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The Innovativeness of the Economies of European Union Candidate Countries – an Assessment of Their Innovation Gap in Relation to the EU Average

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Abstract

Innovation is nowadays seen as an essential success factor in achieving economic prosperity and competing in markets. It is one of the most important determinants of the competitive process throughout the world, helping economies catch up with developing and changing technologies while revealing those countries' innovation perspectives.

The article assesses the innovativeness of the economies of selected European Union (EU) candidate countries based on the Summary Innovation Index (SII). It also estimates the innovation gap between these countries and the EU average of the SII between 2015 and 2022. The analysis is limited to Türkiye, Serbia, Albania, Montenegro, North Macedonia, Bosnia and Herzegovina, and Ukraine due to the availability of data that describes the SII. It provided for all the countries surveyed in the European Innovation Scoreboards, i.e., the reports of the European Commission, only from 2015. The presented analysis is based on a research hypothesis that suggests that the surveyed countries are characterized by a lower level of innovativeness of economies than the EU average, and therefore, they show an innovation gap compared to the average for EU countries in the analyzed period. The results of the analysis confirm this hypothesis – between 2015 and 2022, the economies of all the examined candidate countries recorded a lower level of innovativeness than the EU average. They showed a lower level of the SII than the EU average, and therefore, all these countries demonstrated an innovation gap compared to the EU average. Recommendations for increasing the innovativeness of those economies are formulated separately in the conclusions.

The article reviews the literature on the innovation and innovativeness of economies and the innovation gap. Descriptive analysis, statistical data analysis, and comparative analysis methods are

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applied, and statistical data from the European Innovation Scoreboard 2022 are used. The value added of the article lies in its comparison of the level of innovativeness of the economies of selected EU candidate countries to the EU average, as well as its estimation of the innovation gap between these countries and the EU average.

Keywords: innovation, innovativeness of an economy, innovation gap, European Innovation Scoreboard, Summary Innovation Index

JEL: O30, O31, O43

Introduction

Innovation is nowadays seen as an essential success factor in achieving economic prosperity and competing in markets. It is one of the most important determinants of the competitive process throughout the world, helping economies catch up with developing and changing technologies while revealing the innovation perspectives of those countries (Aytekin et al. 2022, p. 1; Strahl and Sobczak 2017, p. 42). Innovation can be understood broadly and narrowly. In its narrow aspect, an innovation is treated as something new, usually technical, and marketed for the first time. More broadly, the results of innovations are an important element of social reality, organizational structures, and marketing solutions, not only economic practice. Innovations understood in such a way bring benefits to the general public – not only to employers and producers but also consumers and employees (Ziółkowska 2018, p. 72; Maradana et al. 2017, p. 2).

The article assesses the innovativeness of the economies of selected European Union (EU) candidate countries based on the Summary Innovation Index (SII). It also estimates the innovation gap between these countries and the EU average of the SII between 2015 and 2022. The analysis is limited to Türkiye, Serbia, Albania, Montenegro, North Macedonia, Bosnia and Herzegovina and Ukraine due to the availability of data that describes the SII, which are provided for all the countries surveyed in the European Innovation Scoreboards, i.e., reports of the European Commission, only from 2015. The analysis assumes a research thesis supposing that the surveyed countries are characterized by a lower level of innovativeness of economies than the EU average, and therefore, they show an innovation gap compared to the average for EU countries in the analyzed period. The results of the analysis confirm this thesis – all the examined candidate countries in the period recorded a lower level of economic innovativeness than the EU average. They showed a lower level of the SII than the EU average, and therefore all these countries demonstrated an innovation gap compared to the EU average. Recommendations for increasing the innovativeness of those economies are formulated separately in the conclusions.

The article reviewed the literature on the innovation and innovativeness of economies and the innovation gap. Descriptive analysis, statistical data analysis and comparative analysis methods are applied. Statistical data from the European Innovation Scoreboard 2022 were used. The value added of the article lies in its comparison of the level of innovativeness of the economies of selected EU candidate countries to the EU average, as well as its estimation of the innovation gap between these countries and the EU average.

The concept of the innovation and innovativeness of the economy. Defining the innovation gap

Innovation is seen in the economic sciences as one of the key categories of modern economic processes. It is significant that in the literature devoted to the innovativeness of the economy, there is no uniform position on the content and scope of the concept of innovation. Different authors who use this term ascribe to it different meanings.

The concept of innovation in the economic sciences was introduced by Schumpeter in 1912. For the first time in economic theory, he formulated five cases of the emergence of new combinations of various material elements and man's productive power, which he later referred to as innovations. These include (Schumpeter 1960, p. 104):

- introducing new products into production or improving existing ones,
- introducing a new production method, i.e., one not yet tried in a given industry,
- opening a new market,
- acquiring new sources of raw materials or semi-finished products,
- reorganizing an industry, for example, the creation or liquidation of a monopoly.

Schumpeter also pointed to two other phenomena that accompany the creation of innovations, i.e., the invention of a new solution and imitation, which means the dissemination of innovations. He distinguished three phases of economic development (Schumpeter 1960, p. 104):

- the discovery of new goods and methods of production, i.e., the invention of something new;
- the commercialization of this invention, i.e., introducing it to the market, which usually requires a combination of old and new knowledge;
- the imitation of the innovator by others, which means dissemination and spreading (diffusing) innovations.

It is significant that the formula developed by Schumpeter's definition is still considered in the economic literature to be a classic definition, and it is a starting point for defining concepts in the field of innovative activity.

Innovativeness is related to the concept of "innovation" (Okrzesik 2018, p. 314; Dworak and Grzelak 2020, p. 37), and while the two terms are sometimes used interchangeably, they are not the same. Innovativeness is defined as the ability to innovate (Weresa 2012, p. 27) because, according to the terminology, it is an activity aimed at implementing innovations, both in the private and public sector (*Potencjał innowacyjny…* 2016, p. 21). The innovativeness of the economy can also be understood as the ability of the economy to create and implement innovations, where *ex ante* it is the possibility of developing new solutions, while *ex post* it is the combined effect of the innovative activity of the enterprise and other entities operating in a given economy in the analyzed period (Weresa 2012, p. 23).

The ability to innovate makes it possible to assess what resources an economy has at its disposal to create and commercialize new ideas. It is expressed in measures that describe expenditures (e.g., expenditure on R&D, human resources, infrastructure that supports the creation and diffusion of innovations). In the context of considerations on the innovativeness of the economy, it is also worth mentioning the concept of innovative position, which is the result of the creativity of the inhabitants of a given country and the use of financial resources in a given economic and institutional environment. It is described by performance measures (e.g., patents, sales of new and modernized products, or the share of exports of high-tech products in total exports). Separating the category of innovation capacity (the ability to innovate) and innovative position corresponds to the *ex ante* and *ex post* view on the concept of innovativeness of the economy (Weresa 2012, p. 23), and it allows us to indicate three ways to measure the level (*Potencjał innowacyjny…* 2016, p. 23; Szajt 2020, p. 9):

- Measurement using input indicators. These indicators include two main groups of variables: expenditure on research and development and the number of employees in research and development. The basic variable is the amount of expenditure on research and development (Gross Domestic Expenditure on Research and Development – GERD), i.e., the level of national expenditure on R&D presented as a percentage of GDP. It comprises three parts: business expenditure (BERD), higher education expenditure (HERD) and government expenditure (GOVERD).
- Measurement based on result indicators. These indicators include patent registers (e.g., the number of patents introduced by domestic entrepreneurs and guests), data describing the country's balance of payments in technology (e.g., the flow of own technologies and know-how from and to the country, funds obtained and paid for the use

of patents, licenses, trademarks and service), the number of scientific publications, and the volume of sales of new and modernized products.

- Measurement based on synthetic indicators, created on the basis of both input and output measures, but also taking into account the climate for innovation or the business environment. These indicators comprise numerous sub-measures and are developed to make more multifaceted comparisons of the level of innovativeness of economies. Their advantage is the increase in international comparability thanks to the parallel use of many variables that describe the innovativeness of economies.

To assess the innovativeness of an economy, the innovation gap between the economy of a given country and another entity recognized as a point of reference can be estimated. The concept of the innovation gap is variously interpreted in the economic literature. Kubielas defines it as differences in technological advancement between countries, and he proposes several methods to measure its size. He says that it can be measured by the distance between the technological activity of a country and the countries at the technological frontier, calculated either as a ratio of the number of patents per capita or the share of research expenditure in value-added or national income (Kubielas 2009, p. 137).

The literature review also revealed indirect measures, such as the share of high-tech products in exports in relation to a similar indicator for the technology frontier, the relationship between the productivity of a given branch of the country to a country on the verge of the technological frontier or, in aggregate terms, the relationship between GDP per capita and the corresponding indicator of the technological frontier (Kubielas 2009, p. 137). The last two approaches identify the technological gap with a productivity gap or income gap. The global technological frontier shall be deemed as the GDP level, which can be achieved by using the given inputs of capital and labor and the best possible technologies (Growiec 2012). This level of GDP is now achieved by the U.S. economy, in which the distribution of specialization is the standard for a technology leader. The highest competitive advantages are demonstrated by the science-based sector, followed by the specialized supplier sectors. By contrast, the scale-intensive and traditional sectors are characterized by negative indices of comparative advantage; the traditional sector is the lowest on the scale of advantages of the U.S. economy (Kubielas 2009, p. 153).

In the literature, there is also the concept of the innovation gap, understood as the distance between individual economies and the modern technological frontier. It is identified with the last stage of the socio-economic development of economies, i.e., the emergence of a knowledge-based economy (Lundvall 1992, pp. 25–36; Zacher 2007, p. 530; Pawlik 2014, pp. 68–69). The innovation gap is also perceived as a broader concept, encompassing non-technological innovation, such as processes, and organizational or social innovation.

An important research challenge is to connect the topic of dynamics and determinants of the innovation gap with the concept of innovation systems, which underlines the role of the organizational and institutional arrangements, such as public policies, scientific units, and innovative enterprises, which are considered the most essential agents within national innovation systems (Kowalski 2021, p. 1969). The United Nations defines the innovation gap quite generally as the distance between those who have access to technologies and know how to use them effectively and those who are not able to do so (Kraciuk 2006, p. 5). The innovation gap can be considered from the perspective of creating new technology in the home country, as well as from the perspective of its transfer from other countries and effectively adapting it to the needs and capabilities of the nation.

In summary, it can be stated that measuring the innovation gap means estimating the distance between a given country's economy and the most developed economies of Europe and the world, known today as knowledge-based economies, in many areas, e.g., in the sphere of innovation, education, and institutional system.

It is possible to estimate the innovation gap by comparing synthetic measures of innovation, e.g., the SII, developed by the European Commission, and the Global Innovation Index, developed by Cornell University in cooperation with the World Intellectual Property Organization (Mielcarek 2013; Weresa 2014, p. 64), or indicators that describe the advancement of the knowledge-based economy, e.g., the Knowledge Index and the Knowledge Economy Index, derived from the Knowledge Assessment Methodology.

This paper presents an attempt to estimate the innovation gap based on the indicator that shows the difference between the level of the SII for EU candidate countries and the average value of this index for the EU. The indicator of the innovation gap defined in this way takes the following form (Weresa 2014, p. 64):

$$L_{pt} = \frac{SII_{pt}}{SII_{UEt}}, \tag{1}$$

where:

L_{pt} – the innovation gap index for a candidate country in relation to the EU average in year t,

SII_{pt} – the Summary Innovation Index for a candidate country in year t,

SII_{UEt} – the average Summary Innovation Index for the EU in year t.

The value of the innovation gap index greater than 1 means that the country presents a higher level of innovativeness than the EU average. In contrast, a value lower than 1 indicates an innovation gap exists between that country and the EU average. To assess the changes in the innovation gap over time, a formula presenting the difference between the innovation gap index (L_{pt}) in a given year and the value of this index for the previous year should be used. It is written as follows (Weresa 2014, p. 64):

$$D_{pt_1} = \left[\frac{SII_{pt_1}}{SII_{uet_1}}\right] - \left[\frac{SII_{pt0}}{SII_{uet0}}\right], \quad (2)$$

where:

D_{pt1} – index of changes in the innovation gap between a given EU candidate country and the EU average in year t_1 compared to year t_0,

SII_{pt0} – the Summary Innovation Index for a given EU candidate country in year t_0,

SII_{uet0} – the average Summary Innovation Index for the EU in year t_0,

SII_{pt1} – the Summary Innovation Index for a given EU candidate country in year t_1,

SII_{UEt1} – the average Summary Innovation Index for the EU in year t_1.

The index of the change in the innovation gap (D_{pt1}) takes values from –1 to +1. Negative values indicate an increase in the innovation gap between a given country and the EU average, while positive ones indicate a decrease. Nevertheless, the index only indicates the direction of changes; it does not allow us to determine whether the distance shortens or the previously gained advantage is gradually being lost (Weresa 2014, p. 65). Therefore, it is necessary to analyze the index of changes in the innovation gap (D_{pt1}) in relation to the index of the innovation gap (L_{pt}).

Assessing the innovativeness of the European Union candidate countries. Estimating the innovation gap between the European Union candidate countries and the EU average

Table 1 shows the values of the SII for the EU candidate countries and the average value of the SII for EU countries between 2015 and 2022. Based on this index, a ranking of candidate countries for the EU in the analyzed period was prepared (Table 2).

Table 1. The Summary Innovation Index for EU candidate countries and the average value of the SII for EU countries, 2015–2022

SII	2015	2016	2017	2018	2019	2020	2021	2022
EU average	0.493	0.495	0.501	0.512	0.514	0.533	0.539	0.542
Albania	0.201	0.214	0.194	0.2	0.237	0.224	0.227	0.226
Bosnia and Herzegovina	0.185	0.18	0.181	0.158	0.155	0.181	0.194	0.189

SII	2015	2016	2017	2018	2019	2020	2021	2022
Serbia	0.258	0.251	0.271	0.291	0.311	0.344	0.353	0.335
North Macedonia	0.188	0.185	0.191	0.209	0.209	0.21	0.232	0.247
Montenegro	0.225	0.242	0.246	0.219	0.234	0.232	0.,25	0.257
Türkiye	0.261	0.262	0.27	0.299	0.302	0.25	0.251	0.259
Ukraine	0.17	0.164	0.155	0.152	0.148	0.153	0.16	0.168

Source: European Commission 2022, p. 99.

Table 2. Ranking of the EU candidate countries based on the values of the Summary Innovation Index, 2015–2022

No.	2015	2016	2017	2018	2019	2020	2021	2022
1	Türkiye	Türkiye	Serbia	Türkiye	Türkiye	Serbia	Serbia	Serbia
2	Serbia	Serbia	Türkiye	Serbia	Serbia	Türkiye	Türkiye	Türkiye
3	Montene-gro	Montene-gro	Montene-gro	Montene-gro	Albania	Montene-gro	Montene-gro	Montene-gro
4	Albania	Albania	Albania	North Macedonia	Montene-gro	Albania	North Macedonia	North Macedonia
5	North Macedonia	North Macedonia	North Macedonia	Albania	North Macedonia	North Macedonia	Albania	Albania
6	Bosnia and Herze-govina	Bosnia and Herze-govina	Bosnia and Herze-govina	Bosnia and Herze-govina	Bosnia and Herze-govina	Bosnia and Herze-govina	Bosnia and Herze-govina	Bosnia and Herze-govina
7	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine	Ukraine

Source: European Commission 2022, p. 99.

As shown in the data describing the SII values in Table 1, between 2015 and 2022, the highest SII values were noted by Serbia and Türkiye. In 2015, for Türkiye, this index was 0.261, and for Serbia, it was 0.258. In 2022, the values were: Türkiye – 0.259, Serbia – 0.335. Each of these countries was at the top of the ranking four times in the analyzed period. Third place in the ranking in the entire period, with the exception of 2019, was held by Montenegro. The lowest SII values and the lowest places in the ranking in each year were occupied by Bosnia and Herzegovina (in 2022, the SII value was 0.189) and Ukraine (0.168).

Table 3 shows the average annual rate of change (geometric mean) of the SII for the EU candidate countries between 2015 and 2022.

Table 3. The average annual rate of change (geometric mean) of the Summary Innovation Index for EU candidate countries, 2015–2022

Country	Average annual rate of change of SII, 2015–2022 (%)
European Union	101.36
Albania	101.69
Bosnia and Herzegovina	100.31
Serbia	103.80
North Macedonia	103.98
Montenegro	101.92
Türkiye	99.89
Ukraine	99.83

Source: calculations based on the data in Table 1.

Based on the data in Table 3, it can be concluded that an average annual increase in the SII index was observed in the following order: North Macedonia (3.98%), Serbia (3.8%), Montenegro (1.92%), Albania (1.69%) and Bosnia and Herzegovina (0.31%). Meanwhile, an average annual decrease in SII was recorded in Türkiye (0.11%) and Ukraine (0.17%).

Table 4 shows the values of the innovation gap index for a given EU candidate country in relation to the EU average (L_{pt}) and the index of changes in the innovation gap between a given EU candidate country and the EU average (D_{pt1}) from 2015 to 2022.

Table 4. The innovation gap index for EU candidate countries in relation to the EU average (L_{pt}), 2015–2022, and the index of changes in the innovation gap between a given EU candidate country and the EU average (D_{pt1}), 2015–2022

	2015	2016	2017	2018	2019	2020	2021	2022
Lpt for Albania	0.408	0.432	0.387	0.39	0.461	0.42	0.421	0.417
Dpt compared to the previous year for Albania		0.024	−0.045	0.003	0.071	−0.041	0.001	−0.004
Dpt in 2022 compared to 2015 for Albania	−0.015							
Lpt for Bosnia and Herzegovina	0.375	0.374	0.361	0.308	0.301	0.339	0.36	0.349
Dpt in 2022 compared to the previous year for Bosnia and Herzegovina		−0.001	−0.013	−0.053	−0.007	0.038	0.021	−0.011

	2015	2016	2017	2018	2019	2020	2021	2022
Dpt in 2022 compared to 2015 for Bosnia and Herzegovina	−0.026							
Lpt for Serbia	0.523	0.507	0.541	0.568	0.605	0.645	0.655	0.618
Dpt compared to the previous year for Serbia		−0.016	0.034	0.027	0.037	0.04	0.01	−0.037
Dpt in 2022 compared to 2015 for Serbia	0.095							
Lpt for North Macedonia	0.381	0.374	0.381	0.408	0.407	0.394	0.43	0.456
Dpt compared to the previous year for North Macedonia		−0.007	0.007	0.027	−0.001	−0.013	0.036	0.026
Dpt in 2022 compared to 2015 for North Macedonia	0.075							
Lpt for Montenegro	0.456	0.489	0.491	0.428	0.455	0.435	0.464	0.474
Dpt compared to the previous year for Montenegro		0.033	0.002	−0.063	0.027	−0.02	0.029	0.01
Dpt in 2022 compared to 2015 for Montenegro	0.018							
Lpt for Türkiye	0.529	0.529	0.539	0.584	0.587	0.469	0.466	0.478
Dpt compared to the previous year for Türkiye		0	0.01	0.045	0.003	−0.118	−0.003	0.012
Dpt in 2022 compared to 2015 for Türkiye	−0.051							
Lpt for Ukraine	0.345	0.331	0.301	0.297	0.288	0.287	0.297	0.31
Dpt compared to the previous year for Ukraine		−0.014	−0.03	−0.004	−0.009	−0.001	0.01	0.013

	2015	2016	2017	2018	2019	2020	2021	2022
Dpt in 2022 compared to 2015 for Ukraine	–0.035							

Note: the results for Albania and Ukraine are less reliable due to limited data availability, European Commission 2022, p. 99.
Source: calculations based on the data in Table 1.

The analysis of the innovation gap index for all EU candidate countries (Table 4) indicates that throughout the entire period, the level of innovativeness of their economies was below the EU average. In 2022, the lowest innovation gap was recorded in Serbia (0.618), followed by Türkiye (0.478), Montenegro (0.474), North Macedonia (0.456), Albania (0.417), Bosnia and Herzegovina (0.349), and Ukraine (0.31). Taking into account the changes in the innovation gap indicator compared to the previous year, in all countries, slight decreases in the innovation gap were followed by increases and vice versa. North Macedonia, Montenegro, Türkiye, and Ukraine showed a decrease in the innovation gap in 2022 compared to the previous year. In contrast, Albania, Bosnia and Herzegovina and Serbia recorded an increase. As for the change in the innovation gap indicator in 2022 compared to 2015, only three countries showed a reduction: Serbia, North Macedonia, and Montenegro.

Conclusions

To sum up, between 2015 and 2022, the economies of all the analyzed candidate countries were characterized by a lower level of innovativeness than the EU average. They showed a lower level of the SII than the EU average, and therefore, all these countries noted an innovation gap in relation to the EU average. It can, therefore, be concluded that the research hypothesis adopted in the introduction has been positively verified. The highest level of SII in the entire period was found in Türkiye and Serbia, followed by Montenegro and North Macedonia. Turkey and the Western Balkan countries (i.e., Serbia, Montenegro, and Macedonia) also showed the lowest innovation gap in the analyzed period. The Western Balkan countries also reduced the innovation gap compared to the EU average between 2015 and 2022. The lowest values of the SII were recorded by Bosnia and Herzegovina and Ukraine. In 2022, these countries experienced an increase in the innovation gap relative to the EU average, compared to the levels observed in 2015.

In conclusion, among the examined countries, the highest innovation potential is found in Türkiye, Serbia, Montenegro, and North Macedonia. They are characterized by relatively the highest expenditure on R&D among the countries surveyed. For Türkiye, this indicator is 0.96% of GDP (2022), for Serbia – 0.91% (2020), Montenegro – 0.36% (2019), and North Macedonia – 0.38% (2020) (The World Bank 2024). Of particular note among the Western Balkan countries is Serbia's position as a frontrunner on the road to EU membership. Serbia, like Montenegro, is already benefiting from EU funds, detailed policy advice, and stabilization and association agreements that ensure far-reaching progress to the internal market of the EU. Nevertheless, Serbia is mainly based on public sector investments, and many structural reforms are still needed to prepare an innovation environment. It is vital for Serbia to construct an innovation – and technology-based eco-system for the economy to accelerate on the road to EU accession (Kaynak, Atuntas, and Dereli 2017, p. 49).

