CHAPTER 11

Changes in the European Union Countries' Levels of Innovation Performance at Time of Pandemic

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Summary. The main objective of this chapter is to present changes in the levels of innovation performance of the EU economies during the pandemic. This is realised by analysing the changes of the Global Innovation Index (GII) in 28 European Union countries in 2019 and 2022. The empirical research (including data visualisation, descriptive statistics and *k*-means clustering) has been performed in the R programming language. The results clearly show the time of the pandemic was in no way conducive to the growth of innovation in the economies. The mean GII for EU-28 in 2019 was 49.1, to decline to 46.09 in 2022. Twenty-five EU countries experienced falling GII in 2019–2022. Only 3 out of the 28 countries reviewed managed to slightly improve their innovativeness (France, Malta, and Estonia). The added value of this study consists in supplying data on the changes of innovation levels in the particular countries, tracking these changes in comparison with other countries, and identifying similarities (a division into clusters). This may provide valuable information to decision-makers in the individual countries when making informed decisions about innovation policies.

Keywords: innovation, Global Innovation Index, European Union, pandemic, clusters

1. Introduction

The European Union pays considerable attention to the assessment and growth of innovation in its member states. Evaluating changes in the levels of innovation performance in the particular EU countries becomes a key issue, therefore. The analysis and assessment of these changes during the pandemic is an extraordinarily interesting and topical problem. Thus, the chief objective of this chapter is to present changes in the levels of innovation performance in the EU economies during the pandemic. 2019 and 2022, that is, the year before and after the pandemic, are selected for the purpose. To reach the objective, the changes of the Global Innovation Index (*Analysis…*, n.d.) in 28 European Union countries at the time are reviewed.

The United Kingdom is taken into account, not an EU member since 1 January 2020, but still one in 2019. Since the authors were anxious to have as up-to-date figures as possible, the innovation reports for 132 global economies, published annually at the Global Innovation Index (GII) website, are the principal source of data. The following research hypotheses are posited:

HS1: The GII declined for most EU-28 countries in the period under analysis.

HS2: The GII changes for the European Union countries during the pandemic are not homogeneous and certain country groupings (clusters) can be distinguished in respect of their GII structure.

HS3: Migrations of some countries between the clusters identified for 2019 and 2022 are expected.

The hypotheses are verified by analysing the changes of GII for 28 countries and by identifying the changes of cluster structures formed on the basis of the index in 2019 and 2022. The empirical study consists of two stages. First, the basic measures of time series dynamics are used to define the dynamics of the index changes. In order to classify the countries with the similar values and structures of the GII, the cluster analysis is then applied, one of the fundamental unsupervised learning methods.

The added value of this study consists in supplying data on the changes of innovation levels in the particular countries, tracking these changes in comparison with other countries, and identifying similarities (a division into clusters). This may provide valuable information to decision-makers in the individual countries when making informed decisions about innovation policies.

2. Key factors of innovative activity

Innovations have become a driving force of the economy and a major determinant of a country's socio-economic development. They are important for driving economic progress and competitiveness for both developed and developing economies. Many governments are putting innovation at the centre of their growth strategies.

Economic sciences owe the first definition of innovation to J.A. Schumpeter. He defined it as an inimitable, fundamental and radical change; a transformation of a new idea or technological invention into a marketable product or process. This is a broad approach to innovation, which covers the introduction of a new method or production organization, application of new raw materials or semi-products in the market, introduction of new products to the manufacturing process, or developing of a new market (Schumpeter, 1960, pp. 99–101).

These days, the innovation discussed in various studies more often includes both fundamental changes to new products and processes – new for an industry as well as for enterprises – and simple modifications to existing products, processes and practices (Matusiak, 2011, p. 112).

