

EU CONVERGENCE: A PATHWAY TO ECONOMIC STABILITY

Adrian LUNGU*₁

Mihai Daniel ROMAN*₂

Diana Mihaela STANCULESCU*₃

Abstract: *In the context of global systemic transformations, economic security has become a focal point in political and economic debates. The article explores how economic convergence within the European Union (EU) contributes to strengthening regional economic security. Using an innovative approach based on cluster analysis, the study reveals economic convergence trends among EU member states, highlighting the involvement of this process in promoting economic stability and security in the era of systemic changes. Our methodology involves applying clustering techniques to an extensive set of economic indicators to assess the dynamics of economic convergence between EU countries over the last two decades. The cluster analysis carried out allowed the grouping of countries based on their similar economic characteristics, thus providing a clear picture of the progress towards convergence. The results indicate a strong trend of economic alignment within the EU, with the formation of clusters suggesting a reduction in economic discrepancies. This process of convergence not only reflects greater economic cohesion, but also contributes to the macroeconomic stabilization of the region, an important aspect for economic security in the face of global volatility and uncertainties. The analysis shows that the EU is moving towards uniformity and economic convergence, with economic clusters becoming more similar over time.*

Keywords: *Convergence, Economic security, PCA, Clustering analysis, EU countries*

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Introduction

In the current context of globalization and dynamic challenges, the EU faces major challenges, one of them being the strengthening of economic security.

The article focuses on the convergence of key macroeconomic indicators between member countries and proposes an analysis for this purpose, investigated through the two complementary analytical techniques: principal component analysis (PCA) and clustering. Approaches to economic convergence within the EU require a deep understanding of the

*₁Adrian Lungu, PhD student Bucharest University of Economics Studies, lungugeorge19@stud.ase.ro, ORCID: 0009-0005-9085-1611

*₂Mihai Daniel Roman, Prof. Dr. Bucharest University of Economics Studies, mihai.roman@ase.ro, ORCID: 0000-0002-3859-7629

*₃Diana Mihaela Stanculescu, PhD student Bucharest University of Economics Studies, stanculescudiana10@stud.ase.ro

economic dynamics of the member states, and in this sense, PCA becomes a preliminary step in order to reduce the size of complex economic data sets, allowing the identification of the main factors influencing the economies member states. This method helps to uncover general trends and extract the key factors that define the economic profile of each member country.

After performing the PCA analysis, the next step was the clustering of the identified principal components. This approach allows states to be grouped not only based on raw data, but also based on their fundamental economic characteristics identified through PCA, thus making more nuanced and meaningful comparisons between different economies. This process provides a clearer picture of how member states converge or diverge in terms of economic structure and development priorities. For example, comparing the raw clustering of the data with the clustering derived from PCA shows that certain economies that appear similar on superficial analysis may actually have different economic fundamentals or priorities.

The combined use of PCA analysis followed by cluster analysis provides a comprehensive and detailed overview of economic convergence in the EU. This allows us to observe, beyond the obvious differences between member countries, and understand the complexities that define each country's economy. In this way, we can see potential differences not as obstacles but as opportunities to develop more adaptive and effective economic policies. For example, in the EU, northern member states may have different economic characteristics than those in the south or east, and recognizing these differences is essential for developing economic policies that can stimulate growth in less developed regions while maintaining stability in developed regions.

Therefore, economic convergence is not only an end in itself, but also a means to ensure sustainable economic stability within the EU by reducing inequality and promoting balanced economic growth. The combined use of the two analyses not only improves the accuracy and depth of economic analysis, but also facilitates the development of more precise and coherent policies. This is an important step towards a European economic strategy that recognizes and capitalizes on internal diversity and complexity, ensuring that each member state contributes to and benefits from shared economic growth and long-term stability.

The PCA analysis and subsequent clustering provide a more nuanced picture of economic convergence and highlight the key factors contributing to the internal economic dynamics of the EU. For example, PCA indicates that some countries may be heavily influenced by foreign direct investment and exports, while others are dependent on domestic consumption and government investment.

Analysing economic convergence using these two methodologies, this article provides a framework for understanding how the EU can respond to the changing global system, and economic convergence is not only a goal to be achieved, but also an essential tool for strengthening economic and political cohesion in the facing internal and external challenges. Recognizing economic diversity and adapting policies to this diversity is an essential step in

ensuring the economic security of the EU. This detailed approach to economic convergence analysis can not only understand current dynamics but also predict potential future challenges. In a world where economic change is rapid and often unpredictable, the EU's ability to adapt and respond effectively to these changes will not only determine its economic security, but also its importance on the global stage.

This article highlights the importance of adaptability, innovation and cohesion within the EU, which are essential to remain a successful model in an ever-changing world, and adapting economic policies to national diversity and building on the strengths of each member state will play a key role in ensuring the EU's long-term economic security and prosperity.

Literature review

The specialized literature dealing with PCA analysis and cluster analysis is well represented, the articles published in the journal, of which I will mention a few that addressed the same research topic, contributed to the theoretical foundation of this research, as well as provided a comparative framework. The literature dedicated to the analysis and understanding of their structures has validated their ability to reveal hidden patterns and complex relationships in data sets: PCA, clustering and K-means analysis. These techniques have become reference points in the field of statistics and data science, they allow to reduce the size of the data, identify groups or structure the data to obtain a deeper understanding of the relationships between variables.

Laboutková et al (2016) through the cluster analysis, identified groups of countries based on the level of decentralization and economic inequalities, as well as the fact that among the results obtained there is no direct correlation between decentralization and low levels of economic inequality.

In a similar methodological approach, Onuferová et al (2020) investigated the economic and social evolution of EU member states, using cluster analysis based on five international multicriteria indices. The study classified EU countries into groups, revealing changes in their performance over the period 2011-2018, showing a general trend of improvement, as well as the reduction of economic disparities between EU members.

Živadinović et al (2009) investigated the economic profile of Croatia in relation to the other member states of the EU, cluster analysis and factor analysis on a number of key economic indicators. The study highlighted similarities between Croatia and other countries with similar historical and political contexts based on indicators such as GDP per capita, employment rate and comparative price levels.

Akkucuk (2011) classified countries into groups based on a set of 12 economic variables, with the aim of analyzing the similarities and differences between them in a

multidimensional space. Through this approach, he identified an optimal clustering into five groups, corresponding with existing classifications based on GDP and export structure.

Using multiple development indicators, Tang & Salvador (1986), identified five distinct groups of countries in the Asia-Pacific region. Their study highlights the importance of a multidimensional approach to development assessment and planning, demonstrating that the use of a varied set of indicators can provide a more complete picture of the development stage of different countries.

On the other hand, Vichi and Kiers (2001) introduce an innovative model that combines k-means clustering analysis with factor analysis for two-way data. This methodology, called k-means factor analysis, simultaneously aims to reduce and synthesize data, both object-wise and variable-wise, and allows a more precise selection of variables in the clustering process. The proposed methodology represents a superior alternative to the sequential approach, demonstrating the effectiveness of the alternative iterative algorithm in minimizing the distances between data points and centroids, thus allowing more accurate classification of objects within datasets.