Türkiye's high innovative position is of note. It is one of the most significant innovators among the countries studied. Nevertheless, it should allocate more incentives to the investors who will produce high-added value products and provide more qualified innovation facilities through a well-structured R&D strategy. A law related to promoting research infrastructure was approved by the presidency of the Republic of Türkiye on 9 July 2014 and published in the official gazette on 10 July 2014 (Kaynak, Atuntas, and Dereli 2017, pp. 49–50). It can be considered one of the most important initiatives to support R&D activities and sustain innovation-driven development in the country (Kaynak, Atuntas, and Dereli 2017, pp. 49–50). Türkiye should also pay more attention to innovation activities and create awareness for the contribution of innovation to both the country and investor sides, which will help the country jump to the top stage of development in the future. Investment in innovation also plays an important role in meeting a broad range of challenges and opportunities that the Turkish society faces (Dikbaş and Akkoyun 2006, p. 55). It means that making the right investment decisions (at the right time) is as important as innovation itself. Therefore, it is vital to develop an effective eco-system for innovators, investors and policy decision-makers that brings together efforts to evaluate measurement, prioritization and commercialization of both innovations and investments in the country (Kaynak, Atuntas, and Dereli 2017, p. 50). This will probably accelerate Türkiye on the road to EU accession.

Countries with low innovation potential are Albania, Bosnia and Herzegovina, and Ukraine. They are also characterized by low expenditure on R&D – for Albania, it was only 0.15% of GDP in 2008, Bosnia and Herzegovina – 0.21% (2020), and Ukraine – 0.41% (2020) (The World Bank 2024). A necessary condition for these countries' successful accession negotiations and economic development is modernization based on innovative development, which ensures the increase of the profitability of industrial enterprises, real wages and welfare (Zhylinska et al. 2020, p. 10). It is obvious that in the case of Ukraine, it will be difficult to meet these principles during the ongoing war.

The conclusions formulated on the basis of the analysis are important both from the point of view of the EU and the candidate countries (Aytekin et al. 2022, p. 1). The EU should consider the state and dynamics of changes in the innovation potential of individual candidate countries in the ongoing accession negotiations. Therefore, a country with high and growing innovation potential should strengthen its bargaining power and be given priority in these negotiations. High and growing innovation potential means that there is a high probability for the country to conduct successful innovation activity and to manufacture high technology in the future.

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Innowacyjność gospodarek krajów kandydujących do Unii Europejskiej – ocena luki innowacyjnej w stosunku do średniej unijnej

Innowacyjność jest obecnie postrzegana jako niezbędny czynnik sukcesu w osiąganiu dobrobytu gospodarczego i konkurowaniu na rynkach. Jest jednym z najważniejszych wyznaczników procesu konkurencyjnego na całym świecie i pomaga gospodarkom dogonić rozwijającą się i zmieniającą się technologię, jednocześnie ujawniając perspektywy innowacyjne krajów.

Celem artykułu jest ocena poziomu innowacyjności gospodarek wybranych krajów kandydujących do Unii Europejskiej na podstawie Sumarycznego Indeksu Innowacyjności (SII), a także oszacowanie luki innowacyjnej pomiędzy tymi krajami a średnią unijną. Analizę ograniczono do Turcji, Serbii, Albanii, Czarnogóry, Macedonii Północnej, Bośni i Hercegowiny oraz Ukrainy, ze względu na dostępność danych opisujących Sumaryczny Indeks Innowacyjności, przewidziany dla wszystkich krajów objętych badaniem w Europejskich Tablicach Innowacyjności – raportach Komisji Europejskiej, dopiero od 2015 r. W artykule sformułowano tezę badawczą, która zakłada, że badane kraje charakteryzują się niższym poziomem innowacyjności gospodarek niż średnia unijna, a tym samym wykazują lukę innowacyjną w stosunku do średniej dla krajów Unii Europejskiej w analizowanym okresie. Wyniki analizy potwierdzają tę tezę – wszystkie badane kraje kandydujące do Unii Europejskiej odnotowały w latach 2015–2022 niższy poziom innowacyjności gospodarek niż średnia unijna. Charakteryzowały się niższym poziomem SII niż średnia unijna, a więc wykazały lukę innowacyjną w odniesieniu do średniej unijnej. Rekomendacje dotyczące podniesienia poziomu innowacyjności gospodarek zostały sformułowane osobno dla poszczególnych krajów we wnioskach. W artykule dokonano przeglądu literatury dotyczącej innowacji i innowacyjności gospodarek oraz luki innowacyjnej. Zastosowano metody analizy opisowej, statystycznej analizy danych oraz analizy porównawczej. Wykorzystano dane statystyczne pochodzące z Europejskiej Tablicy Innowacyjności 2022. Jeśli zaś chodzi o wartość dodaną artykułu, to należy stwierdzić, że polega ona na porównaniu poziomu innowacyjności gospodarek wybranych krajów kandydujących do UE i średniej unijnej, jak również na oszacowaniu luki innowacyjnej między tymi krajami a średnią unijną.

Słowa kluczowe: innowacja, innowacyjność gospodarki, luka innowacyjna, Europejska Tablica Innowacyjności, Sumaryczny Indeks Innowacyjności

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Prioritization of the IT Sector in the CEE Stock Markets: Investment Policies, Trends and Hidden Gems

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Abstract

Objective: The main purpose of the research is to show that the Central and Eastern European (CEE) market is an essential component of the global stock market. It displays similar patterns to developed countries, and there is a special emphasis on information technology.
Research Design & Methods: The study is supported by various machine learning methods and economic analysis, in addition to using Python and R packages. In order to gain a more comprehensive insight into the developments in CEE-region trends, the paper considers a comparative portfolio that focuses on German business, and there is a simulation of the incorporation of the Ukrainian IT sector. Constructing a business strategy in accordance with the Fama–French approach is boosted by incorporating neural networks.
Findings: An examination of the performance of Czech, Polish, and Hungarian firms on the stock exchanges suggests that the investment policy oriented towards software is a reasonable choice. The results yielded by the IT companies unmistakably reveal the substantial benefits of their stock market ventures, as well as indicating the ongoing trend of investor reliance. The problem of IT business valuation is highlighted as one of the pitfalls of investing.
Implications & Recommendations: The research proposes that maintaining a priority focus on IT, even in challenging circumstances, ensures steady regional advancement.

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Contribution & Value added: This research brings a unique emphasis to the status and outlook of the IT sector, contributing to the existing toolkit, even in the face of repeated crises.

Keywords: Central and Eastern Europe, investment, IT, optimal portfolio, stock market

JEL: E22, G11, G41, O16, O30

Introduction

It is reasonable to presume that the stock markets of Central and Eastern Europe (CEE) do not hold the same level of proficiency as those of developed countries. In comparison to the clear investment in telecommunication, Internet service, software, automation, robotics, and other markets in developed countries during the pandemic, the commitment of CEE stock markets is far from certain, probably due to their relatively short legacy and the institutional insufficiencies of their evolving systems. Nevertheless, the Polish stock market was recently elevated to the status of developed, and the COVID–19 pandemic greatly increased disparities among different industries. Under such conditions, the dynamics and variability of the markets may be unpredictable. Notably, some of the most renowned IT businesses have shown similarities to the established markets' investment preferences, suggesting both short- and long-term trends in terms of investors' and customers' assurance. In recent times, numerous newly established companies have emerged, each with its unique perspective on how business should be both conducted and experienced. Simultaneously, numerous IT businesses are deliberating the suitability of listing on the stock exchange. Meanwhile, Russian aggression has resulted in a new state of affairs, impeding one branch of business while increasing the prominence of another.

The stock market has been significantly impacted by a decrease in customer mobility (as a result of the pandemic), the virtualization of a substantial part of daily life, increased online purchases, accelerated production and delivery operations, increased demand for education, and remote communication. Research, communication, programs and mechanization are essential for markets in both advanced nations and CEE. Social norms determine priorities and thus shape the stock market. The software market's outcomes are the most anticipated. Our assumption is that the CEE market is an essential component of the global stock market, demonstrating similar patterns as developed countries. We focus on Czech, Polish and Hungarian firms since the data are available in the public domain. Furthermore, should Ukrainian IT companies choose to become publicly traded, they are almost certain to succeed in the CEE market and even Western Europe.

Methodology background

As a starting point, we constructed a portfolio of German firms listen on the DAX, supplemented with a cluster of prosperous IT entities (in terms of market capitalization) listed on some stock markets. Appraising the portfolio from the standpoints of profitability and risk allows us to compare the Czech, Polish and Hungarian markets. Subsequently, based upon these countries' most prominent stock indices, we chose portfolios for analysis. The number of these firms is often so small that they all take part in the examined portfolio. In addition, we calculate the profitability of these portfolios (based on cumulative return), assess the risk (calculated using standard deviation and daily return variations), predictability (through machine learning and linear regression procedures), and examine the presence or a lack of a long-term strategy (using the 5-factor Fama–French model over a ten-year period, considering factors for both developed and emerging markets). For the analysis of these portfolios, we utilized several Python packages, including EfficientFrontier, pypfopt, numpy, pandas_datareader, matplotlib.pyplot, and yahoo_fin, as well as R packages PortfolioAnalytics, fPortfolio, and timeSeries.

All data are obtained based on company tickers and the corresponding Python and R packages. The methods for gathering such information evolve significantly every few years, particularly in the realm of companies' accounting statistics. Machine learning techniques were selected to analyze business predictability. Ridge regression increases the strength of the coefficients to combat multicollinearity, while the Lasso is advantageous as it favors solutions with fewer non-zero coefficients.

Elastic-net proves useful in scenarios where there is a correlation between multiple features. A Random Forest is a capable estimator that leverages averaging to enhance its predictive precision and mitigate over-fitting. In the case of Gradient Boosting, a regression tree is fitted to the negative gradient of the applicable loss function for each stage. Support Vector Machine Regressor is beneficial due to the possibility to use a radial basis function kernel or rbf. At the same time, we analyze the trend based on the Arima model. We believe that the selection of input factors (p, d, and q) of this model is suitable for reliable short-term predictions. To implement prediction models the following packages were used: statsmodels.tsa.arima_model, sklearn.tree, sklearn.svm, sklearn.linear_model, sklearn.ensemble and others.

In order to recognize any potential pitfalls of investing in IT business, a suitable regression model and a neural network approach are implemented.

Outline of the problem in recent studies

The UNCTAD Report 'Investment policy responses to the COVID–19 pandemic' contained a serious warning: "The pandemic may trigger increased competition for attracting investment in other industries (not of critical importance for host countries) as economies seek to recover from the downturn and disrupted supply chains need to be rebuilt" (UNCTAD 2020). Meanwhile, according to KPMG's predictions, the world of business will be "forever altered by COVID–19" (McKenzie, Eckhardt, and van Dam 2020; see also Hantrais et al. 2021). Many long-held norms of living, working and doing business have now changed and "are not expected to return to pre-pandemic patterns" (McKenzie, Eckhardt, and van Dam 2020; see also Lazonick 2017). During the pandemic, Ernst & Young (EYGM 2020) recommended "four key areas where European companies should focus: financial scenario and business portfolio assessment; portfolio rebalancing: accelerated divestments; asset transfer: sale and leasebacks; auditable financials" (EYGM 2020).

Nevertheless, did this actually take place? Did the pandemic provoke a permanent change in stock market allegiances that had been established for decades? Shortly before the outbreak of the pandemic the European Investment Bank was responsible for carrying out a particularly interesting study. This study indicated the likelihood of investing in knowledge resources in CEE. In the Czech Republic, such noteworthy potential sectors included education, R&D, transport infrastructure and energy. Meanwhile, Hungary focused on education and physical infrastructure, while Poland requires higher spending on R&D and further improvement to its energy infrastructure (Bubbico et al. 2017). The prevailing trend for startups originating from CEE is to relocate overseas, particularly in the case of Ukraine (60%), followed by Croatia and Serbia, both reaching 40% (Dealroom.co 2021). According to Kitt (2004), investors favor domestic bonds in these markets. He used Markowitz mean-variance optimization to identify optimal portfolios, with one such portfolio proposed for MSCI Eastern Europe Index.

In 2018, PricewaterhouseCoopers predicted that New York, London, and Hong Kong would remain at the forefront of the stock markets for the next decade and that the shift to Indian and Chinese competitors would be quite moderate. Markets would strive for tech companies (see also Pan and Mishra 2018). Meanwhile, according to a Digital Society Index (Dentsu Aegis Network 2019, p. 17) survey of more than 43,000 people around the world, less than half (49%) currently believe their basic digital needs are being met (i.e., access to quality digital infrastructure and the trust that people express in business and government to use their data responsibly in terms of privacy and security; see also Xingfu and Siming 2020). So, what are the obstacles to market advancement? The forecast highlights negative factors such as the lack of liquidity, currency volatility, and an uncertain regulatory framework. "The challenge for the exchanges is how they can adapt to the changing landscape, competing but also collaborating with one another, and complementing other financing alternatives to support the provision of capital across the world" (PwC 2019, p. 2).

Zaimovic, Arnaut-Berilo and Mustafic (2017) stated that diversification enables investors to manage their risk. "The biggest riddle in the world of investments is to find the optimal portfolio within a set of available assets with limited capital". A Markowitz mean-variance (MV) portfolio optimization was used to identify possibilities for diversification. Their research offered insight into the level of integration of South-East European equity markets. Their findings showed that Principal component analysis simplifies asset selection in portfolio management. Meanwhile, Deng et al. (2013) proposed a portfolio optimization framework that selects the portfolio with the largest worst-case-scenario Sharpe ratios. They stated that "traditional Sharpe ratio estimates based on limited historical return data are subject to estimation errors."

Milhomem and Dantas (2020) discussed aspects of portfolio optimization. They found that techniques such as robust optimization, Bayesian statistics, Neural Networks, and Fuzzy Logic can be employed to reduce estimation error. Obtaining data to analyze the optimization model is possible through platforms including Thomson Reuters, OR-Library, and Fama–French, and languages such as Python, R, C++, and Java offer an array of tools for the analysis. Annaert et al. (2011) calculated the market-weighted return index for the largest stocks listed on the Brussels Stock Exchange. They demonstrated that market analysis should focus on market leaders to identify market trends and predict market dynamics.

Within the scientific community, there has been a great deal of research into the stock market in general, the practicality of employing certain tools, as well as Central, South, and Eastern European stock markets (i.e. Syriopoulos and Roumpis 2009; Benaković and Posedel 2010; Bogdan, Bareša, and Ivanović 2010; Syllignakis and Kouretas 2011; Horvath and Petrovski 2013; Guidi and Ugur 2014; Zaimović and Arnaut Berilo 2015). However, there has been no thorough analysis of the emphasis of the market on particular priorities of society, one of which is information technology.

Research and key findings

The CEE market data in its entirety suggests comparable priorities to those of developed countries (Table 1). So, is the stock market adequately reacting to the transformations? Does it impair its capacity to prioritize entrepreneurial initiatives? Does the pandemic give the region no way out?

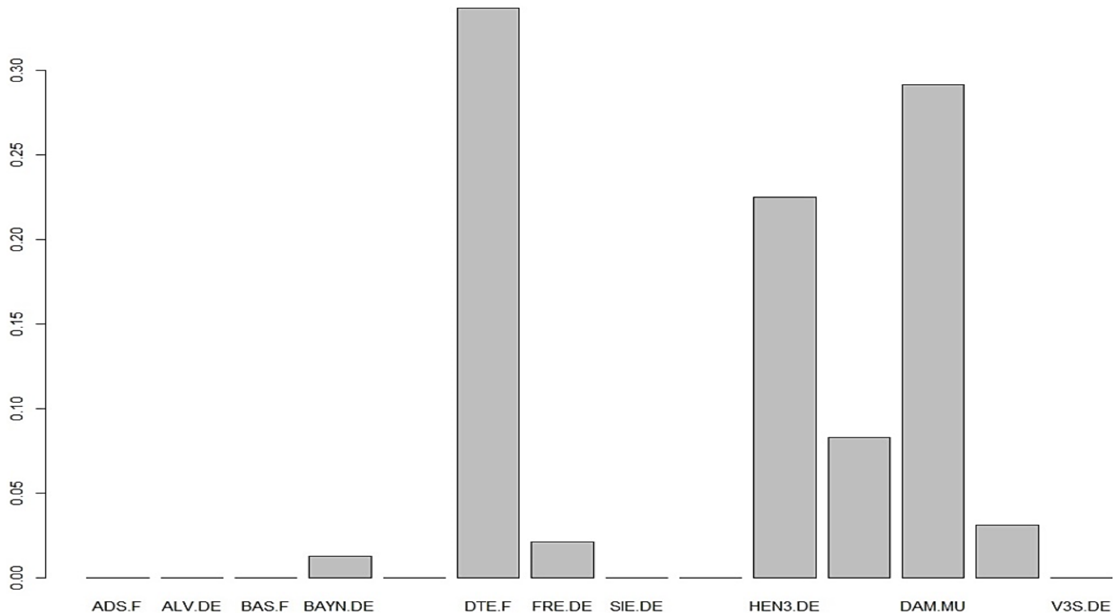
Table 1. CEE investment priorities by sector (€, millions)

	2019		2020	
	amount	percent	amount	percent
ICT (Communications, computer, electronics)	1 425 766	43.6	739 181	44.3
Business products and services	280 349	8.6	193 824	11.6
Consumer goods and services	545 405	16.7	173 076	10.4
Biotech and healthcare	142 549	4.4	240 169	14.4

Source: data from Invest Europe 2023.

The German market as a partner and competitor

Selecting the German market for our analysis, we address the questions raised above. Our aim is to construct an optimal portfolio for the German market, using DAX components, while also including a few promising IT companies. We simultaneously apply a portfolio optimization approach based on maximizing the Sharpe ratio and R packages (Figure 1).



Notes: Data Modul AG (DAM.MU), Viscom AG (V6C.DE), Vectron Systems (V3S.DE), Adidas AG (ADS.F), Allianz SE (ALV.DE), BASF SE (BAS.F), Bayer (BAYN.DE), Deutsche Telekom AG (DTE.F), Fresenius SE & Co. KGaA (FRE.DE), Siemens (SIE.DE), Henkel AG & Co. KGaA (HEN3.DE). Other companies are not included in the opti-mal portfolio. It was used fPortfolio of R. Research period: from = "2019–01–01" to = "2023–02–24". Risk Free/Working Days = 0.06647/253.

Figure 1. German portfolio optimization

Source: own elaboration based on historical prices from Yahoo n.d.

Companies with the highest profile include Deutsche Telekom AG (DTE.F), Henkel AG and Co. KGaA (HEN3.DE), Data Modul AG (DAM.MU), i.e., one of the world's leading integrated telecommunications companies, a chemical corporation, and a worldwide leading supplier of industrial displays and monitors. Our observations show that including the top-performing IT firms in the stock index significantly affects the optimal portfolio. Regarding Figure 2, Deutsche Telecom's superiority is clear, although some IT companies, like Data Modul AG (DAM.MU), Viscom AG (V6C.DE), and Vectron Systems (V3S.DE), also appear to be optimal choices.

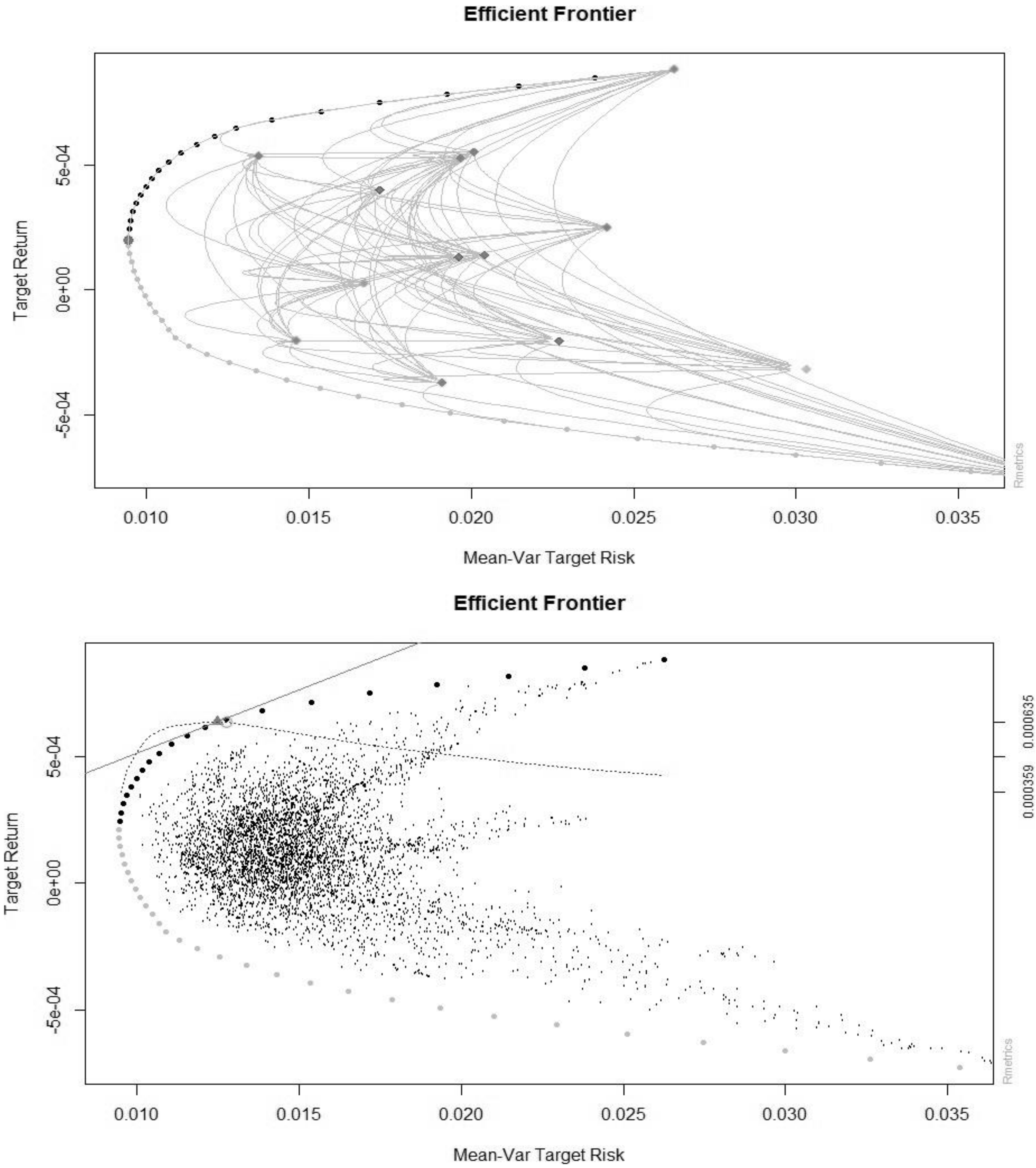


Figure 2. Graphical presentations of Asset Frontiers and the Efficient Frontier for the German portfolio

Source: own elaboration based on Portfolio analytics of R.