Such an understanding of innovation refers to the implementation of a new or significantly improved product (or service) or process, a new marketing or organisational method to economic practice, reorganising a way of working, a workplace or a company's relations with its social environment. Products, processes and methods (technical, organisational and marketing) may be called innovations if they are new or substantially improved, at least from

the viewpoint of the company introducing them. Innovations include social, business model, and technical aspects. Innovative activities are understood as all the activities of a scientific, technical, organisational, financial, and commercial nature which aim at the commercial application of a new solution. Some of these activities are innovative themselves, while others may not involve an element of novelty, but are essential for the development and implementation of innovation. Innovation may be created by an enterprise itself or may rely on purchased external goods or services, including knowledge or consulting services (*Podręcznik Oslo…*, 2008, p. 48). A crucial element of the innovation process is its commercialisation. This is a wide spectrum of activities that refer to the transformation of knowledge into new products, technologies and organisational solutions (Matusiak, 2011, pp. 139–140).

3. Research methodology

The Global Innovation Index figures for 2019 and 2022 (*Analysis…*, n.d.) serve to analyse changes in the levels of innovation performance in 28 EU countries caused by the pandemic. The study addresses the United Kingdom, too, still an EU member in 2019.

The GII reveals the most innovative economies in the world, ranking the innovation performance of 132 economies. It helps countries assess areas in which they need to concentrate their efforts to boost their innovation performance. The Global Innovation Index (GII) was launched in 2007 with the aim of identifying and determining metrics and methods that could capture a picture of innovation in society that is as complete as possible. The purpose of the GII is to provide insightful data on innovation, to track major innovation developments at the country and regional levels and, in turn, to assist policymakers with evaluating their innovation performance and making informed innovation policy decisions (Dutta et al., 2022, p. 57).

Our empirical research was carried out using *k*-means clustering with the aid of the Rprogramming language. More precisely, the implementation of '*k*-means' function belongs to the package 'stats'. We have decided to use Hartigan and Wong algorithm (Hartigan, Wong, 1979) as it usually converges well. The general idea of clustering is to partition points into k groups such that the sum of the squared distances from the points to assigned cluster centres is minimized. Furthermore, all cluster centres lie at the mean of the respective Voronoi sets (Voronoi set is a set of data points nearest to the centre of a cluster). The unique feature of Hartigan and Wong algorithm is the initial assignment of data points to random centroids. Then, in the loop, the centroids are recalculated as the mean of assigned data points. The loop ends when convergence is achieved (meaning that no data point changes its assignment in the next iteration).

4. Innovation performance of the European Union countries in 2019 and 2022 – empirical results

The analysis of changes in the levels of innovation performance by selected countries in 2019 and 2022 clearly demonstrates the time of the pandemic was a period of declining innovation for most of them.

Figure 1 presents a visualisation of changes in Global Innovation Index between 2019 and 2022. The 2019 values are shown on the *x*-axis the 2022 values, on the *x*-axis. All the countries are respectively labelled, the black dots represent the exact pairs of (2019, 2022) values. Therefore, by adding lines between the axes *y* and *x*, we can separate our dataset into two groups:

1) The countries above the line, meaning that their 2022 GII value is greater than the 2019 GII value – we can conclude that these countries are more competitive in terms of innovation now than three years ago. We have identified only three such countries (Estonia, France, and Malta).
2) The countries below the line, meaning that the 2022 GII value is smaller than the 2019 GII value – this implies that innovation competitiveness decreased in the period discussed. A vast majority (25 out of 28) of the examined countries are in this group.