The methodology used in this study combines advanced statistical techniques to effectively and objectively approach such datasets. By using PCA, cluster analysis, K-means method, dendrograms and biplot graphic analysis, they propose a comprehensive approach that allows not only to simplify and reduce the complexity of the data, but also to discover significant structures and relationships between the studied variables.

The purpose of this methodology is to provide a robust framework for data analysis, thereby improving the ability to interpret and make data-driven decisions. In the following sections, we will detail each component of this methodology and illustrate how these techniques can complement each other to provide deeper and more detailed insight into the data being analysed. PCA is a statistical technique used to reduce the size of data while retaining as much variation as possible. PCA transforms the original set of variables into a new set of orthogonal variables, called principal components, which are linear combinations of the original variables. The first principal components capture most of the total variation in the data, Jolliffe (2002). A PCA plot is a graphical representation used to visualize data in the context of a principal component analysis. In a standard PCA plot, the data is plotted on the first two principal components, which are linear combinations of the original variables and capture most of the variation in the data set. Each point on the plot represents an observation from the data set. The position of a point indicates the values of that observation on the two principal components. Thus, the chart can show groupings or patterns within the data.

Cluster analysis is a method of classifying objects into groups so that objects in the same group (or cluster) are more closely related to each other than to those in other groups. This methodology is used to discover hidden structures in data and can be applied through various techniques such as hierarchical methods and partitioning methods, Everitt et al. (2001).

The K-means method is a partitioning clustering technique that divides a data set into k clusters, minimizing the variation within clusters and maximizing the variation between clusters. This involves initially choosing k centroids and assigning each object to the nearest centroid, followed by recomputing the centroids until convergence, MacQueen (1967).

A dendrogram is a visual representation used in hierarchical cluster analysis to show the arrangement of groups and the relationships between them. This tree diagram shows how each cluster is divided into smaller clusters down to the individual object level, Sneath and Sokal (1973).

In conclusion, in the chapter dedicated to the specialty literature, we identified and analysed the significant contributions in the field, establishing the context for the present research. This synthesis of previous studies brought new approaches into view, providing clear directions for the present analysis. Thus, the literature review built a solid foundation in the methodology approach that was the basis of this article.

Data and Methodology

Analysing economic security through the prism of economic convergence within the EU-27 countries from 2000-2021, we approach the complexity of the relationships between economic indicators with the help of PCA and clustering techniques, respectively K-Means and Silhouette analysis, as well as the Index Hubert, which is a graphical method for determining the number of clusters. The latter method was used to further verify the robustness of the cluster structure.

Economic convergence, manifested through similar development directions of the member countries, represents an essential factor for the general economic security of the EU. This reflects an increased level of economic stability and predictability, contributing to the economic cohesion and resilience of the European bloc.

The analysis of economic indicators allows the identification of convergence patterns between the EU-27 countries. These patterns, interpreted through the lens of economic security, provide valuable information on the solidity of the Union's economic foundation. Our study contributes to an in-depth understanding of the complex interactions between various national economic aspects, providing insight into sustainable economic cohesion and stability at EU-27 level.

The process of data cleaning and normalization is very important in any analysis, it prepares the necessary framework for an accurate interpretation of the PCA, which reveals how various economic indicators such as GDP per capita, inflation, unemployment rate or public debt differ, which contributes to shaping the convergence between these EU-27 states. This standardization process is essential for the comparability of economic indicators, ensuring a correct analysis of the dynamics of economic convergence in the EU-27.

PCA is an advanced statistical method used to simplify the complexity of multidimensional data sets that identifies directions (or principal components). This technique is useful in the context of the analysis of economic convergence between the EU-27 countries, as it allows reducing the dimensionality of the data without losing significant information about their economic structure.

The process of PCA begins by exploring and understanding the data by calculating the covariance matrix (C). This matrix reveals how the variables in the data set vary together and helps us identify underlying relationships and patterns in the data.

$$C = \frac{1}{n-1} (X - \bar{X})^T (X - \bar{X}) \quad (1)$$

Where:

n - the number of observations

X - the initial data matrix

\bar{X} - the vector of means of each variable

After the calculation of the covariance matrix, the identification of the eigenvalues (λ_i) and the eigenvectors (v_i). These are calculated from the covariance matrix and are essential for determining the principal components of the data. The formulas for the eigenvalues and vectors are:

$$Cv_i = \lambda_i v_i \quad (2)$$

Where:

Cv_i - the vector resulting from the multiplication of the covariance matrix by a specific eigenvector

λ_i - own values

v_i - the eigenvectors

The clustering approach using PCA-derived principal component scores on economic indicators, and not directly on countries, requires a specific reinterpretation. In this context, each economic indicator becomes an "object" to be grouped according to their similarity in the space of principal components, reflecting how different indicators contribute to the overall economic structure of the EU-27. The goal is to identify groups (or clusters) of indicators that have similar behaviors, suggesting areas of economic convergence that can influence economic security. In this direction, we used K-means and the Elbow and Silhouette clustering methods. To assess the quality of the clustering we applied the Hubert indices as an additional check of the robustness of the cluster structure, providing an additional assessment of the quality and relevance of the identified groups. This sequential methodological process allows us to strengthen confidence in the results of our analysis, ensuring that our interpretations are well-founded and adequately reflect the dynamics of economic convergence between EU-27 countries.

By applying K-Means to the scores of the main components of the economic indicators, it is aimed to group them into clusters based on their similarity in the reduced dimensional space given by PCA. Each economic indicator is represented by a point in the space of principal components, and the K-Means algorithm tries to minimize the internal variation of the clusters. The objective is formalized as minimizing the sum of the squared distances between the indicators in each cluster and its centre:

$$J = \sum_{k=1}^K \sum_{i \in C_k} \|x_i - \mu_k\|^2 \quad (3)$$

Where:

J - the sum of the squared distances to be minimized by the K-Means algorithm

K - the predefined number of clusters

C_k - the set of economic indicators (or observations) in the cluster K.

X_i - is the vector of PCA scores for the economic indicator i which represents the data associated with each indicator in the reduced principal components space.

μ_k - the centre of cluster k, calculated as the average of the vectors of PCA scores for all indicators in C_k

By $\|x_i - \mu_k\|^2$ the squared distance between each economic indicator x_i and the center of its cluster μ_k , and the algorithm tries to minimize this sum by adjusting the clusters. This minimization ensures that each economic indicator is assigned to the cluster with which it has the greatest similarity, according to the distance in the space of the principal components, which leads to as homogeneous and well-defined groups as possible.