CEE optimal portfolio

For our examination, we decided to select constituents of the PX (Czech Republic), Budapest SE (Hungary) and WIG 20 (Poland) indices and a selection of well-known CEE IT businesses.

Table 2. Portfolio optimization based on the Efficient Frontier method

Poland	Czech Republic	Hungary
[('ALE.WA', 0.0), ('ACP.WA', 0.0), ('PEO.WA', 0.0), ('CCC.WA', 0.0), ('CDR.WA', 0.0), ('CPS.WA', 0.0), (**'DNP.WA'**, 0.05142), ('KTY.WA', 0.0), (**'JSW.WA'**, 0.01623), ('KGH.WA', 0.0), (**'KRU.WA'**, 0.14458), ('LPP.WA', 0.0), ('MBK.WA', 0.0), ('OPL.WA', 0.0), (**'PKN.WA'**, 0.04012), ('PPS.WA', 0.0), ('PGE.WA', 0.0), ('PKO.WA', 0.0), ('PZU.WA', 0.0), ('SPL.WA', 0.0), (**'IFI.WA'**, 0.54784), (**'CCE.WA'**, 0.01494), (**'SGN.WA'**, 0.18487), ('LVC.WA', 0.0)]	[(**'CEZ.PR'**, 0.10589), (**'CZG.PR'**, 0.397), ('ERBAG.PR', 0.0),('KOFOL.PR',0.0),('KOMB.PR', 0.0), (**'MONET.PR'**, 0.00246), (**'TABAK.PR'**, 0.27002), ('TMR.PR', 0.0), ('VIG.PR', 0.0), ('TOMA.PR', 0.14665), (**'PEN.PR'**, 0.06273), ('GEN.PR', 0.0), (**'EMAN.PR'**, 0.01524), ('FIXED.PR', 0.0)]	[(**'4IG.BD'**, 0.07993), (**'AKKO.BD'**, 0.04867), (**'ALTEO.BD'**, 0.73881), (**'ANY.BD'**, 0.13246), ('BIF.BD', 0.0), ('DELTA.BD', 0.0), ('ENEFI.BD', 0.0), ('MOL.BD', 0.0), ('NAP.BD', 0.0), ('NUTEX.BD', 0.0), (**'UBM.BD'**, 0.00013), ('AMIXA.BD', 0.0)]
Stock Start Date: 2019–01–01		
Day of study: 2023–03–09		
Expected annual return:		
101.8%	26.5%	39.4%
Annual volatility:		
29.0%	13.6%	26.8%
Sharpe Ratio:		
3.44	1.80	1.39

Notes: Allegro (ALE.WA), Asseco Poland (ACP.WA), Bank Polska Kasa Opieki (PEO.WA), CCC (CCC.WA), CD Project (CDR.WA), Cyfrowy Polsat (CPS.WA), Dino Polska (DNR.WA), Grupa Kety (KTY.WA), Jastrzebska Spólka Weglowa (JSW.WA), KGHM Polska Miedz (KGH.WA), Kruk (KRU.WA), LPP (LPP.WA), mBank (MBK.WA), Orange Polska (OPL.WA), Orlen (PKN.WA), Pepees (PPS.WA), PGE (PGE.WA), PKO Bank Polski (PKO.WA), PZU (PZU.WA), Santander Bank (SPL.WA), Ifirma JSC.(IFI.WA), Clean&Carbon Energy S.A. (CCE.WA), Sygnity S.A. (SGN.WA); CEZ (CEZ.PR), Colt CZ Group (CZG.PR), Erste Group Bank (ERBAG.PR), Kofola (KOFOL.PR), Komercni Banka (KOMB.PR), Moneta Money Bank (MONET.PR), Philip Morris (TABAK.PR), Tatry mountain resorts (TMR.PR), Vienna insurance (VIG.PR), Toma (TOMA.PR), Photon energy (PEN.PR), Gen Digital (GEN.PR), eMan (EMAN.PR), Fixed.zone (FIXED.PR); 4iG Ltd. (4IG.BD), AKKO Invest (AKKO.BD), Alteo (ALTEO.BD), Amixa Holding (AMIXA.BD), ANY Security Printing (ANY.BD), ASTRASUN (ASTRA.BD), Budapesti Ingatlan Hasznosítási és Fejlesztési (BIF.BD), Chameleon Smart Home Zartkoruen Mukodo Reszvenytarsasag (CHOME.BD), CYBERG CORP. (CBRG.BD), Delta Technologies (DELTA.BD), ENEFI Vagyonkezelo (ENEFI.BD), MOL Magyar Olaj- és Gázipari Nyilvánosan Muködo Részvénytársaság (MOL.BD), Nap Zartkoruen Mukodo Reszvenytarsasag (NAP.BD), NUTEX Investments Public Limited Company (NUTEX.BD), UBM Holding (UBM.BD), Amixa Holding Nyilvánosan Muködo Részvénytársaság (AMIXA.BD).
Source: own elaboration based on historic prices from Yahoo n.d.

We have already incorporated companies from the IT sector into separate country portfolios. Polish company Ifirma JSC has developed a website that allows businesses to manage themselves online. The other Polish firm, Sygnity S.A., has designed, implemented and maintains the technology that supports businesses in digital transformation and forms a foundation for digital government. Czech company eMan a.s. develops applications for smartphones, tablets, websites, cars, and other devices. Hungary's 4IG Ltd. specializes in custom software development, while SAP ERP concentrates on business solutions, specifically, data-focused business solutions for executives.

Next, we explore the results of forming a combined portfolio of these three countries from the CEE region (Table 3). Assets with non-zero weights are highlighted in bold. The portfolio comprises the following assets: (**'DNP.WA'**, 0.12057), ('JSW.WA', 0.0), ('KRU.WA', 0.0), ('OPL.WA', 0.0), ('PKN.WA', 0.0), (**'IFI.WA'**, 0.12713), (**'CCE.WA'**, 0.0059), (**'SGN.WA'**, 0.00199), (**'CEZ.PR', 0.03245**), (**'CZG.PR'**, 0.29215), ('MONET.PR', 0.0), (**'TABAK.PR'**, 0.07851), (**'TOMA.PR'**, 0.04487), (**'PEN.PR'**, 0.02486), (**'EMAN.PR'**, 0.0355), (**'4IG.BD'**, 0.08181), (**'AKKO.BD'**, 0.02866), (**'ALTEO.BD'**, 0.10082), (**'ANY.BD'**, 0.02475), ('UBM.BD', 0.0). Using the Efficient Frontier method, the expected annual return is 40.8%, the annual volatility is 14.1%, and the Sharpe Ratio is 2.75. The Sharpe Ratio of this portfolio decreased compared to the Polish market. At the same time, risk is significantly lower than in both the Polish and Hungarian markets. Regarding utility optimization, risk is given less consideration. The aforementioned IT companies maintained significant positions within the optimal portfolio with regard to utility maximization (Figure 3).

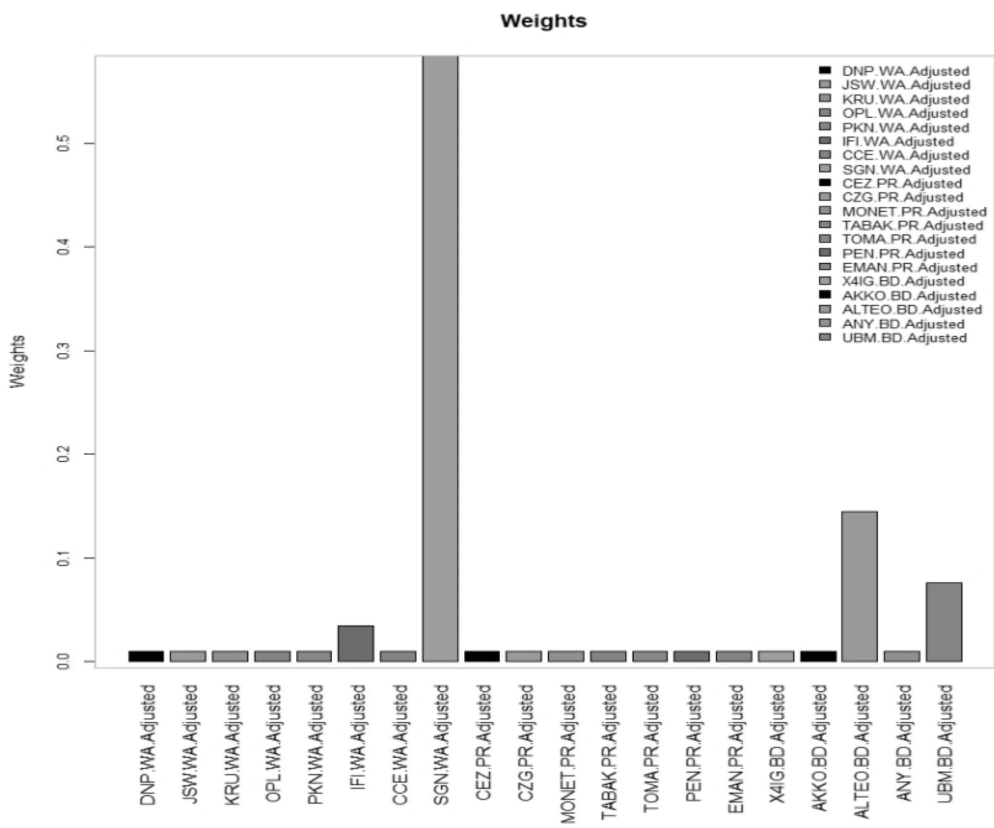


Figure 3. United optimal portfolio (Utility maximization)

Source: own elaboration based on the PortfolioAnalytics of R package.

This approach also guarantees the inclusion of at least two IT firms (i.e., Ifirma JSC. and Sygnity S.A.) in the optimal portfolio. The model we used has limitations with weighting coefficients ranging from 0.01 to 0.9. Figure 4 demonstrates the Efficient Frontier, Global Minimum Variance Portfolio, two-asset frontiers, and the Monte Carlo portfolio. The graphic presentation of the selected portfolio is certainly interesting (Figure 2). The portfolio attains a balance between profitability and risk. The top graph is a good representation of how each company can shape the Efficient Frontier and the maximum Sharpe ratio. We will focus our analysis on the companies included in the optimal portfolios later.

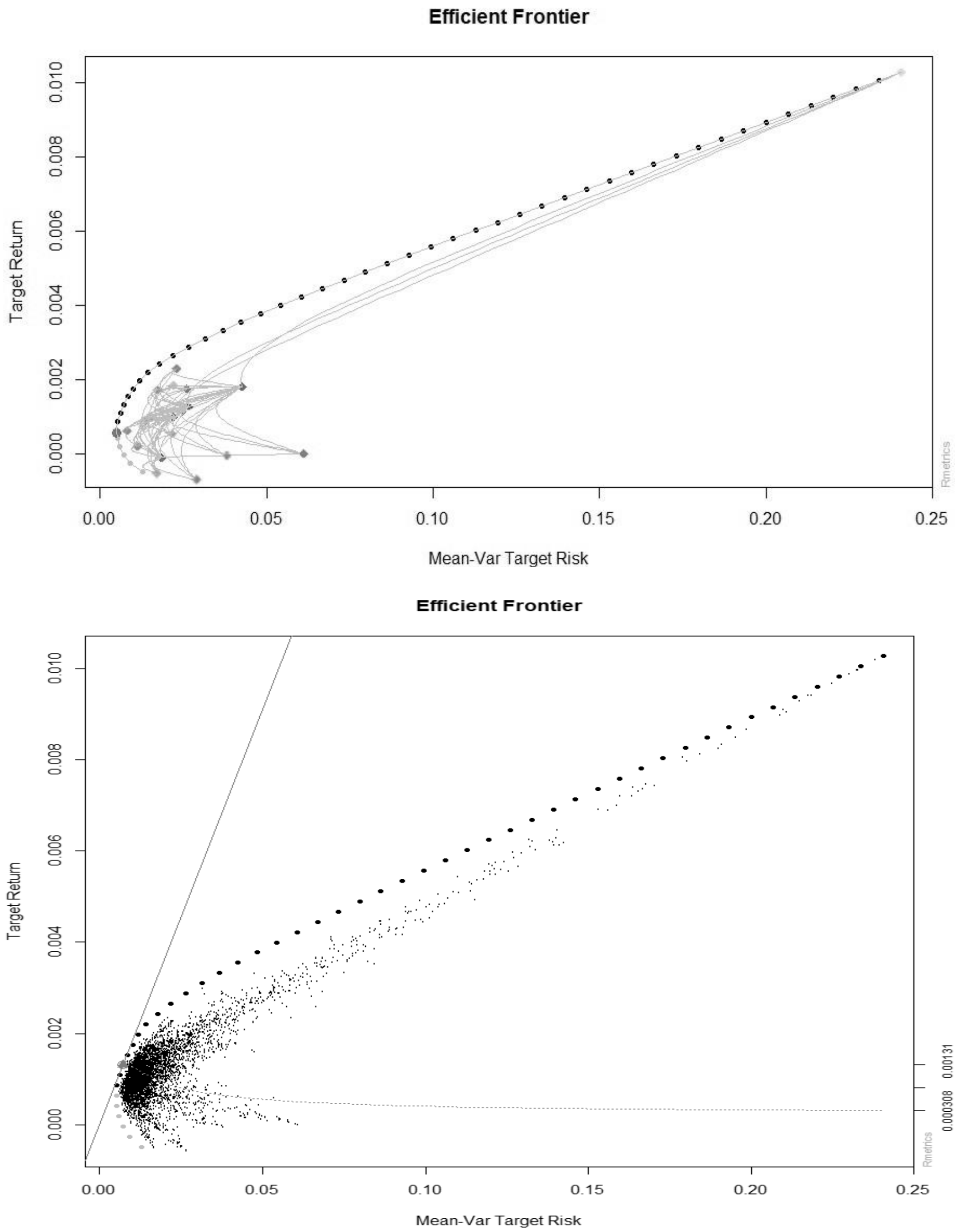
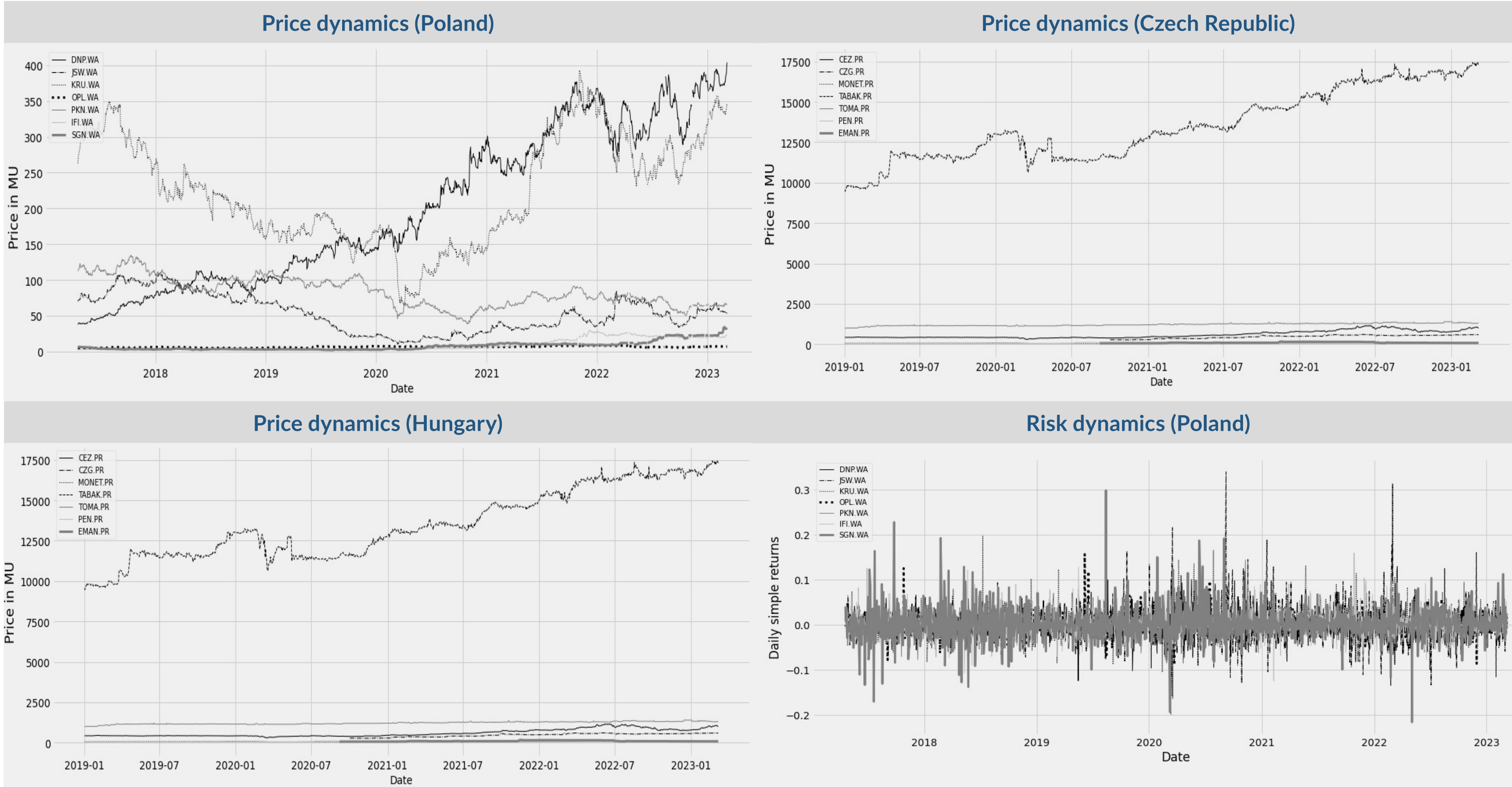
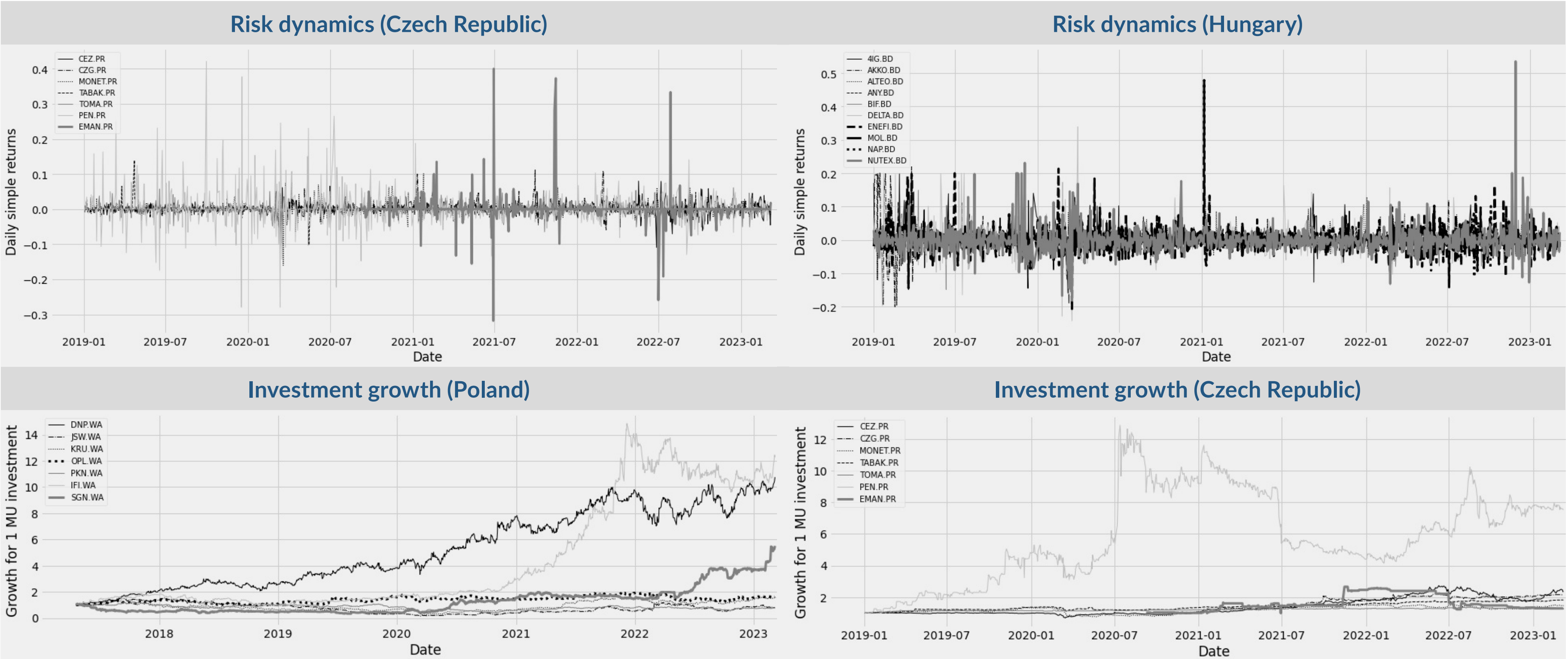


Figure 4. Efficient frontier graphical presentations (CEE united portfolio)

Source: own elaboration based on historical prices from Yahoo n.d.Market analysis


Price dynamics (Poland)
DNP.WA
JSW.WA
KRU.WA
OPL.WA
PKN.WA
IFI.WA
SGN.WA
Price in MU
Date
Price dynamics (Czech Republic)
CEZ.PR
CZG.PR
MONET.PR
TABAK.PR
TOMA.PR
PEN.PR
EMAN.PR
Price in MU
Date
Price dynamics (Hungary)
CEZ.PR
CZG.PR
MONET.PR
TABAK.PR
TOMA.PR
PEN.PR
EMAN.PR
Price in MU
Date
Risk dynamics (Poland)
DNP.WA
JSW.WA
KRU.WA
OPL.WA
PKN.WA
IFI.WA
SGN.WA
Daily simple returns
Date


Risk dynamics (Czech Republic)
CEZ.PR
CZG.PR
MONET.PR
TABAK.PR
TOMA.PR
PEN.PR
EMAN.PR
Daily simple returns
Date
Risk dynamics (Hungary)
4IG.BD
AKKO.BD
ALTEO.BD
ANY.BD
BIF.BD
DELTA.BD
ENEFI.BD
MOL.BD
NAP.BD
NUTEX.BD
Daily simple returns
Date
Investment growth (Poland)
DNP.WA
JSW.WA
KRU.WA
OPL.WA
PKN.WA
IFI.WA
SGN.WA
Growth for 1 MU investment
Date
Investment growth (Czech Republic)
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MONET.PR
TABAK.PR
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PEN.PR
EMAN.PR
Growth for 1 MU investment
Date

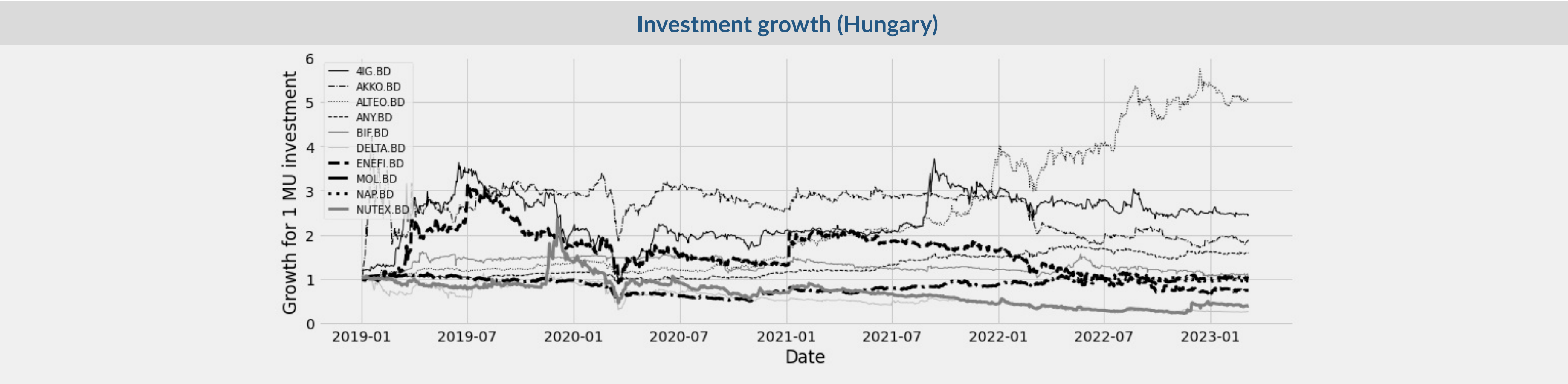


Figure 5. Price dynamics, risk, and economic growth dynamics in Poland, the Czech Republic and Hungary

Source: own elaboration based on historical prices from Yahoo n.d.