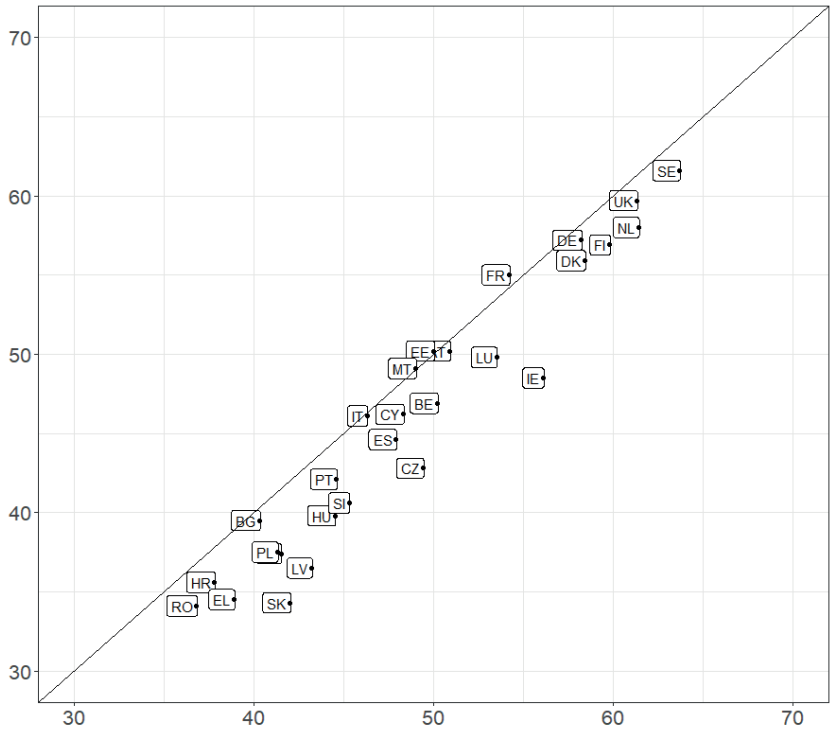

Fig. 1. A visualisation of changes in the Global Innovation Index in the 2019–2022 timeframe

An overall decrease of the Global Innovation Index in the population of countries considered is examined more closely using additional visualisation and statistical tools:

1. Table 1 presents the values of some of the key descriptive statistics indicators – minimum, median, mean, and maximum. We can conclude that all of the above declined in the research period – both in absolute and relative terms.

2. Figure 2 presents two boxplot charts, for the 2019 and 2022 data, respectively. These reinforce our conclusion of an overall decrease in GII – both for the core part of the population represented by the "boxes" and the outliers represented by the "whiskers".
3. The most sophisticated support for our point is achieved by the use of the empirical cumulative distribution function (ECDF) as shown in Figure 3. Separate ECDF functions are plotted for the 2019 and 2022 data for a more convenient comparison. We can conclude that the GII generally reduced in that period as, for any given percentile, the 2019 GII value is greater than or equal to the 2022 GII value.

Table 1. The descriptive statistics of Global Innovation Index data (2019 and 2022 comparison)

	2019	**2022**	**Change**	**Relative change [%]**
Minimum	36.8	34.1	−2.7	−7.34
Median	48.65	46.15	−2.5	−5.14
Mean	49.1	46.09	−3.01	−6.13
Maximum	63.7	61.6	−2.1	−3.30