To decide how many clusters to form, we used the Elbow method, the principle behind this method is to run the clustering algorithm (K-Means in our case) for a range of K values (the number of clusters) and to calculate the sum of squared distances (SSE - Sum of Squared Errors) between points and their cluster centre. The plot of SSE versus K is then examined to identify the point at which increasing K no longer leads to a significant improvement in SSE - this point is often compared to the "elbow" of an arm, hence the name of the method. The Elbow method is useful to provide intuitive guidance in choosing an appropriate number of clusters.

The Silhouette analysis is also a valuable method in evaluating clustering results, providing a quantitative measure of the quality of the classification of each economic indicator within the formed clusters. This silhouette score helps to understand how well each indicator was placed in its cluster, compared to other clusters. The silhouette score ranges from -1 to +1, where:

A score close to +1 indicates that the indicator is very close to the other indicators in its cluster and far from the indicators in the other clusters, suggesting an appropriate classification.

A score close to 0 suggests that the indicator is on the border between two clusters, being almost as close to the nearest different cluster as to its own cluster.

A score close to -1 indicates that the indicator was erroneously placed, being closer to indicators in another cluster than to those in its own cluster. Calculating the average silhouette score for all economic indicators in a data set provides an overall measure of clustering quality.

A mean score closer to +1 suggests that the clustering was mostly adequate, with well-defined and separated clusters. On the other hand, a mean score close to 0 or negative indicates a poor classification with many overlaps between clusters.

The Hubert Index (Gamma) and the D Index (Davies-Bouldin) are specific measures in evaluating the quality of a clustering, helping to determine the optimal number of clusters in the data set. These methods are based on the calculation of statistics that measure the internal cohesion of clusters and the separation between them, providing a quantitative insight into the structure of the clusters formed.

The Hubert index, also known as the Gamma coefficient, is a measure of statistical association between pairs of variables. In the context of clustering, it is used to evaluate how well the separation between clusters is defined. On the other hand, the D(Davies-Bouldin) Index is another measure used to evaluate the clustering quality. The D-index seeks to minimize the internal similarity of clusters and maximize the separation between them

Both Hubert (Gamma) and D indices provide valuable insights into the quality of clustering solutions, helping to identify the clustering structure that best balances internal cohesion and separation between clusters.

By applying PCA techniques and clustering methods, this study addresses aspects of economic convergence in the EU-27, emphasizing objective and quantitative analysis. Through this approach, the study brings to the fore the way in which different economic indicators interact and contribute to the patterns of economic convergence between the EU-27 member states. This methodological approach allows us to obtain a clear and quantifiable picture of economic relations, thus providing a solid basis for understanding economic security within the Union. Therefore, this study can bring more knowledge to the existing literature to support the development of good economic policies substantiated, which promote greater integration and economic security throughout the EU.

Case study

In this chapter, we will detail the applied analytical process and present the results obtained within the chosen case study. The analysis will begin by examining the data, thereby establishing a framework for interpretation and discussion. We will start with descriptive statistics to get to know the data, we will continue with PCA analysis, cluster analysis, as well as the presentation and interpretation of their results, together with the dendrograms and plots determined by the analyses.

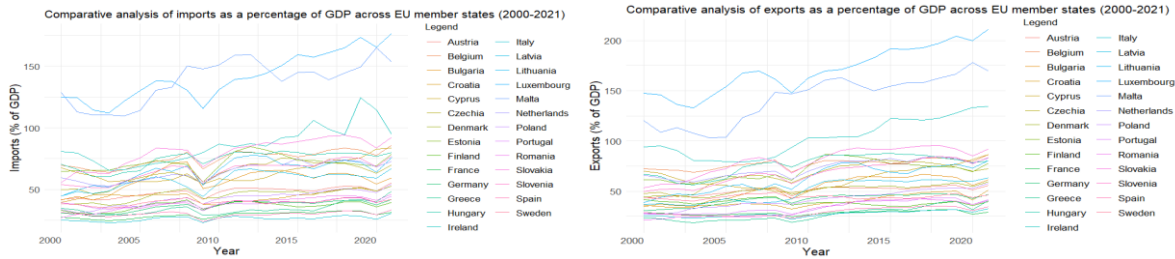


Figure 1. Graphic presentation of the export/import comparative analysis

Source: Eurostat. The data was processed by the author with statistical software R

The graph (Figure 1) reflects the complexity and dynamics of foreign trade within the EU, highlighting the different economic trajectories of the member states in the context of globalization and world economic changes, as well as the complexity and dynamics of international trade relations. Reflecting both the opportunities and challenges of globalization, the data underscore the importance of economic adaptability and resilience in the face of rapid changes in the global marketplace.

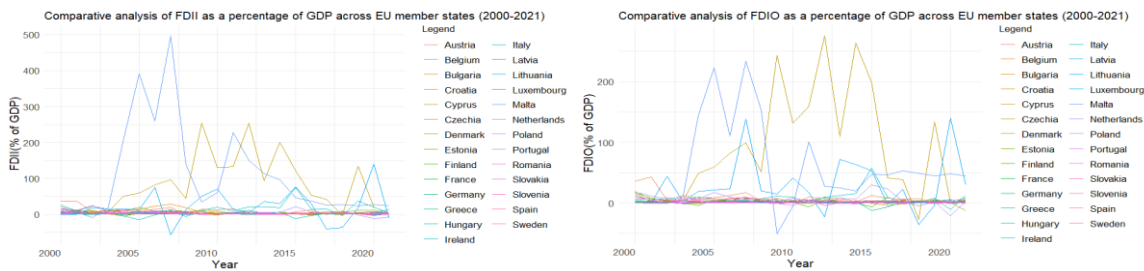


Figure 2. Graphic presentation of the FDI (foreign direct investment inflow)/FDIO (foreign direct investment outflow) comparative analysis

Source: World Bank. The data was processed by the author with statistical software R

Figure 2 illustrates the evolution of foreign direct investment inflow and outflow (FDII & FDIO) as a percentage of GDP between the years 2000 and 2021. This comparative analysis highlights how foreign direct investment flows have changed over time, reflecting trends, economic shocks and investment policies in various countries.

The observed volatility reflects the adaptability and reaction to global market dynamics, as well as the impact of major economic events. The diversity of performance among EU countries underlines the importance of national policies and economic capacities in shaping foreign investment strategies. The evolution of this indicator provides a valuable perspective on the international economic integration of and on how states participate in global markets.