The analysis of the price dynamics, risk, and economic growth dynamics of the three CEE countries made it possible to identify growth trends, level of vulnerability, and economic growth for the constructed optimal portfolios, including their inclusion of IT companies (Figure 5). Although the Hungarian market is not performing as well as the other countries, companies from this country were still included in the optimal CEE portfolio, including a company from the IT sector.

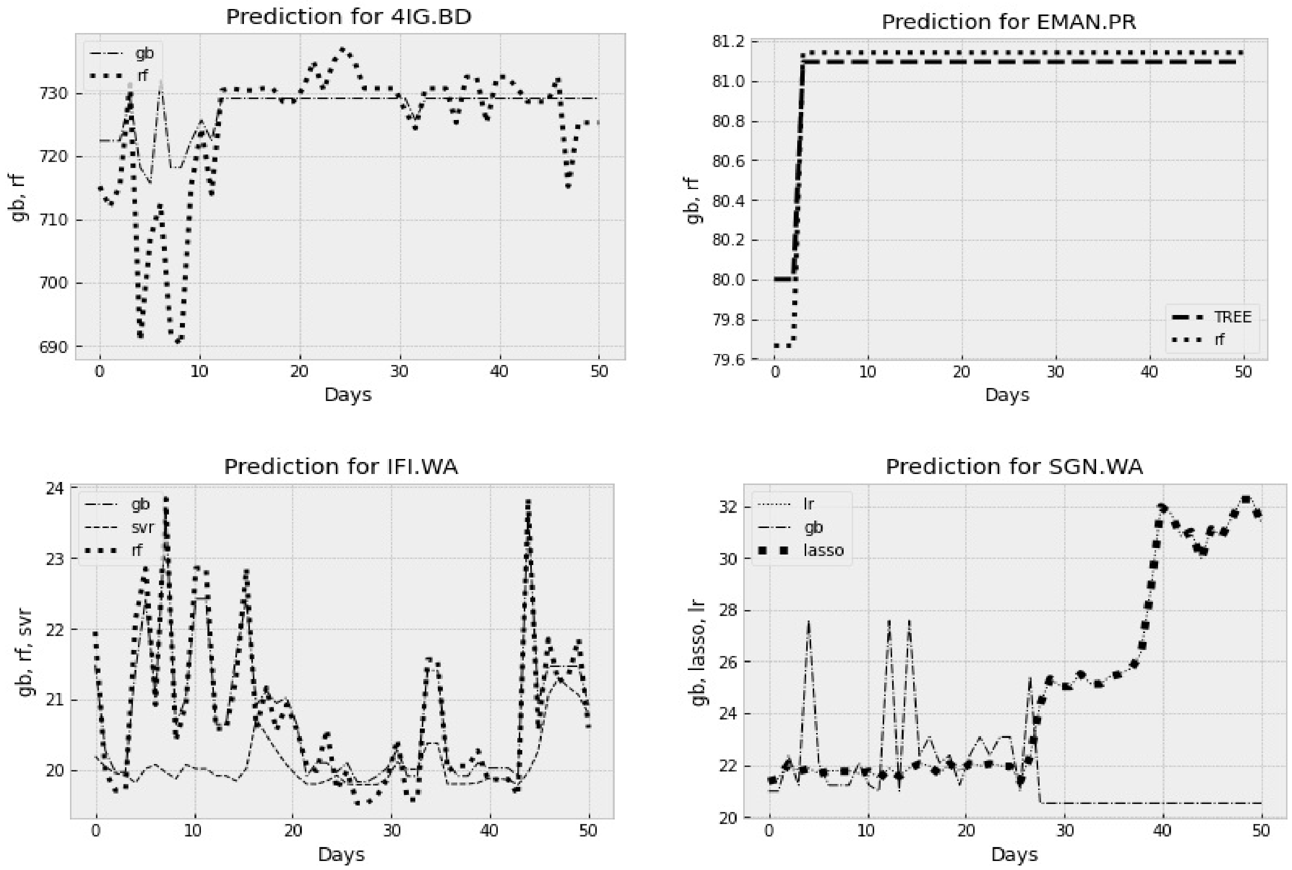
Predictability analysis

Using Support Vector Machine Learning, traditional Linear Regression and Random Forest, Gradient Boosting and Lasso, our aim is to gain a thorough understanding of the previously illustrated trend. The acceptability of such an approach could be analyzed based on R^2, mean absolute error, maximum error, mean squared log of error, mean absolute percentage error, and mean squared error. In our opinion, the coefficient of determination (R^2) is the most suitable indicator.

Table 3. Confidence level (R^2)

Method / Company	4IG.BD	EMAN.PR	IFI.WA	SGN.WA
Linear Regression	0.934	0.382	0.935	0.934
Support Vector Regressor	0.951	0.363	0.984	0.934
Random Forest	0.958	0.658	0.988	0.948
Gradient Boosting	0.957	0.662	0.987	0.946
Lasso	0.934	0.382	0.935	0.934

Source: own calculations based on historical prices from Yahoo n.d.



Notes: abbreviations used: lr (linear regression), svr (support vector regressor), rf (random forest), gb (gradient boosting).

Figure 6. The 50-day prediction for IT portfolio elements

Source: own elaboration.

For IT firms included in the optimal portfolio, we employed a range of techniques to reveal a subtle yet perceptible upward trend (Figure 6). Confidence in the results of these calculations is quite high, typically reaching 93–98% (Table 3). For the single firm, the outcomes of numerous processes revealed inadequate performance (EMAN.PR, 36–38%).

Table 4. Competing ingredients confidence level (R^2)

Method / Company	ALTEO.BD	CEZ.PR	DNP.WA	PEN.PR
Linear Regression	0.970	0.908	0.936	0.675
Support Vector Regressor	0.985	0.951	0.956	0.723
Random Forest	0.990	0.950	0.957	0.796
Gradient Boosting	0.989	0.947	0.955	0.806
Lasso	0.970	0.908	0.936	0.670

Source: own elaboration.

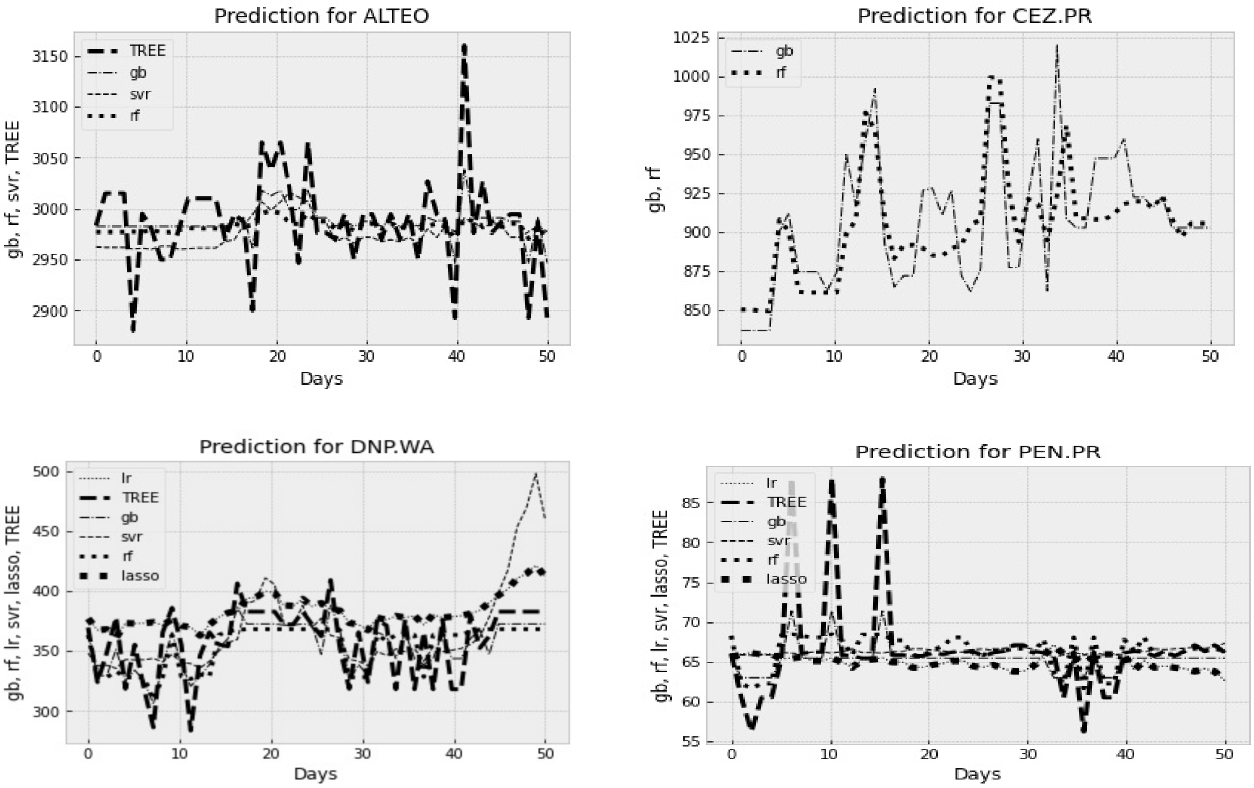


Figure 7. Competing elements of the optimal portfolio

Source: own elaboration.

Regarding other industries, patterns have become more stable, while the applicability of prediction models remains fairly unchanged (Figure 7). At the same time, confidence in the models remains at the same high level (Table 4).

By summarizing the findings of the prognostic analysis, we can draw a preliminary conclusion. Based on our predictive models, we have compelling reasons to consider investing in the proposed IT entities. They are predictable and show an upward trend.

The Ukrainian IT stock market perspective

The appearance of the Ukrainian IT sector is anticipated. We can model its entry by supplementing the existing agricultural and energy sector firms with Polish IT companies that share a similar business orientation. Considering the significant perception and experience of such Ukrainian businesses in the world, we consider such inclusion to be justified.

Thus, the portfolio is comprised of [('AGT.WA', 0.0), ('KER.WA', 0.0), ('KSG.WA', 0.0), ('OVO.WA', 0.0), ('IMC.WA', 0.0), ('AST.WA', 0.0), ('MHPC.IL', 0.0), ('MLK.WA', 0.0), ('CLE.WA', 0.0), (**'IFI.WA', 0.49001**), (**'LVC.WA', 0.50489**), (**'SGN.WA'**, 0.00511)]. Stock Start Date: 2012–01–01; date of study: 2023–03–30. The results of the study are the following: Expected annual return – 32.6%, Annual volatility – 31.2%, and Sharpe Ratio – 0.98.

Evidently, this financial initiative can be viewed as successful. However, it must be taken into consideration that there are almost no Polish IT companies that are directly comparable to the Ukrainian ones. Nevertheless, by studying the nature of the business and its components, this emulation allows us to make an overall assessment.

Assessment challenges

What investments should one consider in order to make a wise decision? This question typically requires a review of both market research and accounting data. To identify appropriate assets to be included in the analysis of IT companies' weighted average return of assets (WARA), a linear regression was applied to a sample of 34 listed CEE IT companies. The objective is to determine assets that are suitable for WARA analysis, based on their direct or indirect, yet considerable, impact on profitability. Given the broad scope of these parameters, the existing methodology allows the use of the ROA ratio in instances where calculating the weighted average cost of capital (WACC) is impossible.

Table 5. Significance of the companies' IT assets

Dependent variable/Factors	g_rec_w beta (t, sign.)	int_rec_w beta (t, sign.)	wc_rec_w beta (t, sign.)	t_rec_w beta (t, sign.)
WACC	−0.372 (−2.3, 0.02)	−0.009 (−0.06, 0.9)	−0.09 (−0.4, 0.68)	−0.26 (−1.1, 0.26)

Notes: Adj. R^2 = 0.339, F (Sig.) = 6.13 (0.001). g_rec_w, int_rec_w, wc_rec_w, t_rec_w – relative weights of goodwill, intangible assets, working capital and fixed assets; goodwill is calculated based on the annual FCF for 2018–2020. The Capital Asset Pricing Model (CAPM) method is used to calculate WACC. Data from 34 CEE IT companies was used.
Source: own elaboration based on accounting data from Yahoo n.d.

Taking into account Table 5, it is evident that if we limit ourselves to solely significant assets, then the WARA for IT companies should be determined exclusively based on one asset: goodwill. This is not unexpected since given the impracticality of accumulating material assets in the IT sector. A traditional example proposed to Economics students in assessing the accounting accuracy of Dell or Apple could demonstrate a negative cash conversion cycle (CCC) for these businesses. This suggests that working capital for an IT business is no longer a reliable reflection of its fiscal situation or makes a substantial contribution to its profitability. In light of the chosen approach, the standard deviation of the relative weight of goodwill (0.23) should be used as an enhancement to the WACC. However, considering data availability, other intangible assets could be incorporated into this model. Nevertheless, when it comes to intangible assets, the concept of market remains a somewhat subjective distinction.

Impact of crises

Table 6. Impact of crises on company strategy

Company, type of neural network	Error	Steps	Model accuracy
IFI.WA; 2 neurons	1.0716	20	0.86963
IFI.WA; c(6,2)	1.0723	21	0.87254
IFI.WA; c(9,9,2)	1.0730	19	0.87632
SGN.WA; 2 neurons	1.3608	23	0.95869
SGN.WA; c(6,2)	1.3628	25	0.95934
SGN.WA; c(9,9,2)	1.3616	17	0.95713

Notes: c(6, 2) is a model with two hidden layers with six and two neurons, respectively; c(9,9,2) is a model with three hidden layers with nine, nine, and two neurons, respectively. The accuracy of the model shows the percentage of similarity between the real and model values. The model uses the smallest learning rate (SLR) algorithm.
Source: own calculations.

Company strategies are typically assessed using the 3- or 5-factor Fama–French model. With reference to the table of factors for developed or emerging markets, it could be possible to describe the company's behavior in terms of business prospects, conservativeness/aggressiveness, profitability, and the level of risk. Additionally, due to the substantial discrepancy of developing markets, this model is frequently unworkable. Generally, we come to this conclusion due to the non-compliance with the F-criterion. Regarding the figure, the model failed to yield the desired results for Ifirma JSC and Signify Poland Ltd. Therefore, it is imperative to explore non-linear correlations between a company's stock price and the Fama–French components. A neural network, as indicated in Table 6, is a viable option. In fact, we apply the effect of neural networks on the Fama–French factor table by judiciously adjusting the number of hidden layers and neurons in them.

The model's strength lies in its ability to replicate the effects of a crisis (by adding an extra layer with more neurons than the initial layer), revealing the intensity of its impact. If the model's accuracy is significantly changed when the crisis is incorporated into the model, we can state that the impact of the crisis on the business was substantial. Our presumption is that the pandemic and the war started by Russia have increased the number of neurons (factors) from five to nine, thus signifying the presence of four further factors that could affect business performance.

It is important to note that such assessments are not without ambiguity. Our evaluation has indicated that while Ifirma JSC was negatively impacted by the current economic difficulties, Sygnity S.A. has remained unaffected. This discrepancy can be attributed to the respective nature of each business – with Ifirma JSC functioning as a digital platform for e-commerce and accounting. It is evident that customer issues are directly correlated with this type of business. Meanwhile, Sygnity S.A. combines both the sale of software and hardware, incorporating spatial data, which makes it much more flexible to any type of crisis. The graphical representation of neural networks is quite clear (Figure 8). The case of two hidden layers with 6 and 2 neurons is displayed accurately below.

In this case, although the impact of crises is evident, it is neither significant nor destructive.

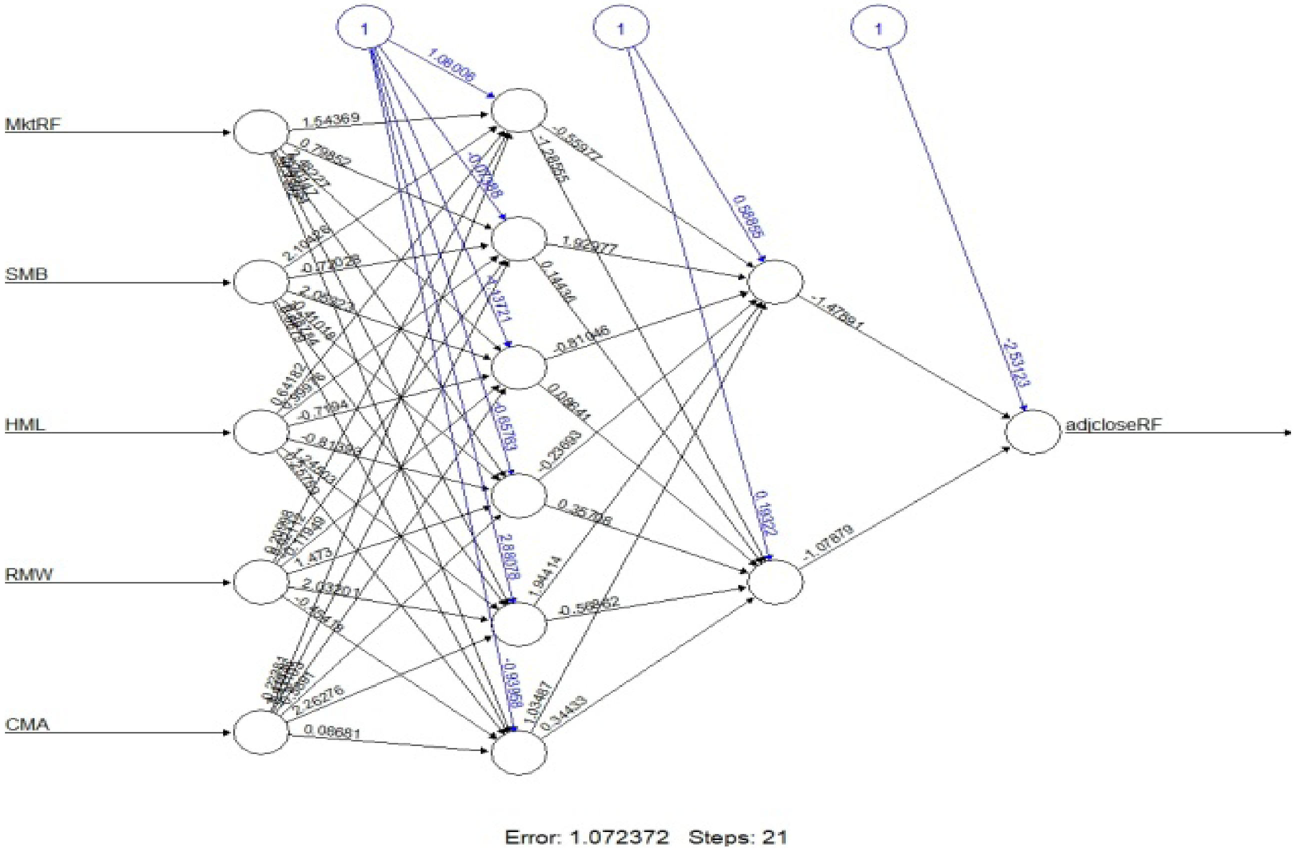


Figure 8. Neural networks in the case of Ifirma JSC

Source: own elaboration.