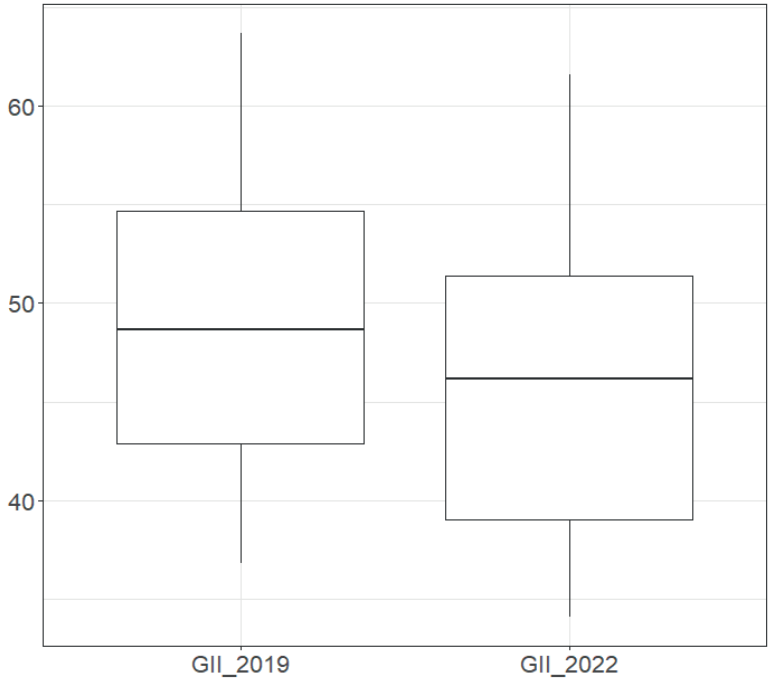

Fig. 2. Boxplots describing the distribution of the Global Innovation Index data for 2019 and 2022

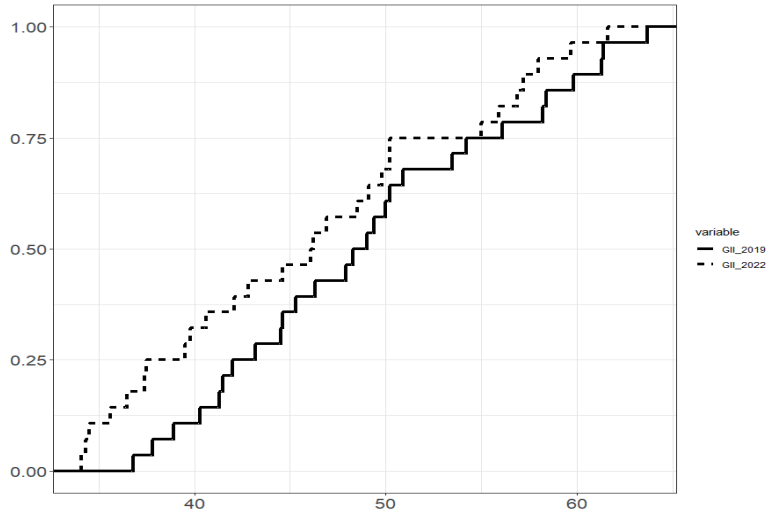

Fig. 3. A comparison of the 2019 and 2022 Global Innovation Index data using the empirical cumulative distribution function

Figure 4 visualises the results of *k*-means clustering applied to the Global Innovation Index data together with its subindices, for 2019 data. Four clusters were set in the Hartigan and Wong algorithm as the results were the most appealing. The number of countries in each cluster is reasonably stable, which was not the case when the number of clusters was increased. Given the split of the GII into two subindices, one can plot the cluster using two dimensional coordinates, therefore, assessing the sensibility and quality of clustering is significantly simpler. We deem the clusters to be separated well and concentrated around their respective centroids (marked as the larger rectangles on the chart). If we enumerate clusters from I to IV, where I represents the cluster with the lowest mean GII and IV is the cluster with the highest mean, we obtain (in alphabetic order):

- I cluster: Bulgaria, Croatia, Greece, Lithuania, Poland, Romania (6 countries);
- II cluster: Hungary, Italy, Latvia, Portugal, Slovakia, Slovenia (6 countries);
- III cluster: Austria, Belgium, the Czech Republic, Cyprus, Estonia, France, Luxembourg, Malta, Spain (9 countries);
- IV cluster: Denmark, Finland, Germany, Ireland, the Netherlands, Sweden, the United Kingdom (7 countries).

Figure 5 visualises the results of *k*-means clustering applied to the Global Innovation Index data together with its subindices, for 2022 data. The results of clustering are as follows:

- I cluster: Croatia, Greece, Latvia, Lithuania, Poland, Romania, Slovakia (7 countries);
- II cluster: Bulgaria, the Czech Republic, Hungary, Portugal, Slovenia, Spain (6 countries);
- III cluster: Austria, Belgium, Cyprus, Estonia, Ireland, Italy, Luxembourg, Malta (8 countries);
- IV cluster: Denmark, Finland, France, Germany, the Netherlands, Sweden, the United Kingdom (7 countries).