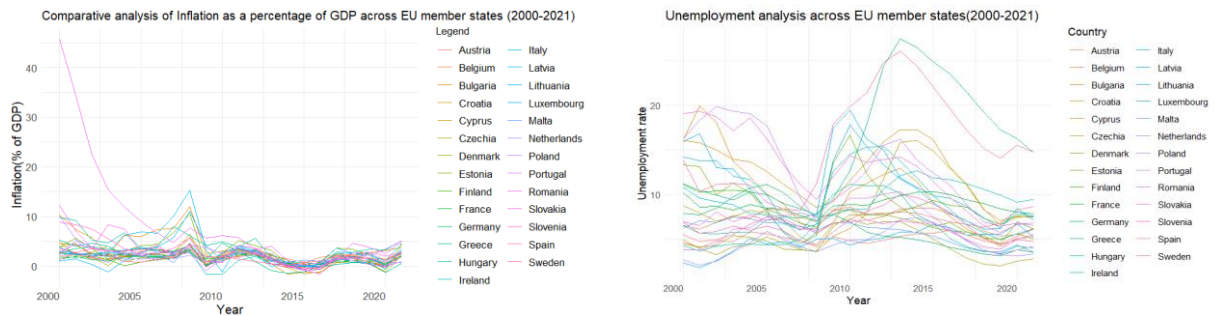


Figure 3. Graphic presentation of the inflation & unemployment comparative analysis

Source: Eurostat. The data was processed by the author with statistical software R

The evolution of inflation and the unemployment (Figure 3) rate in the EU between 2000 and 2021 highlights how these economic indicators have changed in the context of major events such as the global financial crisis and the COVID-19 pandemic. The data generally show a stability and moderation of inflation, which suggests the success of the monetary policies implemented by the European Central Bank and national banks. However, inflation rates have seen increases during periods of crisis, illustrating the impact of global events on price stability. In parallel, the unemployment rate has shown significant fluctuations, with increases during recessions, reflecting the sensitivity of the labor market to economic and policy changes. Variations between EU countries in unemployment reflect differences in economic structures and the effectiveness of employment policies.

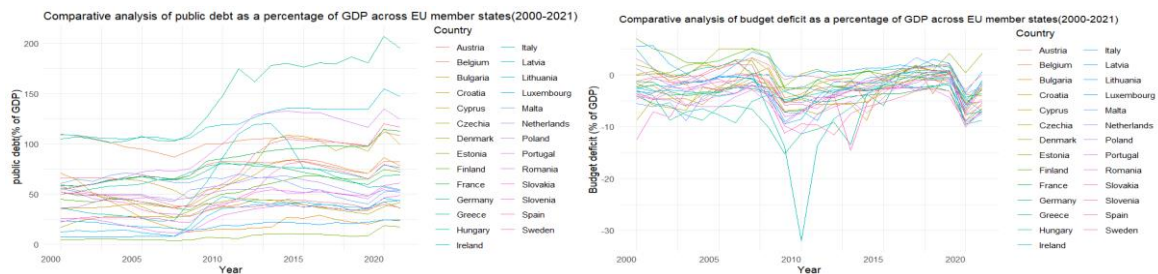


Figure 4. Graphic presentation of the public debt & budget deficit comparative analysis

Source: Eurostat. The data was processed by the author with statistical software R

The graph analysed (Figure 4) provides a perspective on the evolution of the budget deficit and public debt in the member states of the EU between the years 2000 and 2021, highlighting the impact of economic fluctuations on the fiscal health of nations. Significant increases in the budget deficit are noted following major economic crises, such as the global financial crisis and the COVID-19 pandemic, when governments actively intervened through fiscal stimulus and spending measures to mitigate the effects of recessions.

The analysis highlights the challenges of fiscal management in the context of an unstable global economy and shows how periods of crisis call for decisive fiscal action, while phases of economic stability provide a window for fiscal consolidation. We also see significant

differences between EU states in public debt levels, with some countries recording substantial debt-to-GDP ratios, reflecting diverse national fiscal approaches and challenges. This analysis highlights the importance of prudent management and sustainable fiscal policies to maintain economic stability in the face of external uncertainties and shocks.

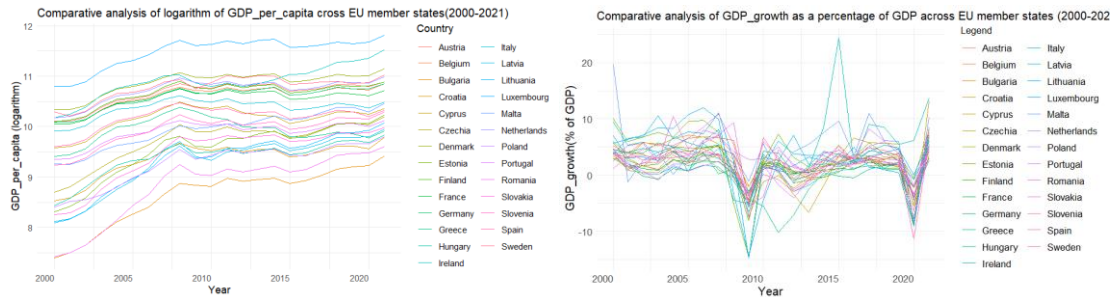


Figure 5. Graphic presentation of the GDP/capita & GDP growth comparative analysis

Source: Eurostat. The data was processed by the author with statistical software R

The graph (Figure 5) analyses the evolution of GDP per capita between the years 2000 and 2021 in the member countries of the EU, highlighting a general growth trend that indicates an improvement in living standards and prosperity. Significant variations are observed between countries, illustrating the different economic trajectories and degree of development. Slowdowns related to major economic crises, such as the 2008-2009 crisis and the COVID-19 pandemic, mark moments of vulnerability and temporary declines in economic growth. Also, a process of income convergence between member states is highlighted, in line with the EU's objectives of economic and social cohesion. The chart also reflects business cycles, with periods of expansion and contraction, highlighting how economies are affected by external and internal shocks. By illustrating these trends, the chart underlines the importance of economic policy and crisis management in promoting sustainable growth and economic stability at EU level. This highlights the complexity and challenges of managing growth in a diversified and interconnected European context.

Interpreting economic indicators in the context of convergence in the period 2000-2021, we note that the convergence process is a complex one, with uneven progress between different fields. They reveal a picture, with real and nominal convergence trends in areas such as inflation and GDP per capita, but divergence in fiscal management and labour market dynamics. This picture highlights the fact that, although European integration has advanced, the process of economic convergence remains uneven and requires continuous and coordinated efforts to address disparities and promote deeper economic convergence among member states.

Thus, economic convergence in the EU proves to be a dynamic, evolving process that requires an adaptive approach and effective policy responses, taking into account the changing global economic climate. The sustainability of this process will depend on the EU's ability to

promote economic policies that aim not only at stability and economic growth, but also at equity and inclusion, thus ensuring shared prosperity across the Union.

To achieve the research objectives, we will analyse the PCA biplot for the year 2000 (Figure 6), which combines the loadings of the economic indicators with the positioning of the EU countries and which provides a valuable insight into the economic structure and relations between the different countries of the EU. This analysis allows the simultaneous evaluation of the influence of economic indicators and the economic performance of the member countries.