Conclusions

Our models indicate that the most profitable investments for businesses in Central and Eastern Europe would be a combination of software, weaponry, the modern energy sector, and a few other industries. To determine an optimal portfolio for this purpose, the Efficient Frontier technique was employed, focusing on three countries: the Czech Republic, Poland, and Hungary, with a combined portfolio also designed and improved. Both individual optimal portfolios and the combined portfolio contained IT entities. The result was confirmed through the maximization of the Sharpe ratio and the maximization of utility.

The in-depth analysis showed the advantages of companies operating in the software market. Within its framework, the cumulative income and risk of the optimal portfolio ingredients were assessed. In all cases, the IT business withstood the competition offered by other areas.

Machine learning techniques made it possible to verify the specified growth trend and an acceptable level of risk. In fact, machine learning methods proved to be a perfect tool to ascertain whether IT companies from the presented optimal portfolios are predictable businesses worthy of investment. The accuracy of such estimates was more than sufficient.

For the CEE market as a whole, the results suggest that investing in the IT sector should be a top priority. Consequently, the analysis of the German market demonstrates that the CEE markets are following similar paths and emphasizing the same goals.

The successful outcome of simulating the inclusion of Ukrainian IT companies in the national portfolio (using a group of Polish companies as a close analogy in terms of intentions and interaction mechanisms) confirmed the expected success of these companies' shares on the stock market.

However, there are major problems with evaluating the IT assets of companies. A commonly used technique today is WARA analysis, which requires particular attention because of the size of goodwill. Briefly, anyone interested in investing in an IT business must be aware of its reputation. Moreover, if other intangible assets are considered, the question of their lack of appropriate market valuation arises. Furthermore, it is frequently challenging for investors to obtain full knowledge of the strategy behind their chosen investment option.

The use of neural networks and adjusting hidden layers was shown as a useful tool to measure the vulnerability of the selected enterprise to crises. Nevertheless, this approach is sufficiently illustrative only in cases of significant damage to a specific business by the crisis. It may be completely invisible in instances of temporary problems.

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Priorytetyzacja sektora IT na rynkach akcji w Europie Środkowo-Wschodniej: polityka inwestycyjna, trendy i ukryte perełki

Cel: Głównym celem badań jest przedstawienie rynku Europy Środkowo-Wschodniej jako istotnego elementu globalnego rynku akcji, wykazującego wzorce podobne do krajów rozwiniętych, ze szczególnym uwzględnieniem technologii informacyjnych.
Metody badawcze: Badanie zostało oparte na metodach uczenia maszynowego, analizie ekonomicznej, a także pakietach Python i programie R. Ponadto w celu uzyskania bardziej kompleksowego spojrzenia na rozwój trendów w regionie Europy Środkowo-Wschodniej uwzględniono portfel porównawczy obejmujący niemiecki biznes oraz symulację oceny ukraińskich technologii cyfrowych. Konstrukcja strategii biznesowej zgodnie z podejściem Fama–French została rozszerzona poprzez włączenie sieci neuronowych.
Rezultaty: Wyniki badań przeprowadzonych na podstawie czeskich, polskich i węgierskich firm na giełdach papierów wartościowych sugerują, że polityka inwestycyjna zorientowana na oprogramowanie jest rozsądnym wyborem. Wyniki uzyskane przez spółki IT jednoznacznie wskazują na znaczne korzyści płynące z ich przedsięwzięć giełdowych, a także sugerują obecny trend zaufania inwestorom. Symulacja włączenia ukraińskich spółek IT do krajowego portfela również potwierdza prognozowany sukces. Problem wyceny biznesu IT jest wskazany jako jedna z pułapek inwestowania.
Wnioski i rekomendacje: Zachowanie dominującej pozycji sektora IT, nawet w niepewnych okolicznościach, jest gwarancją stabilnego rozwoju regionu.
Wkład i wartość dodana: Badanie to wnosi wyjątkowy wkład zarówno w ocenę sytuacji, jak i perspektyw sektora IT, poszerzając już istniejący zestaw rozwiązań, nawet w obliczu powtarzających się kryzysów.

Słowa kluczowe: Europa Środkowo-Wschodnia, inwestycje, IT, optymalny portfel, rynek akcji

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Heterogeneity in Air Pollution Levels and Their Techno-economic Determinants: A Cluster Analysis of the EU–27

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Abstract

The ongoing decline in environmental quality is one of the biggest global challenges facing humankind today. The purpose of this study is to investigate the differences and similarities among the EU–27 countries regarding air pollution emissions (greenhouse gases and acidifying gases) and their techno-economic determinants, which encompass economic, energy, innovation and institutional quality factors. The analysis covers nine indicators that reflect pollution emissions and fifteen variables that illustrate air pollution drivers. Cluster analysis of the data averaged for the period 2015–2020 was used to identify subgroups of countries. The results show that European Union (EU) countries substantially differ in terms of both air pollution levels and the determinants of the emissions. The analysis revealed a noticeable division between Eastern EU countries, which show similar patterns both in terms of pollution and determinants, and Western EU countries, which were characterised by greater diversity in terms of the analysed features. In light of the results, the assertion about backward and polluted new EU member states compared to more advanced and environmentally uncontaminated old EU countries appears to oversimplify the reality. The findings contribute to the ongoing discussion on environmental quality. Our results indicate the need and space for initiatives that address factors that influence air pollution in order to impede environmental degradation. However, due to the revealed heterogeneity among countries, the efforts should be tailored to the specific country's characteristics.

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Keywords: air pollution, greenhouse gas (GHG) emissions, acidifying gas (ACG) emissions, cluster analysis, European Union countries

JEL: O44, Q50, Q53, Q56

Introduction

The deterioration of environmental quality and its consequences are not only a focus of academics and researchers but also an important policy concern. Excessive greenhouse gas (GHG) emissions are recognised as the major reason for climate change, which may lead to more extreme weather events, biodiversity loss, forest fires, water scarcity, decreasing crop yields, and the disappearance of glaciers and rising sea levels. It may also affect people's health (European Parliament 2018; 2023). According to the European Environment Agency, air pollution is the largest environmental health risk in Europe (European Environment Agency 2023). Combating climate change is, therefore, the priority of the European Union's (EU) environmental policy. Article 191 (1) of the Treaty on the Functioning of the European Union provides the objectives of the policy, which include preserving, protecting, and improving the quality of the environment, protecting human health, the prudent and rational utilisation of natural resources, promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combating climate change (*Consolidated versions…* n.d.).

Regarding recent European Union activities to formulate policies aimed at environmental protection, The European Climate Law entered into force on 29 July 2021. This legal act wrote into law and made legally binding the goal proposed under the European Green Deal to reach EU climate neutrality by 2050, in line with the objectives of the Paris Agreement. This means that the EU as a whole should achieve net zero greenhouse gas emissions by 2050. The law also updated the EU's interim target of reducing net greenhouse gas emissions from 40% to at least 55% by 2030, compared to 1990 levels[1] (Regulation (EU) 2021/1119…).

The EU is a leader in tackling air pollution. The EU–27's[2] contribution to global greenhouse gas emissions decreased by 7.9 percentage points between 1990 and 2019 – from 15.2% to 7.3%. The corresponding drops reported for the United States and Russia were 6.9 and 4.9 percentage points, respectively. Nonetheless, in 2019, the EU–27 was still the world's fourth largest greenhouse gas emitter after China, the United States and India (Eurostat 2023, p. 75).

1 A review of the EU's environmental policies can be found in Cifuentes-Faura (2022) and Guterres (2022).

2 EU member states as of February 2020.

In this context, the purpose of this article is to explore differences and similarities in air emissions and their techno-economic determinants across EU countries. Using cluster analysis, we aim to identify groups of countries (clusters) within the EU–27 that are similar. We intend to compare the identified groups and find patterns across clusters of EU countries. We consider this to be the main value added of the article. Air emissions used in the analysis encompass two groups of pollutants – greenhouse gases and acidifying gases. The variables that characterise the techno-economic determinants of air emissions cover economic, energy, innovation, and institutional quality indicators. Using only the most recent data available for 2020 could lead to biased results due to the outbreak of the COVID–19 pandemic, which drove a global slowdown and a reduction of emissions, especially in the first half of the year. Thus, to minimize the impact of cyclical fluctuations, the sample was extended, and all variables were calculated as the 2015–2020 average.

We hope that the research findings will contribute to the discussion about environmental quality and draw attention to the choice of measures available, which should take into account the diversity of each country.

The structure of the article is as follows. The next Section illustrates air pollution in the EU–27 and introduces air emission determinants based on a literature review. Section 3 describes the methodology and data, while Section 4 presents the results of the comparative analysis. The last Section concludes.

Air pollution and its determinants

The deterioration of environmental quality is a global concern due to its negative consequences. Greenhouse gases are recognised as the major reason for climate change (Aghel, Sahraie, and Heidaryan 2020). Meanwhile, acidification arising from acidifying gases may be detrimental to soils, plants and aquatic animals (Singh and Agrawal 2008, p. 15; Aung, Fischer, and Azmi 2020, p. 1760) and may affect human health (Singh and Agrawal 2008, p. 15). Acid rain is considered one of the most serious environmental issues (Singh and Agrawal 2008, p. 15). Although the EU implemented measures to reduce air pollution, the average 2019 EU–27 emissions of greenhouse gases per capita in CO_2 equivalent was 7.6 tonnes, about 25% higher than the world average (Eurostat 2023, p. 76). For reference, the biggest emitters, the United States and China, reached 18.3 and 9.0 tonnes, respectively (Eurostat 2023, p. 76).

Figure 1 presents greenhouse gas (GHG) emissions in CO_2 equivalent in tonnes per capita and total emissions in millions of tonnes for the EU–27 computed as the 2015–2020 average. Greenhouse gases comprise carbon dioxide (CO_2), methane (CH_4), nitrous oxide

(N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6) in CO_2 equivalent.

Figure 1 shows that the top four EU–27 emitters in per capita terms were Luxembourg (14.2 tonnes per capita), Denmark (13.7), Estonia (12.6) and Ireland (12.5). By contrast, Malta (4.2), Sweden (4.5), Croatia (4.5) and France (4.9) were in the bottom four. In terms of total emissions, Germany, Poland, France, and Italy accounted for the largest share of air pollution, with emissions of 709.6, 353.9, 329.8 and 326.1 million tonnes, respectively. The smallest contributors were Malta (2.0 million tonnes), Cyprus (6.9), and Luxembourg (8.5).

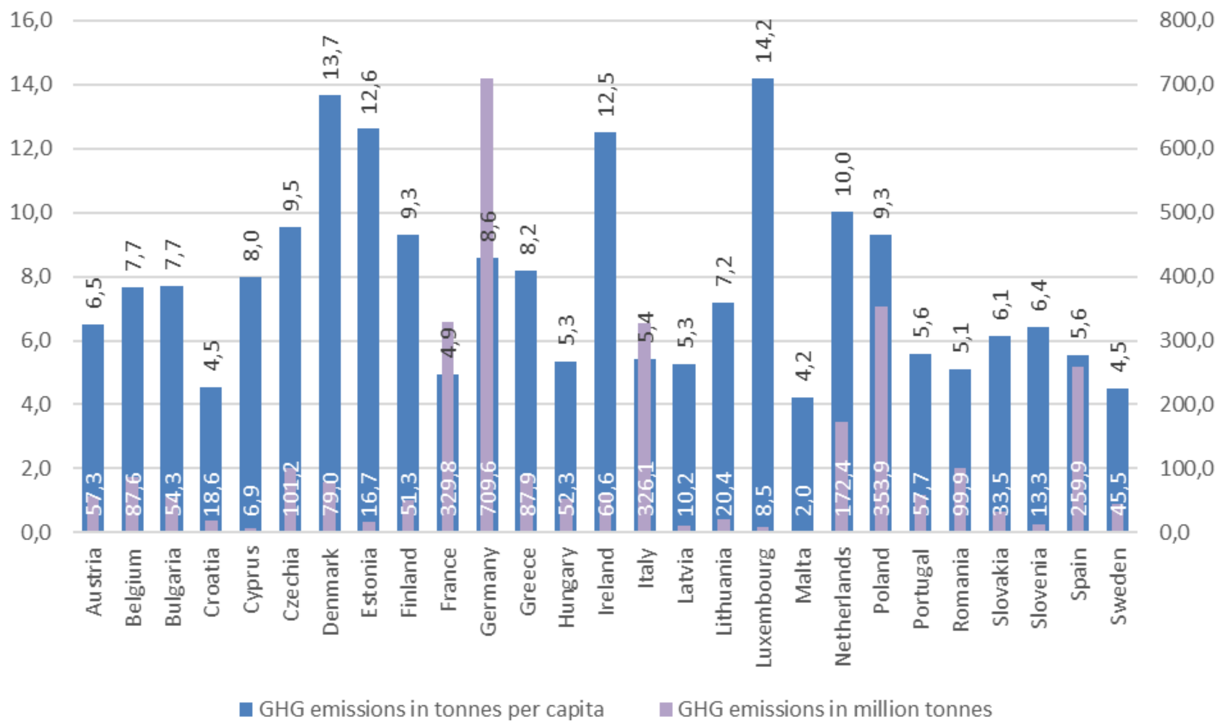

Figure 1. Greenhouse gas emissions in CO_2 equivalent in tonnes per capita (left axis) and millions of tonnes (right axis) for the EU–27 countries – 2015–2020 average.

Source: own elaboration based on Eurostat database.

Figure 2 shows acidifying gas (ACG) emissions in SO_2 equivalent in kilograms per capita and total emissions in thousands of tonnes[3] for the EU–27 calculated as the 2015–2020 average. Acidifying gases include sulphur oxides (SO_x), nitrogen oxides (NO_x) and ammonia (NH_3) in SO_2 equivalent.

Figure 2 shows that Malta, Slovakia, Croatia, and Belgium emitted the least amount of acidifying gases in per capita terms, i.e., 15.3, 20.5, 21.7 and 21.8 kilograms per inhabitant. Denmark was the biggest emitter (240.1 kilograms per capita), followed by Greece (69.6) and Ireland (62.7). Concerning total emissions, Germany and France were

3 Data labels for total emissions are omitted to improve the figure readability.

the main sources of acidifying gases, with emissions of 2,517,518 and 1,733,543 tonnes, respectively. Next were Spain (1,583,241), Italy (1,478,820), Poland (1,434,035), and Denmark (1,384,473). By contrast, Malta (7247), Luxembourg (32,015) and Cyprus (37,044) emitted the least.

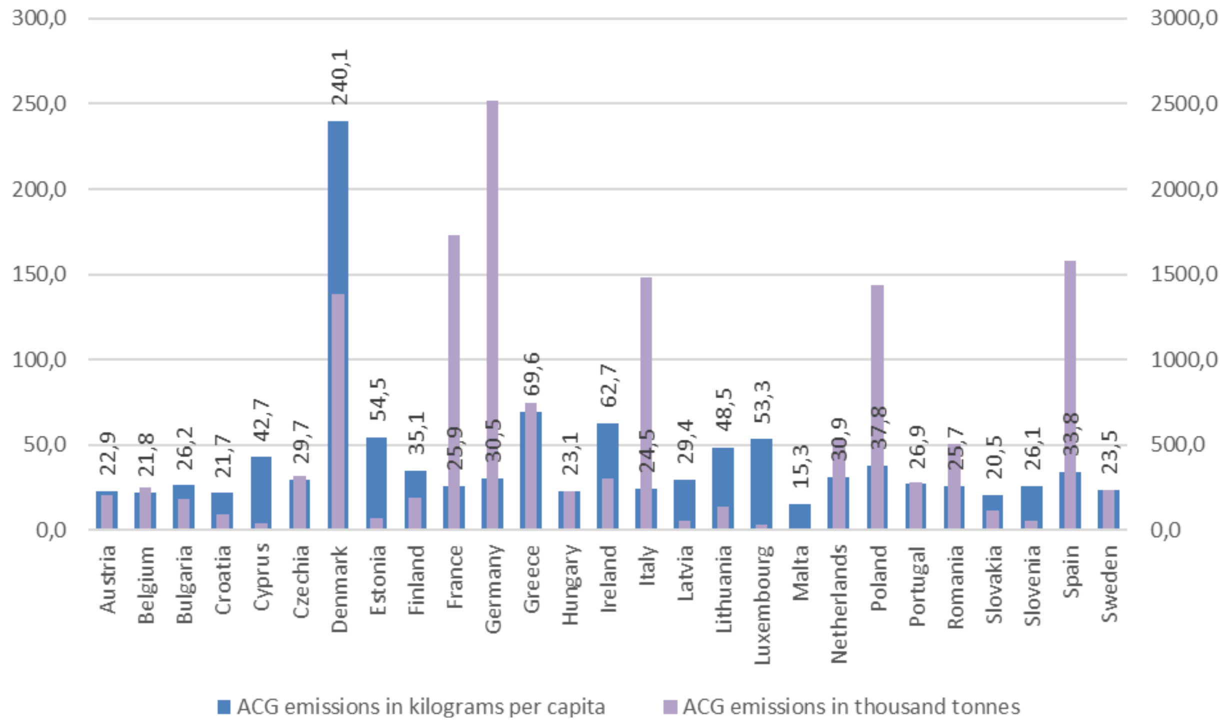

Figure 2. Acidifying gas emissions in SO_2 equivalent in kilograms per capita (left axis) and thousands of tonnes (right axis) for the EU–27 – 2015–2020 average

Source: own elaboration based on Eurostat database.

Our empirical analysis presented in the next section is dedicated to clustering the EU–27 countries according to their air pollution and its determinants. The set of potential determinants of air emissions was selected based on a literature review. A vast amount of literature examines the determinants of air pollution, especially within the environmental Kuznets curve (EKC) framework. The standard EKC proposes an inverted U-shaped relationship between per capita income and environmental quality, stating that pollution increases at the beginning of the development process and then starts to decrease after reaching a certain income threshold. Under the EKC hypothesis, two factors that shape environmental quality are commonly considered – per capita income and a measure of energy consumption. As different measures show different aspects of energy consumption, empirical studies use several indicators (see, e.g., Wu 2017; Arminen and Menegaki 2019; Du, Li, and Yan 2019; Işik, Ongan, and Özdemir 2019; Ehigiamusoe, Lean, and Smyth 2020; Ongan, Isik, and Ozdemir 2020; Wawrzyniak and Doryń 2020; Bekun et al. 2021; Mehmood et al. 2021; Karim et al. 2022; Khan, Weili, and Khan 2022; Wang, Yang, and Li 2023).

On this basis, we chose four variables for our analysis – GDP per capita, which serves as an economic indicator, and three energy indicators, i.e., final energy consumption per capita, share of fossil fuels in gross available energy, and share of energy from renewable sources.

A growing number of studies have investigated the technology-related determinants of air emissions (e.g., Weina et al. 2016; Cheng et al. 2019; Du, Li, and Yan 2019; Wang, Zeng, and Liu 2019; Bai et al. 2020; Cheng et al. 2021; Chien et al. 2021; Shan et al. 2021; Jinqiao et al. 2022; Lingyan et al. 2022; Zheng, Lv, and Wang 2022). Technology innovations, especially green ones, may substantially help mitigate air pollution and facilitate progress towards environmental sustainability (Chien et al. 2021; Shan et al. 2021; Lingyan et al. 2022, pp. 753–754). As innovation has many dimensions, our analysis comprises six indicators: patent stock in all technologies per capita, patent stock in environment-related technologies per capita, patent stock in environment-related technologies associated with air pollution abatement per capita, R&D expenditure stock in % of GDP, researchers in R&D per million people, and gross enrolment ratio for tertiary education in %.

In addition to the factors above, many studies focused on aspects related to the impact of institutional background on environmental pollution (Wu 2017; Gholipour and Farzanegan 2018; Arminen and Menegaki 2019; Wawrzyniak and Doryń 2020; Bekun et al. 2021; Mehmood et al. 2021; Karim et al. 2022; Khan, Weili and Khan 2022). Thus, we extended the set of variables to include institutional quality indicators, namely government effectiveness, control of corruption, and rule of law.

Several other factors that affect air emissions were also discussed in the literature. One of them is the industrial structure (Zhang et al. 2014; Gholipour and Farzanegan 2018; Liu and Bae 2018; Du, Li, and Yan 2019; Bai et al. 2020; Yildirim, Alpaslan, and Eker 2021; Jinqiao et al. 2022; Wang, Yang, and Li 2023). It was argued and verified that the tertiary sector has a carbon emission-reducing influence (Zhang et al. 2014) while the secondary sector has an increasing carbon emission effect (Liu and Bae 2018; Du, Li, and Yan 2019). So, we utilised two variables to represent the industrial structure, i.e., industry (including construction) value added in % of GDP and services value added in % of GDP.

Methodology and data

The empirical part of the paper is dedicated to identifying groups of countries (clusters) within the EU–27[4] that are similar in terms of two criteria: (i) emissions of greenhouse and acidifying gases and (ii) determinants of air pollution. Thus, the cluster analysis

4 EU member states as of February 2020.

for the 2015–2020 average was applied twice, separately for each criterion described by a distinctive group of variables.

The first input data set includes nine variables that report greenhouse and acidifying gas emissions by pollutants, i.e.:

1. Greenhouse gases:

X_1 – carbon dioxide (CO_2) emissions in kilograms per capita,

X_2 – methane (CH_4) emissions (CO_2 equivalent) in kilograms per capita,

X_3 – nitrous oxide (N_2O) emissions (CO_2 equivalent) in kilograms per capita,

X_4 – hydrofluorocarbon (HFC) emissions (CO_2 equivalent) in kilograms per capita,

X_5 – perfluorocarbon (PFC) emissions (CO_2 equivalent) in kilograms per capita,

X_6 – nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6) emissions (CO_2 equivalent) in kilograms per capita.

2. Acidifying gases:

X_7 – sulphur oxide (SO_x) emissions (SO_2 equivalent) in kilograms per capita,

X_8 – nitrogen oxide (NO_x) emissions (SO_2 equivalent) in kilograms per capita,

X_9 – ammonia (NH_3) emissions (SO_2 equivalent) in kilograms per capita.

All emissions data come from Eurostat.

