely reflecting the influence of population size and domestic demand, whereas Burundi, Malawi, Lesotho, and the Republic of the Congo record the lowest values.

The regression line confirms a strong positive relationship between ICT development and services imports. Overall, the four clusters remain clearly differentiated, while the largest deviations from the general trend are associated with country-specific structural characteristics rather than ICT development alone.

Conclusions. The cluster analysis confirms a strong relationship between digitalisation, international trade transformation, and the overall level of economic development. By applying logarithmisation, standardisation, Principal Component Analysis (PCA), and K-means clustering, the study provides a statistically robust framework for identifying groups of countries with similar patterns of ICT development and trade performance. PCA effectively eliminated multicollinearity among the digitalisation indicators while preserving more than 95% of the total variance, ensuring reliable clustering results.

For both merchandise and services trade, a four-cluster solution proved to be the most meaningful. The identified clusters closely correspond to countries' income levels, with high-income economies consistently demonstrating the highest levels of digitalisation and the greatest participation in international trade. In contrast, low- and lower-middle-income countries remain concentrated in clusters characterised by limited ICT development and relatively weak trade transformation. These findings highlight the persistence of the global digital divide and its close association with international competitiveness.

The results also demonstrate that higher ICT development is positively associated with larger volumes of both exports and imports of goods and services. Nevertheless, digitalisation is not the sole determinant of trade performance. Significant deviations from the general trend indicate that factors such as economic size, industrial structure, resource endowments, participation in global value chains, workforce skills, tourism development, and integration into international outsourcing networks also play an important role. Large emerging economies may achieve substantial trade volumes despite only moderate digitalisation, whereas highly digitalised small economies often record comparatively limited trade because of their market size.

Overall, the findings suggest that digital transformation constitutes an important, but not sufficient, condition for successful integration into global trade. Policies aimed at enhancing ICT infrastructure and digital capabilities should therefore be complemented by broader measures supporting structural economic transformation, export diversification, innovation, human capital development, and deeper participation in international production and services networks. Such a comprehensive approach is essential for strengthening countries' competitiveness and ensuring sustainable growth in the digital economy.

Declaration on the Use of Artificial Intelligence Tools. During the preparation of this article, generative artificial intelligence tools (ChatGPT-4, OpenAI, 2025) were used to search and summarize the literature, as well as to improve the structure and logic of the manuscript. No AI-generated text was used without critical human editing. The authors bear full responsibility for the academic validity, accuracy, and integrity of the content.

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