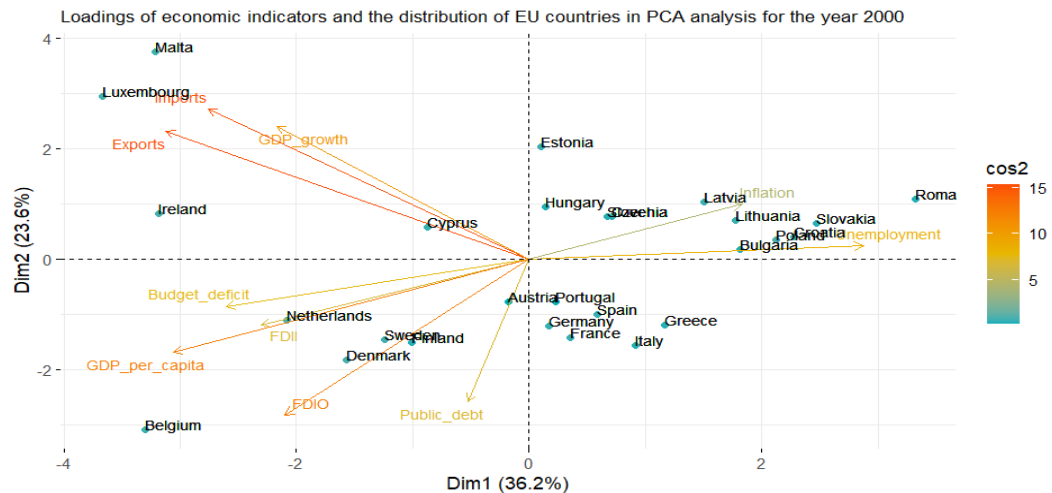


Figure 6. Loadings of economic indicators and countries in PCA analysis – year 2000

Source: Eurostat & World Bank. The data was processed by the author with statistical software R

The analysis of each quadrant separately reveals very interesting associations between the loadings of the economic indicators and the countries under analysis. We will analyse and interpret each quadrant separately, then issue a conclusion following these analyses.

In quadrant I (top right) countries such as Estonia, Latvia and Lithuania, Romania or Bulgaria can be observed, alongside economic indicators such as the inflation rate and unemployment. This suggests that in 2000 they were facing challenges specific to the post-communist transition, such as macroeconomic adjustments needed for stabilization. The transition to market economies, structural reforms and EU integration efforts have created pressures on the labour market and led to high levels of inflation. This association of countries and indicators reflects not only the post-communist transition, but also the process of European integration at different stages for these countries. Positioning in this quadrant underlines the fact that, despite the economic challenges associated with the transition and preparation for EU accession, the countries of Central and Eastern Europe have been engaged in an active process of reform and adaptation. Pressures on the labour market and inflation reflected not only the difficulties of the transition, but also the progress towards stabilization and European integration.

Quadrant II (upper left) clearly reflected that the countries placed here are outward-looking economies, indicating a strong orientation towards open economies with significant reliance on international trade and external economic performance. These countries appear to be benefiting from globalization and European integration, with export-oriented economies driving GDP growth. Their presence in this quadrant reflects a successful adaptation to the globalized economy, with an emphasis on export-oriented sectors that drive economic growth. These countries demonstrate that small but open and flexible economies can achieve high economic performance. These, through the success they had, managed to capitalize on niches and specific economic sectors, benefited from a competitive advantage on the single European market, but also at the global level.

In quadrant III (bottom left) we see countries such as Belgium, Sweden, Finland or Denmark, together with indicators such as public debt and budget deficit. The combination of these countries and indicators suggests mature economies with complex fiscal systems facing the challenges of managing public debt and budget deficits. The positioning of these countries in this quadrant suggests continued concern for macroeconomic balances and the need for prudent debt and deficit management policies, essential for long-term economic stability.

Foreign investment flows, both inward and outward, suggest that these countries have been active as both recipients and sources of FDI. The length of the vectors of these indicators indicates the significant importance of foreign investment in their economies, both in attracting foreign capital and in their companies' investments abroad. The existence of capital flows alongside the concerns related to public debt and the budget deficit, highlights the complexity of fiscal policy management in a globalized context. This underlines the importance of fiscal policy not only in domestic terms but also in its relationship with international capital flows. This situation illustrates the principles of the Mundell-Fleming model, which extends the IS-LM model to the open economy, showing the interplay between fiscal policy, exchange rates, and capital flows.

In conclusion, this quadrant provides a complex perspective on the challenges and strategies of the EU's mature economies in the year 2000.

The absence of indicators in quadrant IV (bottom right) may indicate that there is no clear trend or dominant economic theme associating direct economic growth with specific negative aspects, in the context of the analysis for the year 2000. The absence of indicators in this quadrant indicates that, in the year 2000, although there were no dominant trends, each faced its own economic challenges at the turn of the millennium. For example, Italy and Portugal were facing increased public debt, while Spain and Greece were beginning to face budget deficit problems that would become more acute over the next decade.

In conclusion, the positioning of Austria, Germany, Greece, France, Italy, Spain and Portugal in the IV quadrant reflects the characteristics of mature and integrated economies,

which, in the year 2000, were not marked by extremes in economic performance in relation to the indicators selected for PCA analysis.

In conclusion, the PCA analysis (Figure 6) for the year 2000 reflects the diversity of development stages and economic challenges facing EU countries at the beginning of the millennium. CEE countries, at various stages of EU integration, are showing signs of adapting to the Union's economic criteria, despite initial challenges. This diversity underlines the complexity of the economic convergence process and the importance of political adaptation to the specific context of each country. The EU accession process provided a framework for economic and political reforms that stimulated macroeconomic stability and economic growth. Despite the challenges, the progress made by the CEE countries indicates a positive trend of convergence towards EU economic and social standards, underlining the Union's ability to support the development and integration of its members.

The joint PCA indicator/country chart for the year 2000 provides a valuable insight into the economic complexity and diversity within the EU, while highlighting the challenges and opportunities associated with economic integration and convergence. The review reiterates the need for a balanced and coordinated approach to economic policies and development strategies to promote stability, growth and cohesion in the EU.

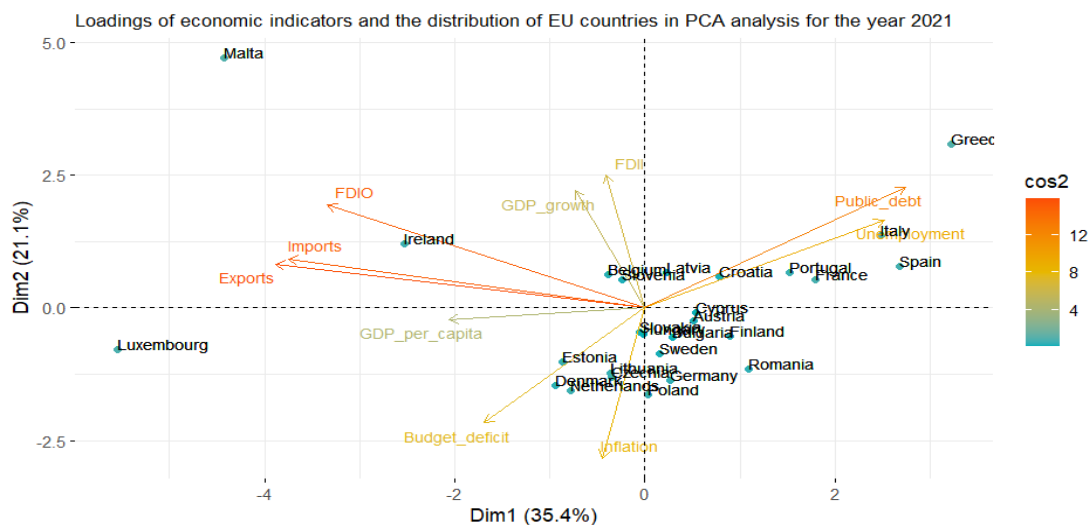


Figure 6. Loadings of economic indicators and countries in PCA analysis – year 2000