The second input data set comprises fifteen variables that represent the techno-economic determinants of air pollution divided into four groups, covering:

1. Economic indicators:

Y_1 – GDP per capita in constant 2015 US$,

Y_2 – industry (including construction) value added in % of GDP,

Y_3 – services value added in % of GDP.

2. Energy indicators:

Y_4 – final energy consumption (energy use) in thousand tonnes of oil equivalent per capita,

Y_5 – share of fossil fuels in gross available energy (in %),

Y_6 – share of energy from renewable sources (in %).

3. Innovation indicators:

Y_7 – patents stock in all technologies per capita,

Y_8 – patents stock in environment-related technologies per capita,

Y_9 – patents stock in environment-related technologies associated with air pollution abatement per capita,

Y_{10} – R&D expenditure stock in % of GDP,

Y_{11} – researchers in R&D per million people,

Y_{12} – gross enrolment ratio for tertiary education (in %).

4. Institutional quality indicators:

Y_{13} – government effectiveness,

Y_{14} – control of corruption,

Y_{15} – rule of law.

The economic indicators data are obtained from the World Development Indicators (WDI) database of the World Bank. The energy indicators come from the Eurostat[5] database, while the institutional quality indicators are from the World Governance Indicators (WGI) database (Kaufmann and Kraay 2023), which follows the methodology of Kaufmann, Kraay, and Mastruzzi (2010). The innovation indicators come from diverse sources. The researchers in R&D and gross enrolment ratio for tertiary education[6] variables are sourced from the WDI database. The next four variables, which measure patent stocks and R&D expenditure stocks, are calculated based on data from the OECD and WDI databases, respectively.

We followed the perpetual inventory method to estimate the stocks from data on flows of patents and R&D expenditures. The stock measures were calculated using the following formula (cf. Piva and Vivarelli 2018):

$$innov\_stock = \begin{cases} \dfrac{innov\_flow}{g+\delta} \; for\, t = 0 \\ (1-\delta) innov\_stock + innov\_flow \; for\, t > 0 \end{cases} \tag{1}$$

5 Data are converted into per capita using population figures from the World Development Indicators (WDI) database.

6 Due to a break in data, the value of the variable for Greece in 2015 is calculated as the average of 2014 and 2016, for the Netherlands in 2019 – the average of 2018 and 2020, and for Estonia, the value of the variable in 2020 is set at the 2019 level.

where *innov_stock* represents a stock measure of the corresponding flow (*innov_flow*) indicator, g is the 2005–2020 compound growth rate[7] of the *innov_flow*, and δ denotes the depreciation rate. For the depreciation rate, we have adopted the value of 20% as a compromise between the estimates of 0% and 40% provided by Hall (2007) for R&D.

Considering that stock values are highly dependent on their initial estimates (for $t = 0$), we have computed the stocks for 2005–2020, ensuring that the initial values depreciate over time. This allowed us to enhance the reliability of the stock estimates for the period 2015–2020. The stock values were converted into per capita terms using the population figures from the WDI database.

Research results

We employed clustering to analyse and compare the air pollution in EU countries and the factors that determine pollution emissions. Clustering involves grouping similar objects (countries) into homogeneous groups based on the multivariate distance between the objects. In this study, the similarity between the countries was calculated using the Euclidean distance, which is one of the most commonly used metrics. In this metric, the proximity between two observations (points on a plane) is determined in geometric terms by the length of a line segment connecting them, which can be expressed in multivariate space as:

$$dist_{Euc} = \sqrt{\sum_{i=1}^{n} \left(x_i - y_i\right)^2}, \quad (2)$$

where $dist_{Euc}$ is the Euclidean distance between objects x and y in the space of n parameters, while x_i and y_i is the i-th element (dimension) of objects x and y, respectively. As we had no preliminary knowledge of the number of clusters in our data, we applied the hierarchical cluster analysis (Hastie, Tibshirani, and Friedman 2009, p. 520; Kula and Ünlü 2019, p. 239), which aims to build a hierarchy of clusters (visualised as a tree diagram or dendrogram). We used the Ward linkage method in agglomerative hierarchical clustering, one of the most commonly used techniques in air pollution studies (Govender and Sivakumar 2020). The algorithm starts with singletons (every object that forms its own cluster in the leaves of the dendrogram) and then, at each iteration, joins two clusters based on the smallest increase in total within-cluster variance after merging. The procedure ends with a hierarchy of clusters (when all observations belong to a single cluster at the root of the tree diagram) (Nielsen 2016, pp. 221–222).

7 Negative growth rates were replaced with zeros.

We omitted highly correlated variables (with a Pearson correlation coefficient greater than 0.8) and standardised input variables by subtracting their mean and dividing them by their standard deviation so that the data have a mean of 0 and a variance of 1. The standardisation equalised the weighting of each input variable (dimension) and ensured that the clustering was not based on the variability of dimensions (Jajuga and Walesiak 2000, p. 106). The final list of variables includes: X_1, X_2, X_3, X_4, X_5, X_6, X_7 and Y_1, Y_3, Y_5, Y_6, Y_9, Y_{10}, Y_{12}, Y_{14}.

Figure 3 shows the results of the cluster analysis based on the countries' air pollutant emissions (greenhouse gases and acidifying gases), and Figure A1 in the Appendix shows the scaled values of the variables examined in the determined clusters.

As determining the number of clusters is largely arbitrary (OECD 2008, p. 76), we decided to distinguish five clusters of countries. Table 1 presents the extracted groupings. The cluster analysis revealed the outlier position of Denmark and Ireland (clusters 1 and 2). Denmark has the EU's highest sulphur oxide emissions in kilograms per capita terms, the second-highest level of methane, and the third-highest level of nitrous oxide emissions. However, it had one of the lowest hydrofluorocarbon emissions. Ireland has the highest emissions of both methane and nitrous oxides and relatively high perfluorocarbon emissions, but the lowest sulphur oxide emissions. Both countries are also characterised by relatively high carbon dioxide emissions.

Cluster 3 comprises countries that have high hydrofluorocarbon and relatively high perfluorocarbon emissions while maintaining mostly low levels of the other analysed pollutants. The countries in cluster 4 exhibit high levels of nitrogen trifluoride and sulphur hexafluoride and relatively low levels of sulphur oxide emissions. Cluster 5 covers nearly all new EU member states whose emissions (mostly) follow the pattern of mean emissions in the EU–27.

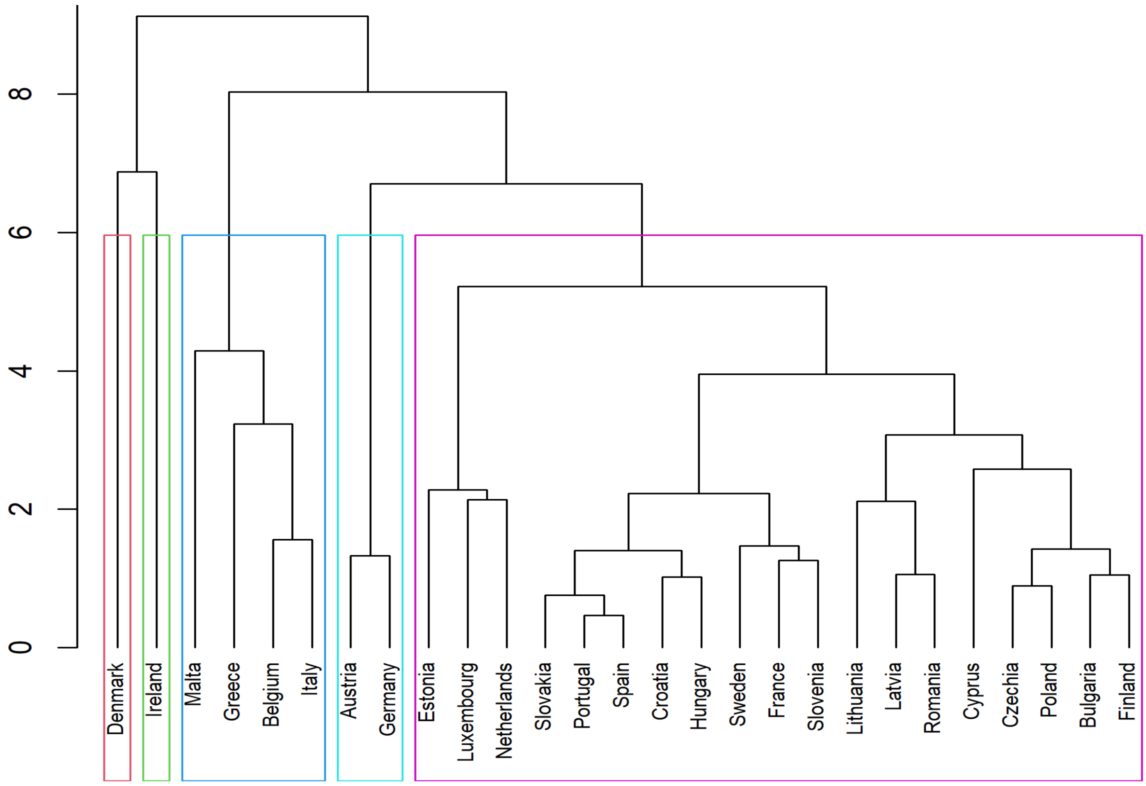

Figure 3. Dendrogram derived for air pollution of the EU–27 countries

Source: own elaboration.

Table 1. Cluster composition – air pollution

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Denmark	Ireland	Belgium, Greece, Italy, Malta	Austria, Germany	Bulgaria, Croatia, Cyprus, Czechia, Estonia, Finland, France, Hungary, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden

Source: own elaboration.

Figure 4 presents the results of cluster analysis based on the factors that determine pollutant emissions. In this case, we also extracted five groupings of countries. Table 2 presents the structure of the clusters. Figure A2 in the Appendix illustrates the levels of the variables analysed in each cluster.

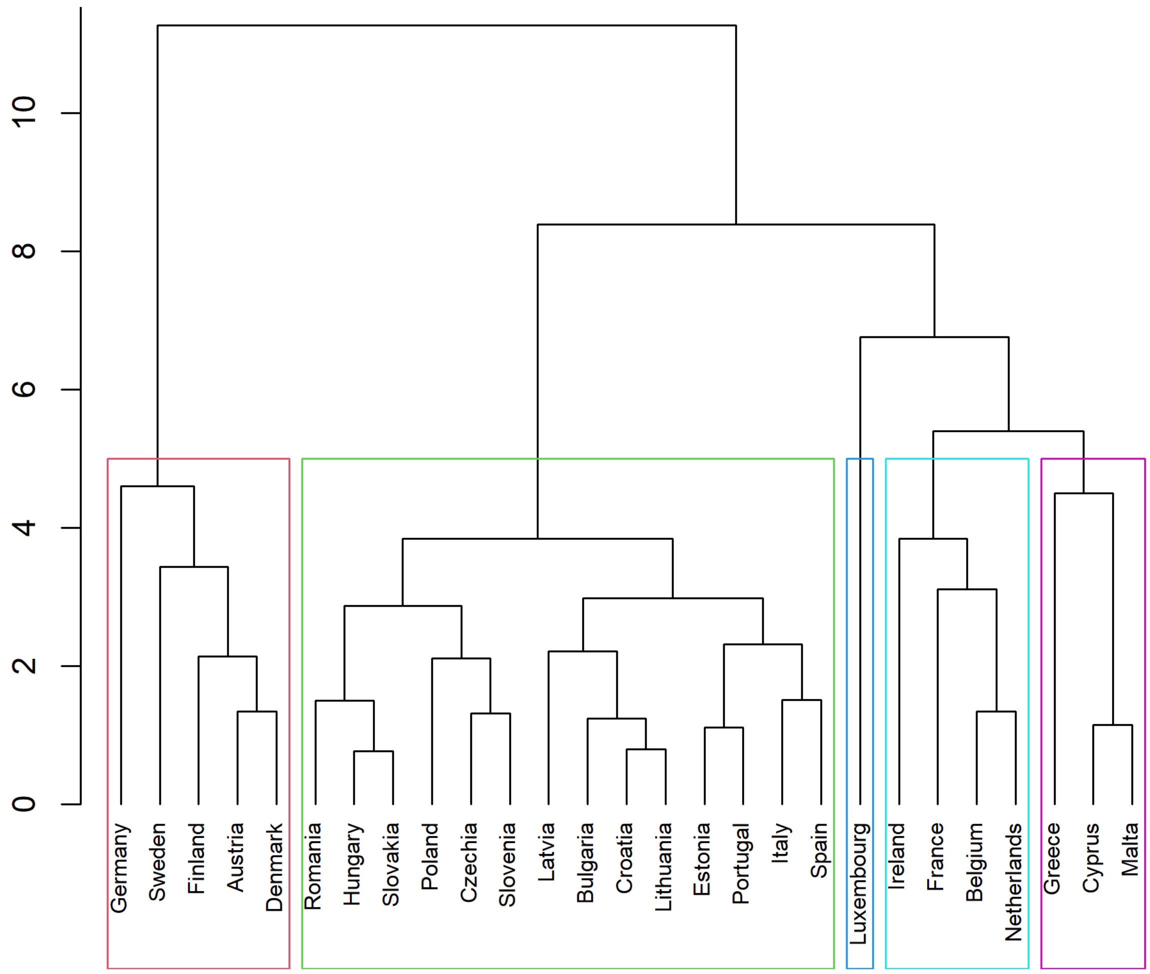

Figure 4. Dendrogram derived for air pollution determinants of the EU–27 countries

Source: own elaboration.

Table 2. Cluster composition – air pollution determinants

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Austria, Denmark, Finland, Germany, Sweden	Bulgaria, Croatia, Czechia, Estonia, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain	Luxembourg	Belgium, France, Ireland, the Netherlands	Cyprus, Greece, Malta

Source: own elaboration.

Cluster 1 comprises countries with the highest stock of R&D expenditures, a high stock of patents in air pollution abatement technologies, a mostly high share of energy from renewable sources, an above-EU average GDP per capita, and strong institutions (measured by the control of corruption index). Cluster 2 is dominated by the new EU member states, with low levels of GDP per capita and low innovation performance regarding patent stocks in technologies associated with air pollution abatement and stock of (total) R&D expenditures. Moreover, this group's share of services in GDP is mostly below the EU average, with low levels of institutional quality. Cluster 3 is formed solely by Luxembourg. It is considered an outlier as it has the highest GDP per capita, the highest share of services in GDP, the lowest renewable energy consumption, the lowest tertiary school enrolment, and high institutional quality. Cluster 4 contains rich countries with a relatively high stock of R&D spending and a stock of patents in air pollution abatement technologies close to the EU average. They have a low share of energy from renewable sources and high institutional quality. Cluster 5 is characterised by a higher than EU average share of the service sector in GDP, a high share of fossil fuel energy consumption combined with a low share of energy from renewable sources, and low innovation performance measured by patent stocks in technologies associated with air pollution abatement and stock of (total) R&D expenditures.

Conclusion

The article presented the results of an analysis of the differences (and similarities) of EU countries in terms of air pollution emissions and their techno-economic determinants. We conducted a cluster analysis on preselected sets of indicators using averaged data for 2015–2020. Groups (clusters) of countries that were similar in terms of the considered characteristics were identified, and thus, we achieved our research goal. Our findings confirm that individual groups of countries exhibit distinctive patterns of air pollution, as well as factors that determine the emissions. In both groupings, the Eastern EU countries formed a separate cluster, revealing homogeneity both in terms of pollution and its determinants. Western EU countries showed greater diversity in terms of the variables analysed: some showed levels of air pollution intensities similar to those of Eastern EU countries (i.e., Finland, France, Luxembourg, Spain, and Sweden) and factors that determine pollution similar to Eastern EU countries (i.e., Italy, Portugal, and Spain), while the others formed the remaining clusters. As far as Cyprus and Malta are concerned, in the case of clustering based on the determinants of pollution, they formed a separate cluster together with Greece. When analysing the pollution levels, however, only Malta showed a different pollution pattern, while Cyprus was included in the Eastern EU cluster. Therefore, in light of our results, the conclusion about backward and 'dirty' new member states and advanced and 'clean' old EU countries would be a far-reaching simplification of reality.

The multivariate analysis leads to the conclusion about the heterogeneity of the EU regarding both air pollutant emissions and the factors that potentially affect pollution levels. The analysis indicates that there are still significant differences between EU members and that much still needs to be done to improve air quality. The results of this study may contribute to the debate on environmental protection. The findings indicate the need and space for initiatives in the area of factors that influence air pollution in order to impede environmental degradation, though there may be no single recipe for all EU countries. The revealed heterogeneity among countries suggests that the actions should address a country's specific settings.

According to the World Health Organization (2021, pp. 13–15), bad air quality has strong adverse health effects, including increased premature mortality. Therefore, reducing air pollution should be a priority for all countries that exceed acceptable emissions levels. Current WHO air quality guidelines are more stringent than EU standards, and only long-term EU policies aim to reduce environmental pollution to health-safe levels. However, given the current progress in meeting the EU air pollution targets by individual member states, it will be challenging to meet further pollution reductions.

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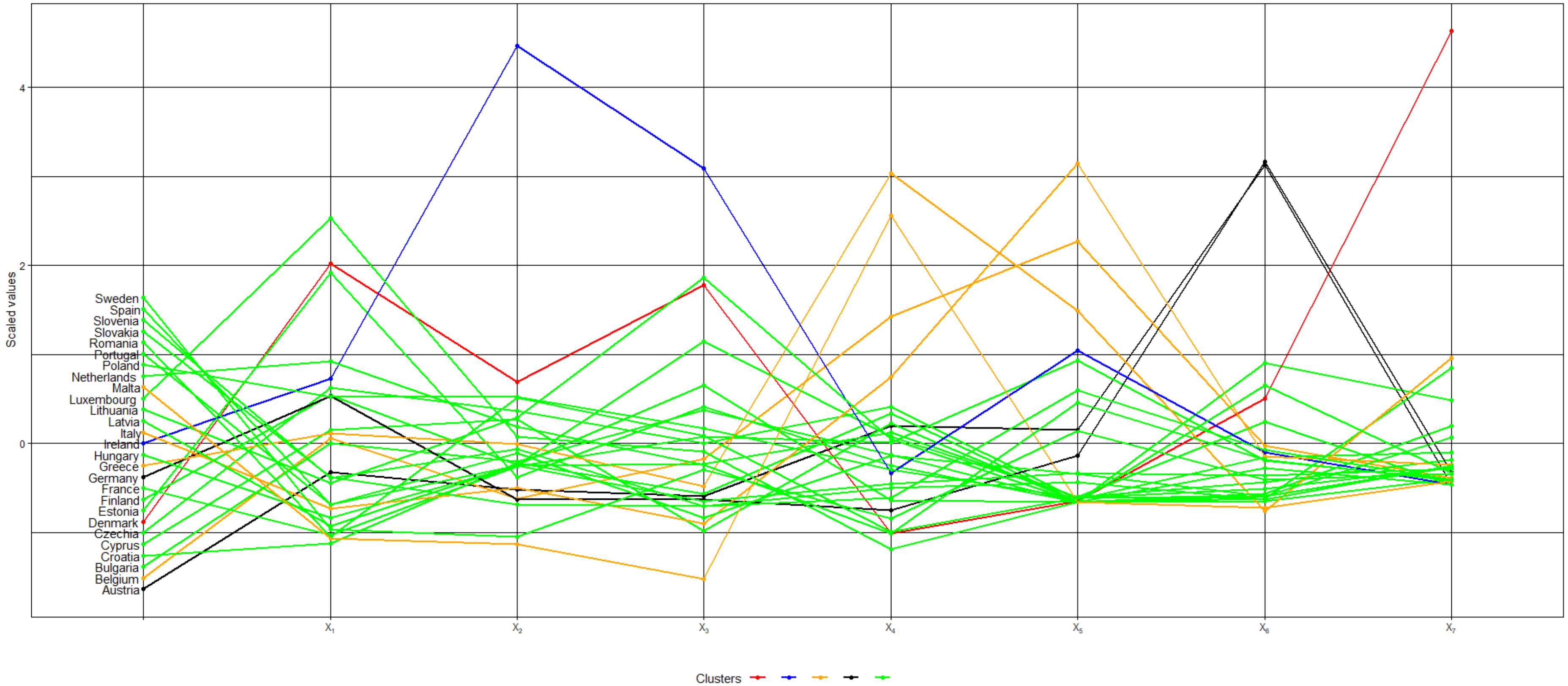
Zróżnicowanie poziomu zanieczyszczenia powietrza i jego uwarunkowań techniczno-ekonomicznych: analiza skupień dla krajów UE–27

Ciągłe pogarszanie się jakości środowiska naturalnego jest jednym z najważniejszych globalnych wyzwań, przed którymi stoi obecnie ludzkość. Celem niniejszego badania była analiza różnic i podobieństw między krajami UE–27 w zakresie emisji zanieczyszczeń powietrza (gazów cieplarnianych i gazów zakwaszających) oraz ich uwarunkowań techniczno-ekonomicznych, obejmujących czynniki ekonomiczne, energetyczne, instytucjonalne oraz poziom innowacyjności. Analizę przeprowadzono na podstawie dziewięciu wskaźników ilustrujących emisje zanieczyszczeń oraz piętnastu zmiennych reprezentujących determinanty zanieczyszczenia powietrza, wykorzystując ich średnie wartości z lat 2015–2020. Do zidentyfikowania podgrup krajów o podobnych wzorcach zastosowano analizę skupień. Otrzymane wyniki wskazują na znaczące zróżnicowanie krajów UE zarówno pod względem poziomów zanieczyszczenia powietrza, jak i determinant emisji. Przeprowadzona analiza ujawniła istotne różnice pomiędzy wschodnimi krajami UE, wykazującymi wspólne wzorce zanieczyszczeń powietrza i determinant emisji, oraz zachodnimi krajami UE, które cechowały się większym zróżnicowaniem pod względem analizowanych cech. W świetle uzyskanych wyników twierdzenie o zacofanych i zanieczyszczonych nowych państwach członkowskich UE w porównaniu z bardziej zaawansowanymi i nieskażonymi środowiskowo starymi krajami UE wydaje się nadmiernie upraszczać rzeczywistość. Nasze wyniki stanowią wkład w toczącą się dyskusję na temat jakości środowiska. Wskazują na potrzebę i przestrzeń do podjęcia działań w obszarze czynników wpływających na zanieczyszczenie powietrza w celu zahamowania degradacji środowiska naturalnego. Niemniej jednak, ze względu na ujawnioną heterogeniczność między krajami, wysiłki powinny być dostosowane do ich specyfiki.