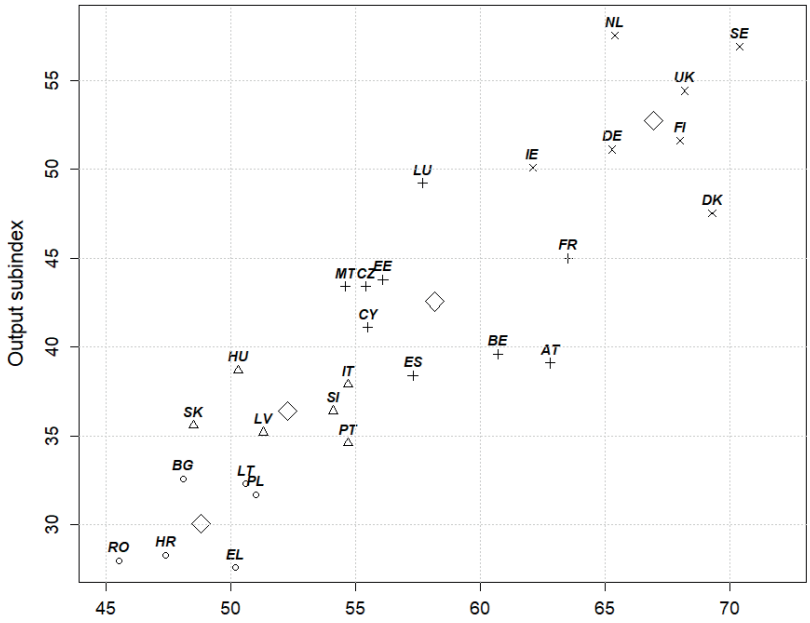

Fig. 4. A visualisation of *k*-means clustering applied to the 2019 Global Innovation Index data

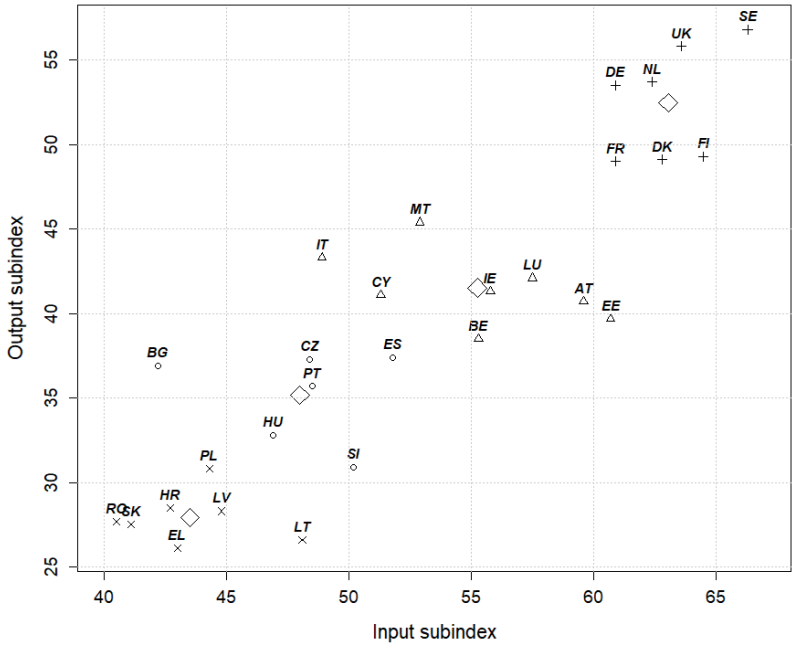

Fig. 5. A visualisation of *k*-means clustering applied to the 2022 Global Innovation Index data

Analysing the Global Innovation Index for the countries concerned as set against EU-28 average (which was 49.1 in 2019 and 46.09 in 2022), we can conclude that:

- In 2019, 15 out of 28 countries exhibited GII values below EU-28 average – Bulgaria, Croatia, Cyprus, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, and Spain.
- In 2022, 13 out of 28 countries were assigned to GII values lower than EU-28 average – Bulgaria, Croatia, the Czech Republic, Greece, Hungary, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, and Spain.
- In 2019, Romania had the lowest GII (36.8), while Sweden reached the highest GII (63.7)
- The lowest GII value was noted for Romania in 2022 – 34.1. On the other hand, the highest GII value was achieved by Sweden in 2022 – 61.6.
- GII values greater than EU-28 average in both the years under review were scored by the following countries: Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Sweden, and the United Kingdom.
- The highest absolute increase in GII (0.8) and the highest relative increase (1.476%) were generated by France.
- The largest absolute and relative decreases in the GII are observed for Slovakia, −7.7 and −18.33%, respectively.

5. Conclusion

The objective of this chapter is to present the changes of innovation performance in the EU economies during the pandemic. To this end, the research hypotheses are verified.

The analysis of results shows the GII exhibited some changes between the two years discussed, i.e., 2019 and 2022. The changes are distinctly negative, as they involve the substantially lower levels of innovation performance in most economies reviewed in the period studied.

Hypothesis 1, which states GII declined for most EU-28 countries in the period under analysis, is upheld. The average GII for EU-28 was 49.1 in 2019, to reduce to 46.09 in 2022. 25 EU countries experienced GII falls in 2019–2022. Only France, Estonia, and Malta noted modest GII increases at the time (1.48%, 0.4%, and 0.2%, respectively).

Hypothesis 2, according to which the GII changes for the European Union countries during the pandemic are not homogeneous and certain country groupings (clusters) can be distinguished in respect of the GII structure, is affirmed as well. 4 clusters are distinguished for both 2019 and 2022. Cluster I comprises the countries whose GII is minimum among the countries analysed in a given year, whereas cluster IV consists of countries that reached the highest values of the Global Innovation Index in a year. These most innovative countries included Denmark, Finland, Germany, the Netherlands, Sweden, and the UK in both 2019 and 2022. It should be pointed out, though, all these economies displayed lower innovation indices in 2022 than in 2019. Among the most innovative economies, the decline was the sharpest in the case of Ireland (by 13.55%), which slid down to cluster III in 2022 as a result.

Both in 2019 and 2022, Austria, Belgium, Cyprus, Estonia, Luxembourg, and Malta belonged to cluster III. Ireland joined them in 2022, though it had been classified into cluster IV in 2019. The Czech Republic and Spain, cluster III in 2019, have moved up to cluster II

in 2022. It should be noted Italy moved from cluster II to III in 2019–2022, although its GII reduced by 0.43% at the time.

Hungary, Portugal, and Slovenia were in cluster II both in 2019 and in 2022. In 2022, Spain joined cluster II, shifted from cluster III. In 2019, Latvia and Slovakia qualified for cluster II, in 2022 moving to cluster I, which includes countries with the lowest GII.

Croatia, Greece, Lithuania, Poland, and Romania were in cluster I in both 2019 and 2022. Bulgaria was assigned to that cluster In 2019, too, yet it moved to cluster II in 2022, although its GII fell by 1.99% in 2019-2022.

The above migrations of states between the clusters prove the hypothesis 3, which anticipates migrations of some countries between the clusters identified for 2019 and 2022.

The results of this analysis clearly show the years of the pandemic were extraordinarily difficult for a great majority of economies worldwide, not only those weakest. Countries with the highest levels of innovation performance (Sweden, UK, the Netherlands, Germany, Finland, and Denmark) experienced declining innovation indices as well.

To achieve a high level of innovation performance, countries need a balanced innovation system performing well across all dimensions. They need an appropriate level of public and private investment in education, research and skills development, effective innovation partnerships among companies and with academia, as well as an innovation-friendly business environment, including strong digital infrastructure and skills (*European Innovation…*, 2022, p. 6). This research implies the period of the pandemic escalated these needs even more.

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