Source: Eurostat & World Bank. The data was processed by the author with statistical software R

Regarding the analysis for the year 2021 (Figure 6), we can note that countries such as Greece, Italy or Spain are placed in quadrant I (top right) close to indicators such as public debt and unemployment, which suggests that the challenges associated with debt and the labour market are relevant to these economies. This may reflect the continuing impact of previous economic crises and fiscal and social sustainability challenges. The presence of these countries near the public debt and unemployment indicators highlights a common set of economic

challenges, including the long-term impact of financial and debt crises, labour market difficulties and fiscal sustainability challenges. This indicates that despite their geographic diversity and differences in economic structure, these nations face similar problems in managing public finances and the labour market.

Geographically, countries such as Greece and Spain have been deeply affected by the European sovereign debt crisis and have implemented extensive austerity programs and economic reforms. Public debt and unemployment problems reflect the difficulties of economic recovery and structural adjustment. In CEE, although not as affected by the sovereign debt crisis as the southern countries, these states face their own challenges related to fiscal sustainability and labour market structure, partly resulting from the post-communist transition and EU integration. On the other hand, France, as part of the western core of the EU, demonstrates that public debt and unemployment challenges are not limited to the periphery of the Union, but also affect larger, developed economies struggling with structural rigidities and fiscal pressures.

This geographical diversity in Quadrant I underlines that, despite different economic contexts and histories, EU countries share common challenges related to managing public debt and unemployment. This highlights the importance of European solidarity and coordinated policies to address these challenges. The common presence of these challenges may indicate a form of real convergence, in the sense that countries face similar problems at their respective stages of development and European integration. This suggests that, regardless of economic and historical diversity, EU economies tend to experience common challenges, which require coordinated solutions and adaptive policies.

However, the presence of these common challenges could also suggest areas of divergence, particularly if the pace of recovery and the ability to respond to these challenges differ significantly between countries. The divergence could become apparent if some countries manage to overcome their public debt and unemployment problems more quickly, while others lag behind.

Ireland and Malta, part of Quadrant II (top left) alongside exports, FDII, FDIO and GDP growth, indicate strongly outward-oriented economies as well as the benefits of integration into the global economy. Significant arrows (loadings) for FDIO and FDII indicate deep integration into the global economy through foreign investment. The size of the arrows suggests a considerable influence of direct investment flows on the economies of these countries. This may reflect attractive investment policies and a favorable business environment. In the same vein, the considerable size of the arrows for exports and imports underscores the heavy dependence of these economies on international trade. This highlights the competitiveness of their export sectors and the need for imports to support domestic production and consumption. Concluding the above, we can state that the length of the arrow associated with GDP growth illustrates the direct impact of international trade and foreign direct

investment on economic growth. This suggests that external economic strategies contribute significantly to overall economic performance.

This quadrant highlights how economic integration, trade openness and policies attractive to foreign direct investment play a very important role in promoting economic growth. In conclusion, the success of countries in this quadrant demonstrates the value of European integration and international cooperation in boosting economic performance in a globalized environment.

Looking at quadrant III (bottom left) of the 2021 CPA analysis, which includes Luxembourg, Estonia, Denmark, the Netherlands and Lithuania, close to the intersection of the axes, and focusing on economic indicators such as inflation, GDP per capita and budget deficit, we can say that the mentioned countries are effectively managing inflationary pressures, maintaining inflation rates that do not deviate significantly from the average, which indicates a balanced monetary and fiscal policy. On the other hand, the significant size of GDP/capita for Luxembourg and the proximity for the other countries highlight the high levels of income per capita, indicating general economic well-being and a higher quality of life.

The presence of the budget deficit highlights fiscal challenges, but the positioning close to the intersection axis for some countries suggests that they are managing to keep the budget deficit within manageable limits, reflecting fiscal prudence and sustainability in the medium to long term.

Placing these countries in the same quadrant, given the diverse economic context of the EU, may also reflect a form of convergence in terms of economic stability and sustainability. This could suggest that, despite the structural and economic diversity, the political and economic coordination mechanisms of the EU contribute to the promotion of common principles of stability and sustainable economic growth among states.

The lack of indicators in quadrant IV suggests a concentrated distribution of countries around other major axes of economic interest in the PCA analysis.

Understanding the positioning of a group of countries such as Romania, Poland, Denmark, Sweden, Finland, Slovakia, Cyprus, Austria and Germany in the PCA analysis for the year 2021, with all being placed between the values specified on dimensions 1 and 2, suggests a distinct economic profile for these countries within the EU. This placement indicates economic characteristics and performance that are worth exploring in detail. Countries' placement near 0 and towards 1 on this dimension suggests economic performance that is less negatively influenced by the predominant factors captured in this principal component. These countries may have relatively balanced and stable economies with good management of the main macroeconomic challenges, which allows them to avoid extremes on both dimensions of the PCA analysis.

Economies such as those of the Nordic countries (Sweden, Finland, Denmark) are known for innovation and a high level of social and economic development, which could contribute to

their distinct placement in the analysis. Germany and Austria, as major EU economies, alongside developing countries such as Romania and Poland, illustrate resilience and adaptability, reflecting a combination of sustainable economic growth and macroeconomic stability.

The placement of these countries in a relatively compact and specific area of the PCA diagram could indicate aspects of economic convergence within the EU, especially in terms of balanced management of the economy and the promotion of innovation and sustainable growth. This suggests that although there are differences between member countries' economies, there are also common features that can serve as a basis for cooperation and common policies in the EU.

In conclusion, the PCA analysis for the year 2021 illustrates the complex relationships between economic indicators and the performance of EU countries, highlighting the impact of economic integration, globalization and domestic economic policies on different dimensions of economic performance. We see a diversity of economic trajectories among EU countries, from those facing fiscal and labour market challenges, to economies that are strongly outward-looking and benefiting from integration into the global economy. This underlines the importance of continued structural reforms, economic policy adaptability and European cooperation to address economic disparities and promote sustainable and inclusive growth.

The next analysis, regarding the progress of convergence, we will perform the cluster analysis with visualization through the related dendrograms of the years 2000 and 2021.