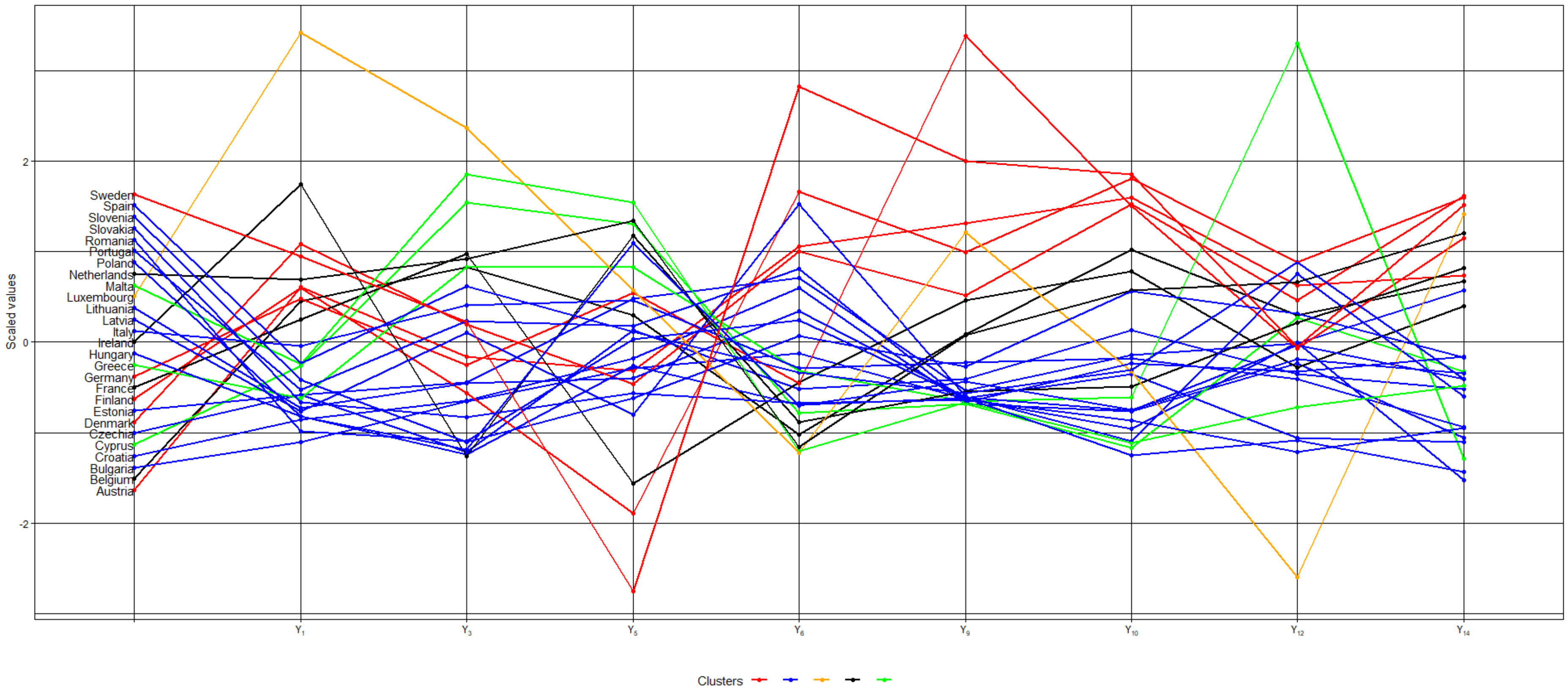
Słowa kluczowe: zanieczyszczenie powietrza, emisja gazów cieplarnianych, emisja gazów zakwaszających, analiza skupień, kraje Unii Europejskiej

Appendix A1. Country air pollutant emissions of the EU–27 by cluster



Source: own elaboration.

Appendix A2. Country determinants of air pollution among the EU–27 by cluster



Source: own elaboration.

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The Potential for High-tech Exports from Selected EU Member States to China and the Related Opportunities Arising from the Belt and Road Initiative

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Abstract

The EU's economic relations with China are characterised by a significant trade deficit. Enhancing EU exports of high-tech products, in particular, to China is the best way out of this imbalance. In doing so, EU countries can take advantage of the opportunities provided by the Belt and Road Initiative (BRI) that intends to improve connectivity between Europe and Asia.

Objective: This study aims to identify the untapped potential for high-tech exports of selected EU countries in trade with China and to evaluate the opportunities arising from the BRI in utilising this potential.

Research Design & Methods: To assess the overall high-tech export potential of selected EU countries to China, the export gap was calculated using the concept of revealed comparative advantages.

Findings: Among the examined EU countries, Hungary and the Czech Republic were found to have the greatest high-tech export growth potential to China. The largest export gaps were recorded in electrical machinery and equipment.

Implications & Recommendations: The findings of the study can be used by European businesses to adjust their export strategies. It can also be used by government institutions of the studied

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countries when designing their economic and trade policies, particularly vis-à-vis China and the BRI initiative, within the field of supporting infrastructure projects, as well as high-tech industries. Contribution & Value Added: The study contributes to the literature on the potential of EU export growth to China that has not been sufficiently explored yet. The novelty of the study is in identifying specific high-tech commodities with the highest potential for export to China.

Keywords: European Union, China, export potential, high-tech products

JEL: F10, F50, P45

Introduction

China's ambition to become the leader of the world's strongest economies is evident. It was one of the reasons for launching the most significant initiative in modern Chinese history, the Belt & Road Initiative (BRI), in 2013 to revive the ancient Silk Road using the most modern technologies.

The BRI aims to increase China's and allegedly also its trading partners' economic and trade potential by improving connectivity between Europe and Asia. The BRI can, therefore, be understood as a mutual connection of countries and economies, especially those of the Eurasian continent, through various projects.

China actively promotes its interests in the European part of the continent, which is largely represented by the EU. Therefore, it is extremely important for the future of the EU to cooperate effectively with China within the BRI so that it is a "win-win" cooperation for both parties. This need is especially evident when looking at the EU's high trade deficit with China. Enhancing EU exports to China, in particular, high-tech products, is the best way out of this imbalance. In the high-tech sector, the EU and its member countries achieve comparative advantages, while China remains a significant importer of a variety of their products. Therefore, this article aims to identify the unused export potential of selected EU countries in trade with China in high-tech products and to evaluate the opportunities arising from the BRI in utilising this potential.

Currently, we can observe that the opportunities arising from BRI implementation differ depending both on the country's economic characteristics and its approach to the initiative. For this reason, we selected several EU countries, including Germany, France, Italy, the Netherlands, Greece, Hungary, the Czech Republic, and Slovakia. Germany and France represent the largest economies in the EU and are China's most important trade partners among the member countries. Together with the EU authorities, they share concerns that key elements of China's trade and industrial policy, such as infringement of intellectual property rights, forced technology transfer, a lack of investment transparency, and a lack of reciprocity, are economic threats to the EU. They are also concerned about the influx of Chinese investment and its alleged implications, particularly political influence, control of key transport hubs, and access to sensitive technologies. Although they are sceptical about the BRI, they cannot be excluded from the initiative because of their economic size and geopolitical position.

Hungary, the first EU country that officially joined the BRI, the Czech Republic, and Slovakia represent EU member states with a positive attitude towards the BRI. They are involved in the 16+1 platform for cooperation among China and the Central and Eastern European (CEE) countries. They were the first EU countries to sign cooperation memoranda with China in 2015. In deepening cooperation with China, they are primarily motivated by economic factors, especially interest in Chinese investments. Improving relations with China gives these rather small and economically weak European countries, which in the past were influenced by Russia and currently depend economically on Germany, more strategic and economic freedom.

Following the CEE countries, other EU economies with key European ports, such as Greece, the Netherlands, and Italy, joined in supporting the BRI initiative. Italy and Greece represent indebted EU countries. They welcome participation in the BRI as they expect that, thanks to Chinese help, they can overcome their own economic problems. Italy was the first G7 country to join the BRI, drawing public criticism from both Germany and France. However, according to the Italian Minister of Economic Development, Luigi Di Maio, such cooperation can contribute to reducing the trade imbalance between Italy and China (Astana Times 2019). Greece is another EU country that welcomes BRI cooperation. Although European creditors imposed austerity measures on Greece in 2010, China has invested in Greece since 2009 in the port of Piraeus. Piraeus has thus become the busiest port in the Mediterranean and is one of the key hubs of the BRI. The Netherlands has a unique position as an important European re-export hub, and it sees the BRI as an opportunity to improve that position.

Literature review

The potential for EU export growth to China is not sufficiently exploited within the literature. The export potential of some EU countries to China has been investigated by Bronček (2019) and Kašťáková, Luptáková, and Družbacká (2022). Bronček addressed Slovakia's unused export potential to China based on data from 2001 to 2017. He found that Slovakia has the potential to export products from engineering, chemistry, agriculture, the woodworking industry, and metallurgy with a lower level of sophistication compared to the products of Western European countries. To determine the unused export potential, he proposed an export gap index using the concept of revealed comparative advantages. Revealed comparative advantages are based on Ricardo's (1817) classical theory of international trade, according to which trade between countries results from relative differences in labour productivity. This theory is based on the assumption that labour is the only factor of production.

Later, within the neoclassical theory of international trade, the differences in relative endowments of all production factors, including labour, natural resources and capital, have been used to explain countries' comparative advantages. Comparative advantages are useful in comparing relative production costs, explaining the export specialisation of a country, and identifying products that are most likely to succeed in foreign markets. As pointed out by Stellian and Danna-Buitrago (2019), the concept of comparative advantages refers not only to the ability to produce some goods with higher productivity compared to other countries but also, in line with the new trade theory, to increase product differentiation. It can also provide useful information about a country's potential business prospects with new partners. For example, it is unlikely that countries with similar revealed comparative advantages have high bilateral trade intensities, except for intra-industry trade (World Bank 2010). Much research has been based on the concept of revealed comparative advantages, including Balassa (1965; 1986), Vollrath (1991), Hinloopen and Van Marrewijk (2001) and Hoen and Oosterhaven (2006).

Kašťáková, Luptáková, and Družbacká (2022) identified the export potential to China of its largest trading partners within the EU – Germany, France, Italy, and the Netherlands. To identify products that have good prospects of additional export to China, they calculated the Export Potential Indicator using the methodology of Decreux and Spies (2016). The potential EU export value of a specific product to China, according to this methodology, is determined by three factors: supply (i.e. exporter performance in exporting the product), demand for the product (by the importing country), and the ease of exporting any good from one partner to another. The findings of this study indicate that Germany has the largest export potential to China, followed by France, Italy, and the Netherlands. The untapped export potential for these four countries amounts to US$174 billion, of which Germany accounts for US$114.7 billion. The products that the four countries could sell to China the most include mainly cars and car parts, machinery, medicine, and aeroplanes.

In contrast to the two studies above, this study focuses on examining the export gap of EU member states in the high-tech sector because, in the 21st century, these technologies play a key role in achieving competitiveness. EU countries should, therefore, develop their export potential primarily in high-tech products. Over the last two decades, investments in research, development, and innovation have been an important part of EU economic strategies such as the Lisbon Strategy and the "Europe 2020" strategy.

Braja and Gemzik-Salwach (2020) point out that growing global competition for less knowledge-intensive products naturally pushes the EU and its member states to move to knowledge-intensive industries. They state that European business owners must be involved in these industries to win the economic competition at the European and global levels. Similarly, Ribeiro, Carvalho, and Santos (2016) argued that European countries should support the export of high technology. In addition, they state that a shift towards greater diversification of export partners is desirable. Namely, there should be a shift from the most representative countries in the export portfolio, such as the USA, to less representative ones, and countries with higher growth potential, such as China.

The literature contains several empirical studies that look at the BRI initiative in the context of trade between China and the EU. Focusing on nine railway lines, Li, Bolton, and Westphal (2018) examined the impact of transcontinental railways under the BRI on trade between China and its trading partners in Central Asia and Europe. The results showed that railways increase the intensity of trade between China and its trading partners. This applies mainly to the import of Chinese products but only to a limited extent to the export of European and Central Asian products to China. If trade prospers, partner countries can use their comparative advantages, leading to win-win situations. Therefore, trade expansion is a common goal of many countries. The railways under study here are significant factors in achieving this goal.

Liu et al. (2019) investigated the impact of the route of the New Silk Road through the North Sea on China–Europe trade potential. Based on the analysis of the impact of building a sea route and expanding the use of sea routes in trade through a gravity model and regression analysis, they measured the trade potential between China and Europe. The results indicate the Northern Route has a positive impact on the growth of trade potential between China and Europe. The export, import, and overall trade potential of China to Northern European countries has increased significantly, mainly because of route shortening. Germany, Great Britain, the Netherlands, and France, which are China's biggest trading partners in Europe, have also seen a big increase in their trade potential.

Garcia-Herrero and Xu (2016) used a gravity model to determine the relationship between transportation costs and trade of the BRI countries. They found that a 10% reduction in railway, air and maritime costs increases trade by 2%, 5.5% and 1.1%, respectively. Similarly, Fardella and Prodi (2017) assessed the potential benefits for Europe of infrastructure development, including railways and ports, along the BRI. They consider new investments in railway and port infrastructure, which decrease transportation costs and increase trade volumes, to be an important stimulus for the growth of trade between the EU and China. They conclude that the development of new railway connections will benefit most of the Northern and Central European countries that export high-value products to China.

As part of the New Silk Road, Ma et al. (2019) analysed Chinese foreign direct investment (FDI) inflows to the EU to examine their impact on bilateral trade. They performed the analysis using a gravity model for the years 2003 to 2016, which was a period when not only Chinese trade but also Chinese FDI outflows grew rapidly. They found that both BRI and Chinese FDI had a positive effect on China's exports to European countries and a negative effect on exports from European countries to China in the period under study but with a small level of significance. According to the study, Chinese FDI had both complementary and substitution effects on trade with the EU, and the complementary effects were much stronger than the substitution effects. The authors expect EU exports to China will grow gradually thanks to the BRI.

Using a gravity model, Karkanis (2018) assessed the factors that influenced exports and imports between the EU and China from 2001 to 2015. Because, in the long term, the EU imported more from China than it exported to China, he wanted to identify factors that could help reduce this imbalance. His results confirmed that the distance factor had a significant negative impact on both EU exports to China and EU imports from China, but this impact was stronger with EU exports. As expected, market size and income had a positive impact on EU exports and imports, while the EU's GDP per capita had a relatively stronger impact on EU exports than on imports.

In addition, he investigated the influence of two variables that do not change over time (time-invariant proxies), namely the insularity and the landlocked nature of EU countries. For both variables, he found a positive impact on EU trade with China. He explained the positive impact of insularity, especially on EU exports to China, with the case of Ireland. It is an island country with a small market size and relatively limited expansion potential. To boost economic growth, the pro-export nature of the economy was therefore supported. With Malta and Cyprus, the island character had a more significant influence on imports from China because these countries have limited human and natural resources, as well as a limited range of domestically produced goods. The rather unexpected positive impact of the landlockedness of some EU countries (e.g., Austria, the Czech Republic, Hungary, Slovakia, and Luxembourg) on exports to China is explained by the positive externality of being at the crossroads of large markets such as Germany, France, Italy, and Poland, on the one hand, and China on the other, particularly regarding the established transport networks. Karkanis assumes that building railways will help exports to China, especially for the EU countries that are landlocked.

From the empirical studies mentioned above, it follows that building infrastructure within the BRI has a positive effect on "shortening" the distance between the EU and China, which contributes to the growth of mutual trade, even if, so far, the positive effect is manifested mainly on the side of Chinese exports to the EU.

Methodology

To assess the overall high-tech export potential of selected EU countries to China, we calculated the "export gap." For the calculation, we used disaggregated annual data on trade in goods at the HS–6 level from the International Trade Centre (ITC) database

(International Trade Center 2022a), which is based on data from UN COMTRADE and ITC statistics. At the HS–6 level, we selected 279 commodity groups identified as high-tech products by Fontagné, Freudenberg, and Ünal-Kesenci (1999). This list is a modification of the joint list of high-tech commodity groups prepared by Eurostat and the OECD (Lemoine and Ünal-Kesenci 2002).

First, we identified high-tech products in which the selected EU countries achieve comparative advantages. We calculated the Revealed Comparative Advantages (RCA) index, which is extensively used in the literature to evaluate a country's export potential (Hauk and Deb 2017). There are several methods for calculating RCA while the selection of a particular RCA index should be governed by the objective of the research (French 2017). In this study, we use one of the original formulas for calculating RCA by Balassa (1965). His index measures the relative advantage or disadvantage of a country's exports in a particular commodity group with respect to the world exports of this commodity group. It is widely used in the literature due to its clear economic interpretation and simplicity (Hadzhiev 2014). Recently, it was used by Brakman et al. (2022), who determined the comparative advantages of the Netherlands relative to the world, Falkowski (2018), to evaluate the competitiveness of the Baltic States in trade in high-technology goods, Pitoňáková (2020), who identified the comparative advantages of Slovakia on extra EU markets, Arsyad et al. (2020) to assess the competitiveness of palm oil products of Indonesia and Malaysia, and Torrecillas and Martínez (2022), who calculated the RCA for various product categories associated with the olive fruit using export data.

The used mathematical formula of RCA is:

$$RCA_{jk}^{n} = \frac{\dfrac{X_{jk}^{n}}{X_{j}^{n}}}{\dfrac{X_{wk}^{n}}{X_{w}^{n}}}, \tag{1}$$

where X_{jk}^{n} represents the export of country *j* in commodity group *k* in year *n*, X_{j}^{n} represents the total export of country *j* in year *n*, X_{wk}^{n} represents the world export of commodity group *k* in year *n* and X_{w}^{n} represents the total world exports in year *n*. The basic interpretation of the result is that if $RCA_{jk}^{n} > 1$, the country achieves a comparative advantage in the given commodity group, and conversely, $RCA_{jk}^{n} < 1$ indicates a comparative disadvantage. According to Hinloopen and Van Marrewijk (2001), the results of the index, i.e. the intensity of comparative advantages, can be interpreted as follows:

$0 < RCA \leq 1$ indicates a comparative disadvantage,

$1 < RCA \leq 2$ indicates weak comparative advantage, 2 < RCA ≤ 4 indicates a moderately strong comparative advantage,

4 < RCA indicates strong comparative advantage.

Separately, for each of the selected EU countries, we calculated the RCA for all commodity groups at the HS6 level for which data was available. The RCA was calculated for five years – from 2016 to 2020. From the values of annual RCA indexes, we calculated an arithmetic average, which helped to "smooth out" potential fluctuations in exports in individual years.

Subsequently, the Import Significance (IS) index was calculated and used to identify products that China imports to a greater extent than the rest of the world (Brónček 2019). In this way, it was possible to identify commodities with increased demand from China and, thus, from the EU's point of view, commodities with a good export perspective. The formula for calculating the IS index is a changed formula for calculating RCA, using import values instead of export values. Its mathematical formula is:

$$IS_{jk}^{n} = \frac{\frac{M_{jk}^{n}}{M_{j}^{n}}}{\frac{M_{wk}^{n}}{M_{w}^{n}}}, \quad (2)$$

where M_{jk}^{n} represents the import of country *j* in commodity group *k* in year *n*, M_{j}^{n} represents the total import of country *j* in year *n*, M_{wk}^{n} represents the world import of commodity group *k* in year *n*, and M_{wk}^{n} represents the total world import in year *n*. If the value of IS > 1, the country imports the given commodity group to a greater extent than the rest of the world, and in the case of IS < 1, the country imports the given commodity group to a lesser extent than the rest of the world.

In this study, we calculated China's IS index values for 247 commodity groups at the HS6 level from 2016 to 2020, from which the average IS for the five years under study was calculated.

Next, we calculated an export gap defined by Zábojník and Borovská (2021) as:

$$EG_{jik}^{n} = \left(\frac{\sum_{n0}^{n} \frac{X_{jk}}{M_{wk}}}{(n-n0)+1} - \frac{X_{jik}^{n}}{M_{ik}^{n}} \right) M_{ik}^{n}, \quad (3)$$

where:

EG^{n}_{jik} is the export gap of country *j* for commodity *k* exported to country *i* in year *n*,

X_{jk} is the export of commodity *k* to country *j*,

M_{wk} is the world import of commodity *k*,

X^{n}_{jik} is the export of commodity *k* from country *j* to country *i* in year *n*,

M_{ik} is the import of commodity *k* to country *i* in year *n*,

n is the year for which we calculate the export gap,

*n*0 is the first year in the interval in which we calculate the average RCA_{jk}.

The condition for calculating the export gap is that the average share of the examined EU country's exports in world imports for the given time interval is greater than the share of the examined EU country's exports in Chinese imports in year *n*.

We calculated the export gap for commodity groups that meet the following condition:

$$\overline{RCA}^{t}_{j'} \geq 1 \cap \overline{IS}^{n}_{ik} \geq 1 \quad (4)$$

in which selected EU countries achieve comparative advantages, and China has comparative disadvantages with a minimum Balassa index value of 1.

The calculation of the export gap based on the intersection of exports (supply) of one country and imports (demand) of another country serves as a starting point for assessing prospective export commodities. For this aim, we supplemented the results of the export gap calculation with an assessment of several market access data, such as the average tariff imposed by China, the concentration of supplier countries, the average distance between China and its import partners, the average distance between the country and all its import markets, or the number of requirements related to China's import of the commodity.

One of the main limitations of our approach is that the calculation of the export gap is based on historical trade data and thus considers only products that one country already exports and the other imports. Another limitation concerns the measurability of export market access. The utilisation of the export gap depends on several factors that cannot be measured, like the specific needs of buyers, the administrative burdens and marketing opportunities in the importer's country, or the costs of export support activities.