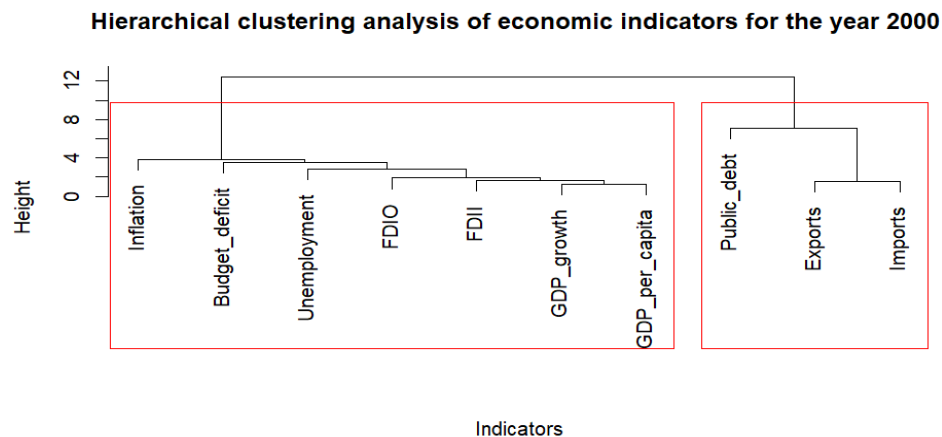


Figure 7. Dendrogram after cluster analysis for the year 2000

Source: Eurostat & World Bank. The data was processed by the author with statistical software R

The dendrogram analysis for the year 2000 (Figure 7) reflects an economic structure where domestic policy (reflected by inflation, unemployment, GDP and foreign investment) and external performance (represented by the trade balance and public debt) form two major axes of analysis. In the context of economic convergence, this model suggests that there are two main directions in which countries can work to improve economic

performance: internally (by stimulating economic growth and attracting investment) and externally (by optimizing trade and managing debt).

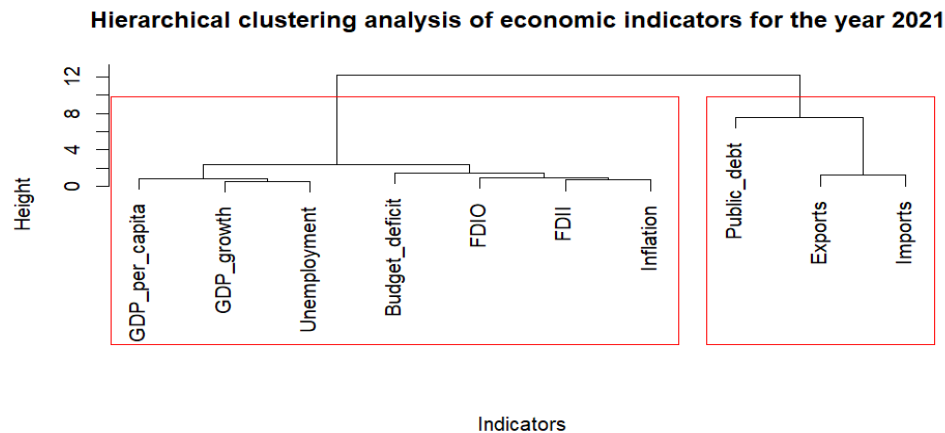


Figure 8. Dendrogram after cluster analysis for the year 2021

Source: Eurostat & World Bank. The data was processed by the author with statistical software R

The dendrogram of 2021 (Figure 8) confirms the trends towards greater global economic integration and the importance of balanced management of external and internal relations. Indicators show that a holistic approach, combining economic stimulation (through growth and investment) with fiscal prudence (reflected in debt management and inflation), is essential to ensure sustainable economic convergence.

Following the analysis of the dendrograms, it can be seen that the years 2000 and 2021 present a common cluster with the same indicators, while the other cluster differs in the associations between the indicators. This segmentation is interesting and may at first seem counterintuitive in the context of a discussion of economic convergence. This phenomenon can be interpreted by the complexity and dynamics of the global economy, as well as by the way economic indicators interact with each other during different economic cycles and stages of development.

The analysis of the dendrograms from 2000 and 2021 illustrates an evolution of the economic structure, marking a transition from more simplified to more complex and interconnected segmentations. This highlights the impact of globalization, the very important role of foreign investment and the need for prudent management of public finances. Prospects for economic convergence should take into account these complex dynamics, balancing economic stimulus with fiscal and trade sustainability to move forward effectively in an ever-changing global environment.

The next step in the analysis is to interpret the PCA results to identify the directions in which the data show the most variation, and how each indicator contributes to these directions.

Table 1. PCA of EU Economic Indicators - year 2000

Indicators	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Exports	-0.404	0.370	0.080	-0.036	-0.051	-0.236	-0.411	0.051	-0.044	-0.679
Imports	-0.357	0.433	0.194	0.013	-0.100	-0.183	-0.266	0.086	0.208	0.695
FDII	-0.298	-0.190	0.559	-0.298	0.280	-0.167	0.221	-0.485	-0.286	0.041
FDIO	-0.271	-0.452	0.176	-0.231	0.294	-0.010	0.003	0.655	0.346	-0.046
GDP_growth	-0.280	0.384	0.203	0.210	0.074	0.663	0.429	0.198	-0.116	-0.084
Inflation	0.237	0.158	0.050	-0.775	-0.240	0.273	-0.182	0.207	-0.322	0.062
Unemployment	0.372	0.038	0.307	0.333	0.501	0.058	-0.457	0.201	-0.383	0.077
Public_debt	-0.068	-0.413	0.408	0.227	-0.557	0.367	-0.364	-0.140	0.100	-0.031
Budget_deficit	-0.337	-0.137	-0.472	-0.130	0.384	0.453	-0.390	-0.335	0.047	0.099
GDP_per_capita	-0.395	-0.269	-0.291	0.179	-0.228	-0.162	0.043	0.268	-0.691	0.157

Source: Eurostat & World Bank. The data was processed by the author with statistical software R

The analysis of the main components for the year 2000 (Table 1) shows us a perspective on the data structure of the economic indicators, identifying the directions in which the data show the greatest variation (the main components) and how each indicator contributes to these directions. PC1 and PC2 together account for almost 60% of the total variation in the data, with 36.22% for PC1 and 23.56% for PC2. This suggests that these two components capture a significant portion of the information in the data set. PC3 and PC4 add another 11.57% and 10.41%, reaching almost 82% of the explained variation.

Later components (PC5 - PC10) have smaller contributions, indicating that most of the useful information can be effectively represented by the first four components.

PC1 is negatively influenced by indicators that refer to external economic performance (exports, imports, FDII, FDIO, GDP/capita) and positively by inflation and unemployment. This suggests that PC1 might represent a dimension of internal versus external economic performance and provides insight into the duality between internal and external aspects of the economy. This configuration suggests that PC1 captures the contrast between a country's domestic economic health and external commitments. On the one hand, a high value of this component indicates an economy with higher unemployment and inflation, suggesting potential domestic challenges such as weak domestic demand, cost pressures or labour market inefficiencies. On the other hand, the negative contributions from exports, imports, foreign direct investment and per capita underline the importance and impact of external economic interactions.

PC2 shows mixed contributions, with imports and GDP growth having positive influences, while FDIO and public debt are negative. This could indicate a dimension related to external versus internal financial balances. This principal component, which presents a mixture of positive influences from imports and GDP growth, negative influences from the foreign direct investment portfolio and public debt, provides insight into the dynamics between an economy's external and internal financial balances. This suggests that PC2 may reflect a tension

between the economic stimuli generated by domestic activity and the pressures or constraints generated by the external financial situation and public debt.

According to the PCA analysis for the year 2000, the main forces shaping the economy appear to be related to the balance between domestic and foreign economic performance.

Table 2. PCA of EU Economic Indicators - year 2021

Indicators	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Exports	-0.493	0.136	0.055	0.014	-0.300	0.013	-0.207	-0.140	-0.201	-0.737
Imports	-0.476	0.152	-0.021	-0.037	-0.336	0.010	-0.366	-0.196	-0.154	0.663
FDII	-0.052	0.411	-0.453	-0.131	0.528	-0.281	0.058	-0.462	-0.176	-0.027
FDIO	-0.423	0.318	-0.031	-0.225	0.034	-0.193	0.210	0.345	0.683	0.007
GDP_growth	-0.093	0.363	-0.050	0.851	-0.035	0.119	0.321	0.085	-0.056	0.066
Inflation	-0.057	-0.466	-0.395	0.095	-0.430	-0.326	0.398	-0.362	0.184	0.001
Unemployment	0.319	0.271	0.306	0.065	-0.256	-0.788	-0.124	0.104	-0.117	-0.002
Public_debt	0.348	0.374	0.251	-0.074	-0.263	0.307	0.005	-0.575	0.418	-0.040
Budget_deficit	-0.214	-0.355	0.367	0.375	0.429	-0.215	-0.326	-0.310	0.347	-0.010
GDP_per_capita	-0.261	-0.035	0.584	-0.218	0.111	-0.024	0.627	-0.184	-0.304	0.104

Source: Eurostat & World Bank. The data was processed by the author with statistical software R

In order to interpret the 2021 main components (Table 2) of the 2021 economic data, we will focus on how they capture different aspects of economic dynamics, based on the weights of each economic indicator in the first main components, as well as the proportion of variance explained by each of these components. PC1 (35.42% of the total variation) is dominated by exports, imports, FDII, FDIO and public debt, with exports and imports having large negative weights. This indicates that PC1 could reflect forces related to trade balance and capital flows. A large negative value for exports and imports suggests a shift towards import-dependent economies, while a large positive weight for public debt reflects the impact of public finances on the economy. A negative weight for FDII and FDIO also indicates an impact of foreign investments on the domestic market.

PC2 (21.13% of the total variance) shows strong positive influences from FDII and negative influences from inflation, which may suggest that this component seems to distinguish between foreign direct capital and domestic pressures such as inflation. The positive contribution of FDII together with the negative contribution of inflation could reflect the tension between attracting foreign investment and maintaining price stability.

In PC3 (16.01% of the total variance) the large positive share of GDP per capita is remarkable, suggesting that this component could represent the level of development or economic prosperity. Negative contributions from FDII may indicate that in more developed countries, domestic direct investment may be more important than foreign direct investment.

The analysis suggests that the economy in 2021 is strongly influenced by the balance between foreign trade and the state of public finances (PC1), the balance and tension between

foreign investment and domestic stability (PC2) and the degree of economic development measured by GDP per capita in contrast with foreign direct investments (PC3).

The comparative analysis of economic data through the prism of principal components analysis for the years 2000 and 2021 reveals a significant evolution in the approach and structure of economies in the context of globalization and macroeconomic changes. During these two decades, changes in economic dynamics are not just reflections of variations in numbers, but rather of a strategic adaptation and maturation of economic policies at the global level.

In 2000, economies were marked by a clear distinction between domestic and external performance, illustrated by the contrast between domestic economic health (inflation and unemployment) and external commitments (exports, imports, foreign direct investment). This divide shows the struggle of economies to balance domestic needs with international pressures and opportunities, an important aspect in the context of accelerating convergence.

As we move into the year 2021, we see a significant shift, where economic concerns are no longer divided into domestic and foreign, but rather reflect a complex interdependence, where trade balance, public debt management and attractiveness for foreign direct investment take on new dimensions. This evolution reflects an adaptation to a changing global environment, in which the impact of public finances on the economy becomes more and more evident, and the need to attract foreign capital is balanced with the need to maintain internal stability, especially in the context of inflation.

Moreover, the increased focus on GDP per capita in 2021 indicates a shift towards recognizing the importance of sustainable economic development and prosperity. It is no longer just a performance indicator, but becomes a central objective of economic policies, reflecting a deep understanding that economic growth must be inclusive and benefit the entire population.

Conclusions

The detailed analysis of the economic data for the member states of the EU during the period 2000-2021 showed that the process of convergence continues, but critical aspects related to this process were also identified. PCA and dendrogram analysis revealed a clear trend towards economic alignment between member countries, signalling a deeper integration among EU economies. This convergence, manifested by the convergence of inflation rates and GDP per capita, reflects the success of unified monetary policies and harmonized economic frameworks at European level. However, the persistence of divergences in fiscal and labour market management underlines the limits of current convergence and the need for more coordinated and tailored approaches at the level of each member state.

Referring back to the year 2000, macroeconomic indicators are dispersed, indicating diverse economic profiles between EU countries, convergence being suggested by a closer grouping of these indicators over the years. Thus, indicators such as inflation and

unemployment form a separate cluster, suggesting a dissociation from other economic variables. Over time, we see a tendency to unify the indicators into more coherent clusters, indicating a harmonization of economic trends between member states. This trend of clustering and convergence between different indicators suggests economic convergence in the EU, possibly reflecting more uniform economic policy and strengthened economic integration.

The observed convergence may be influenced by several factors, including the global financial crisis of 2008-2009, which changed the perspective on global interconnections and the role of macroeconomic policies. Also, an increase in global economic integration, changes in the structure of world trade, and increased attention to the impact of foreign investment on local economies could contribute to this convergence trend.

Therefore, it is essential to know that, although economic convergence between EU countries is a fundamental objective, it is not sufficient on its own to ensure economic security. Convergence must be accompanied by robust solidarity mechanisms, effective cohesion policies and an increased capacity of the Union to respond collectively to economic crises. This requires a dynamic and adaptable approach that capitalizes on the progress made in convergence, but is also prepared to address new economic challenges and mitigate remaining divergences.

In conclusion, the economic security of the European Union in a volatile global environment requires more than achieving economic convergence, it requires a comprehensive vision and concerted actions that promote not only economic alignment, but also increased collective resilience. The integrated approach, comprising structural reforms, fiscal consolidation and cross-border cooperation, will be the key to a more secure and prosperous European Union, able to adapt effectively to the challenges of the 21st century.

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