Results and discussion

Exports of high-tech products accounted for up to 20% of total world exports in 2020, and their dynamics helped improve performance in other sectors (World Bank 2022). The World Intellectual Property Organization (2021) reported that the pandemic hurt international trade in 2020, but trade in high-tech goods expanded because of the boom in communication, computing, processing, and data equipment used for remote work. The EU is among the world's key producers of high-tech products. During the period under review, high-tech products accounted for approximately 16% of its total exports. In 2018, the EU had an estimated 40,358 companies in the high-tech manufacturing sector, which represents 0.2% of the total number of businesses in the EU. The countries with the most high-tech manufacturers were Germany (8,461), Italy (5,318), and Poland (4,446) (European Commission 2021).

The revealed comparative advantages of selected EU countries

Chart 1 summarises the number of commodity groups in which individual EU countries achieve a comparative advantage based on the average RCA value between 2016 and 2020 in the high-tech sector. Germany had the most comparative advantages, with a total of 108 commodity groups with an RCA ≥ 1. According to the chosen approach, Germany achieved a moderate comparative advantage in 49 commodity groups and a strong comparative advantage in 10 of these. Strong comparative advantages were recorded, especially in the fields of optical, photographic, cinematographic, measuring, and control instruments and devices. For example, Germany exports up to seven times more stereoscopic microscopes and hydraulic and pneumatic automatic controls than the rest of the world, making it the world's largest exporter of these commodities.

In the high-tech industry, France has a comparative advantage in 79 commodity groups, and it is strong in 14 instances. With aeroplanes and other motor aircraft commodity groups, France reached a Balassa index of 13.7, mainly because of Airbus, which is one of the world's major manufacturers of civil transport aircraft and regularly competes only with Boeing. The Netherlands, Italy, and the Czech Republic achieve comparative advantages in the high-tech sector in approximately 60 commodity groups.

The Czech Republic exports the most commodity groups, with a Balassa index value of over ten among all countries analysed. For example, it exports up to 35 times more weapons than the rest of the world, mainly thanks to Česká zbrojovka a.s., which ranks among the world's largest manufacturers of small arms. The country also dominates the export of microscopes, proton microscopes, and diffraction instruments ($\overline{RCA}_{jk}^{t} = 25$), mainly thanks to Tescan Orsay, Delong Instruments, and Thermo Fisher Scientific.

Slovakia has a comparative advantage in high-tech exports in 25 commodity groups. The highest comparative advantage was recorded for commodity group HS 854081 – receiver or amplifier valves and tubes ($\overline{RCA}^t_{jk} = 19$), which were exported by companies such as LEONI Slovakia, spol. s.r.o., Klauke Slovakia s.r.o., and KE Prešov Elektrik, s.r.o. among others. In most cases, these companies have foreign capital. Greece has the fewest high-tech commodity groups (11) with a comparative advantage among the analysed EU countries.

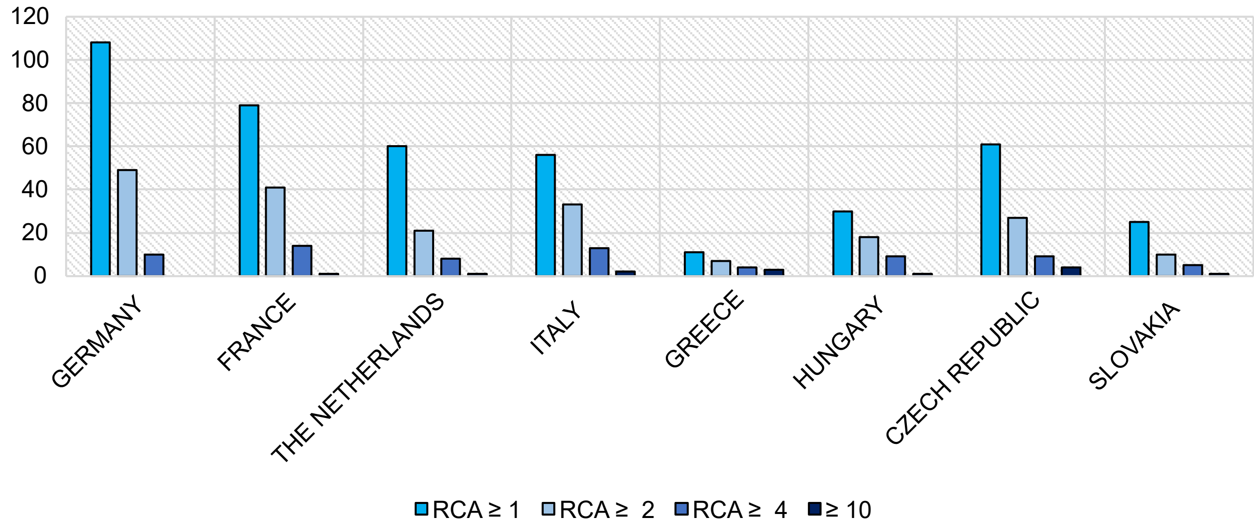

Chart 1. The number of high-tech commodity groups at the HS–6 level in individual EU countries based on the average RCA value between 2016 and 2020

Source: processed based on own calculations of data from International Trade Center 2022a.

China's import significance

According to the World Bank (2022), China's high-tech products account for up to 31% of its total exports, placing it at the forefront of technology exporters. Even in these sectors, there are commodity groups where China achieves high import signifiance index values. The list of China's most important imported high-tech commodities based on the average IS index from 2016 to 2020 is given in Table 1. On the first three rungs, optical instruments predominate. The highest index value was achieved by optical microscopes for photomicrography, cinephotomicrography, and microprojection, of which China is the largest importer in the world, with Germany, Japan, and Singapore accounting for most imports. The second highest value of the index was recorded for other liquid crystal devices assembled from products not more precisely specified, which China imports mainly from other Asian countries such as Japan, Singapore, and the Philippines. These devices are used in the production of LCD televisions and displays, for instance.

Another important commodity group for China includes sheets and plates of polarising material, which are used in the production of optical fibres and to remove glare from windows and objects such as car dashboards, LCD screens, and television screens. Similarly, Japan, South Korea, and the United States are major Chinese suppliers of these commodities. Germany and France round out the top ten most important Chinese suppliers of this commodity group.

Even though China has a lot of natural mineral resources, silicon has a high import significance index. It is also an important commodity for the Chinese industry, as it is used in semiconductor manufacturing to produce the silicon wafers necessary to produce integrated circuits, computer chips, solar cells, and other devices. In 2020, the value of this commodity's imports into China exceeded US$1 billion, with Germany accounting for nearly 50% of the total. They are mainly followed by commodities belonging to the category of electrical machines and devices. Fourteen of the examined commodities had an IS index greater than 3, indicating that China needs these high-tech commodities three times more than the rest of the world.

Table 1. China's top 10 high-tech commodity import groups at the HS–6 level with the highest average IS value between 2016 and 2020

HS code	Product label	Average IS index 2016–2020
901120	Optical microscopes for photomicrography, cinephotomicrography or microprojection	7.126
901380	Liquid crystal devices, n.e.s. and other optical appliances and instruments not elsewhere specified	5.650
900120	Sheets and plates of polarising material	5.297
280461	Silicon containing >= 99,99% by weight of silicon	3.882
854160	Mounted piezoelectric crystals	3.871
854190	Parts of diodes, transistors, and similar semiconductor devices; photosensitive semiconductor products	3.766
853224	Fixed electrical capacitors, ceramic dielectric, multilayer (excluding power capacitors)	3.658
846031	Sharpening „tool or cutter grinding" machines, numerically controlled	3.562
284410	Natural uranium and its compounds; alloys, dispersions, incl. cermets, ceramic products	3.519
846040	Honing or lapping machines for working metals, metal carbides or cermets	3.346

Source: processed based on own calculations of data from International Trade Center 2022a.

Export gap between selected EU countries and China

Among all of the examined high-tech commodity groups, a total of 58 items for the examined EU member states were identified as having an export gap, provided that the results of the average indices of RCA of the given country and IS of China for 2016 to 2020 met or exceeded a minimum value of 1. These items have a potential export value of US$151,500,000 for the EU members under consideration.

Table 2. The export gap of high-tech products in individual countries and the number of commodity groups with an identified export gap (in 2020)

	Total EG value (in mil. USD)	Number of high-tech commodity groups with an export gap
The Czech Republic	46.74	11
Hungary	31.28	8
The Netherlands	30.84	11
France	20.24	8
Germany	13.14	5
Slovakia	4.45	6
Italy	4.18	3
Greece	0.69	6

Source: processed based on own calculations of data from International Trade Center 2022a.

Table 2 contains information on the value of the export gap for each country and the number of commodity groups for which we identified an export gap. From the perspective of individual countries, the Czech Republic had the largest total export gap, amounting to nearly US$47 million. It comprises eleven high-tech commodity groups, primarily in optical, electrical, and mechanical machines. An export gap of over US$31 million was identified for Hungary and the eight high-tech commodity groups. The Netherlands ranked 2nd, with a gap of US$30.8 million and eleven high-tech commodity groups. We can, therefore, conclude that, among the examined nations, these three have the greatest export growth potential. Germany and France, the European export giants, achieve relatively low export gaps, which we attribute to their extensive use of comparative advantages and the export of many high-tech products to China. For example, Germany accounts for nearly half of China's aircraft and silicon imports.

In contrast, France has a large share of Chinese imports, particularly combustion turbines. Additionally, thanks to large pharmaceutical companies such as Sanofi, it also has a large share of the import of many pharmaceuticals. Slovakia recorded an export gap of only US$4.45 million for six high-tech commodity groups. Greece, which has the fewest commodity groups with a comparative advantage in high technology, does not have an export gap of even one million dollars.

Considering the relatively large number of high-tech commodity groups in which an export gap was identified, we narrowed down the selection of the most significant ones to commodity groups in which the export gap reached a value of at least US$1 million, which gave us 31. The top ten of these groups of goods are listed in Appendix 1, along with factors that we will take into account when assessing the possibilities for using the existing export potential:

- **Average tariff imposed by China on imports of a commodity** (International Trade Center 2022b).
- **Tariff imposed by China on imports of a commodity from a specific EU country** (International Trade Center 2022b).
- **Concentration of supplier countries** based on the Herfindahl index. It is calculated as the sum of the square root of each supplier country's import share in the selected country. According to the ITC (2022b), a country's imports are moderately concentrated if the Herfindahl index value is between 0.1000 and 0.1800. A value higher than 0.1800 suggests that imports are concentrated.
- **Average distance between China and its supplier countries,** which corresponds to the average distance between China as a target market and all its supplier countries weighted by the trade value. This indicator helps in determining if the target market is mostly supplied by regional partners. The ITC (2022b) derives its data on the geographical distance between countries from the CEPII database using Mayer and Zignago's (2006) methodology.
- **Average distance between the given EU country and its export markets,** which is determined on the same basis as the average distance between China and its suppliers (International Trade Center 2022b).
- **The number of import requirements related to the import of a commodity from the supplier country to China** (International Trade Center 2022b).

Table 3 presents the ten highest export gaps that were calculated, while the next section elaborates on the first five commodity groups in more detail. Most of the ten largest export gaps were recorded for commodities belonging to the commodity group of electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles (HS 85).

Table 3. The highest export gaps in high-tech products of selected EU countries in trade with China (in 2020)

Country	HS Code	Product label	Average share in world imports in 2016–2020 (%)	Share in China's imports in 2020 (%)	Exports to China in 2020 (million USD)	Export gap in 2020 (million USD)
Czech Republic	853224	Fixed electrical capacitors, ceramic dielectric, multilayer (excluding power capacitors)	1.35	0.00	0.33	21.69
Hungary	853400	Printed circuits	0.64	0.02	2.30	11.54
The Netherlands	853222	Fixed electrical capacitors, aluminium electrolytic (excluding power capacitors)	3.33	0.05	0.82	9.77
Czech Republic	853221	Fixed electrical capacitors, tantalum (excluding power capacitors)	7.44	0.26	1.86	8.91
The Netherlands	902750	Instruments and apparatus for physical or chemical analysis, using UV, visible or IR optical …	4.38	0.54	12.62	7.90
Germany	840130	Fuel elements „cartridges", non-irradiated, in casing with handling fixtures, for nuclear reactors…	10.21	0.00	0.00	7.37
Czech Republic	851830	Headphones and earphones, whether or not combined with a microphone, and sets…	2.14	0.00	0.00	5.99
Czech Republic	902710	Gas or smoke analysis apparatus	3.50	0.06	0.51	5.85
France	284420	Uranium enriched in U 235 and its compounds: plutonium and its compounds; alloys, dispersions	12.59	0.00	0.00	4.93
Hungary	300432	Medicaments containing corticosteroid hormones, their derivatives or structural analogues	1.45	0.00	0.00	4.69

Source: processed based on own calculations of data from International Trade Center 2022a.

The largest export gap was found in the Czech Republic and the commodity group electric capacitors, solid, ceramic, and multilayer (HS 853224), which store energy in an electric field and are used in the automotive industry, the IT industry, and the camera manufacturing industry. It reached US$21.7 million. The main manufacturers of these goods in the Czech Republic are VISHAY ELECTRONIC spol. s r.o. and KYOCERA AVX Components s.r.o. China imports these products mostly from Japan (40.6% of Chinese imports), the Philippines (9.5%), and Taiwan (8.5%), followed by other (geographically close) Asian countries, as indicated by the relatively small average distance of supplier countries (2199 km) and high import concentration (0.24). This raises obstacles for European "players" to enter the Chinese market. As China imposes no tariffs on imports of these items from the majority of countries, a trade agreement between the EU and China could help boost EU exports only if it includes the elimination of non-tariff barriers. Exports of these goods from the Czech Republic flow to neighbouring European nations located an average of 906 kilometres away. During the monitored period, the Czech Republic exported also to China, but at a modest amount (in 2020, it was US$0.3 million). In line with the findings of Karkanis (2018), which suggest that building railways helps landlocked EU countries export to China, accelerating and improving the efficiency of land transport routes could help the Czech Republic utilise the export gap identified for this commodity group.

We recorded the second-largest export gap for Hungary, at US$11.5 million for HS 853400, which contains electronic printed circuits or printed circuit boards used in the building of a variety of electrical appliances and electronic equipment. Several Continental Automotive Hungary facilities, IBM Data Storage Systems Kft, and Nokia Solutions and Networks Kft are among the main producers and exporters of this commodity. In 2020, China accounted for 21.8% of worldwide imports of this product, making it the world's top importer. Interestingly, according to the ITC (2022a), China was its own top supplier (30% share), which can be partially explained by re-imports. Over 90% of Chinese imports are manufactured in China, shipped to Hong Kong, and then re-imported. Up to 73% of re-imported items are used as raw materials for inward processing, with Guangdong Province importing 70%. The geographical and logistical advantages of Guangdong Province and Hong Kong are the primary factors that explain this trade. China-origin goods entering Hong Kong for processing are exempt from import duties, and business management and distribution centres of global corporations are frequently based in Hong Kong. We can, therefore, assume that around one-third of the reported imports are generated in China. Next, the imports originate in Asian countries such as Taiwan (with a 28.8% share of Chinese imports), Japan, South Korea (both with a roughly 13% share), and Hong Kong (with a 7.8% share). The import concentration of China is high (0.24). Hungary mostly exports to EU countries such as Germany (5% of Hungarian exports of the commodity) and Belgium (7.3%), as well as to the geographically close Ukraine (7.1%). China imposes no tariffs on imports from the EU, but numerous import requirements apply to these products. Improved access to trade routes and the establishment of stable rail connections to the centre of Europe could have a positive impact on Hungarian exports to China.

An almost US$9.8 million export gap was calculated for the Netherlands and solid, aluminium, and electrolytic electrical capacitors (HS 853222), which are frequently employed in smaller electronic circuits and consequently have a wide range of applications. China, a global exporter and importer of electrical machinery and equipment, was, the world's largest importer of these products in 2020, with a 29.3% share. Even in this case, China's major suppliers included Asian countries such as Japan, Indonesia, and Malaysia, and the import concentration was high (0.22). In 2020, the Netherlands was the tenth greatest exporter of these commodities worldwide. The average distance between the Netherlands and importing countries is a little over a thousand kilometres, which implies that exports are concentrated in Europe, particularly in the EU despite the direct access of Dutch exporters to the Port of Rotterdam that is the largest seaport in Europe and an important logistics hub for exporting to the whole world. While the Netherlands' exports over the past five years have averaged approximately only US$180 million, China's imports have averaged US$1.5 billion. We can assume that the Dutch exporters, most of which are medium-sized businesses, would have difficulties supplying the quantities requested by China and competing with large Japanese industry leaders such as Toshiba or Murata Manufacturing, as well as the lower labour costs in Indonesia. The prospects for exploiting the export gap identified for the Netherlands are, therefore, not optimistic.

Electric capacitors, specifically tantalum (HS 853221), represent a commodity group for which the Czech Republic has a nearly $9 million export gap. Tantalum capacitors are used in computer electronics, audio amplifiers, automotive circuits, medical devices, and mobile phones. As in the first examined group, VISHAY ELECTRONIC spol. Ltd. and AVX Czech Republic s.r.o. are among the largest manufacturers. They are divisions of companies that are leaders in their respective industries. As a result, the Czech Republic was the eighth-largest exporter in the world in 2020. As for Chinese imports, almost 27% came from Thailand, 20% from Indonesia, and 11% from Japan. Despite this, we observe lower market concentration (0.16) compared to the commodity groups analysed so far. The average distance of China from its import partners is up to 5414 km. In addition, the average distance between the Czech Republic and importing countries was 4521 kilometres, and the export concentration was only 0.14. It is noteworthy that, for the Czech Republic, the seventh-largest supplier to China, the customs rate is 0%, as it is for most other suppliers. By comparison, as China's fifth largest supplier on the Pacific coast, El Salvador's exports are subject to tariffs of up to 35%. Even in this instance, we can assume that a more efficient logistical connection between the Czech Republic (or the EU) and China would boost this export.

The Netherlands reported an export gap of over US$8 million for the HS 902750 commodity group, which contains other instruments, apparatus, and equipment using optical radiation (ultraviolet, visible, and infrared) mostly used in medicine (e.g. x-rays or ultrasounds). As the world's largest importer of this group of commodities, China imported over a third from the United States in 2020. Singapore and Japan accounted for almost 20% of China's imports, followed by Germany with a much smaller 8.4% share. According to the methodology, this market can be regarded as moderately concentrated. The Netherlands, the sixth largest exporter of this commodity group in the world, has even fewer concentrated exports than Germany (the Herfindahl index was only 0.06), meaning its exports are "scattered" among many partners. Philips Healthcare, whose parent business is the Dutch Koninklijke Philips Electronics, is one of the top producers of these goods. China also applies a 0% tariff. From the perspective of export growth or the exploitation of the export gap by the Netherlands, ratification of the Comprehensive Agreement on Investment (CAI), which would allow EU investments to be implemented in China, might have a positive effect on the EU. China's commitments under the CAI include the establishment of privately funded hospitals and foreign-owned clinics in Beijing, Tianjin, Shanghai, Nanjing, Suzhou, Fuzhou, Guangzhou, Shenzhen, and throughout Hainan Island, as noted by Gigler (2021). The agreement would also be a big step toward better relations between the EU and China, which could help China switch from buying American goods to buying Dutch ones.

The commodity group with the smallest export gap, according to Table 3, is also interesting when considering events from 2020. HS 300432 includes medications, specifically corticoids or hormones of the adrenal cortex. Hungary was found to have here an export gap of nearly US$4.7 million. Unlike the other commodity groups listed, they are pharmaceutical industry products. Corticosteroids may be used to treat anaemia, osteoporosis, and hypertension. They are typically prescribed to patients with adrenal gland health problems. According to Research and Markets (2021), various well-known brands such as Pfizer, Novartis, Merck, Sanofi, Johnson & Johnson, GSK, AstraZeneca, Cipla, and LEO Pharma dominate the market for these pharmaceuticals. In terms of exporters, Australia was the leading supplier in 2020, accounting for 33.2% of Chinese imports.

Several of the aforementioned enterprises are based in Australia. 2020 and 2021 brought dramatic changes to trade relationships between Australia and China, which culminated in a trade war. Australia demanded an independent investigation into the origins of COVID–19 in 2020, which outraged Chinese officials. They responded with an unprecedented wave of trade restrictions, which halted the import of several Australian commodities and led to the severing of economic ties (Wilson 2021). Although the Chinese measures did not have a direct impact on the pharmaceutical business, strained relations may manifest themselves in these industries soon.

The second greatest percentage of Chinese imports of this commodity group (17.2%) was recorded by France, which is home to one of the top EU pharmaceutical companies, Sanofi. In Hungary, the pharmaceutical companies mentioned above have multiple branches.

However, Hungary has not yet exported pharmaceutical products to China, instead prioritising exports to countries that are physically closer (the average distance between Hungary and all its import markets is 933 km). China imposes an average import duty of 0% on this category of goods, creating favourable conditions for Hungarian export growth. The trade war with Australia, from which Hungary could gain due to its ever-improving relations with China, and the emerging train connections between the EU and China within the framework of the BRI, can contribute to the faster and more secure transportation of pharmaceutical products.

During the COVID–19 crisis of 2020, train lines were used for the rapid transport of a variety of medical necessities. Between January and May 2020, 12,524 tons of anti-pandemic materials were transported by train from China to Europe. In less than ten days, COSCO moved 35 containers from the central Chinese province of Hubei to Duisburg (Xinhua 2020). However, it is advantageous for the EU to also employ these routes for exports to China. Corticoids may be one of the most significant export products using the emerging rail connections. However, the problem with the commodity group is that, compared to the other commodities with an export gap, it has the most import requirements in China (177).

To summarise, five commodity groups with the largest export gap benefit from zero tariffs when imported from the EU to China. Therefore, reducing customs barriers will not increase EU exports. The number of import requirements representing non-tariff barriers for the export of these products to China shows the possibility of exploiting the identified export gaps by negotiating a trade agreement between the EU and China that would eliminate these barriers. However, the cautious attitude of EU institutions, as well as Germany and France, towards China in the current geopolitical situation does not indicate the prospect of concluding such an agreement in the foreseeable future. A relatively high import concentration of Chinese imports in geographically close countries was observed mainly for the top three commodity groups, including specific electrical capacitors and printed circuits. EU exports of the commodities concerned flow to closely located countries. This trade pattern reflects that transportation costs arising because of the geographical distance between the EU and China represent an important barrier to export growth, which is in line with the findings of Garcia-Herrero and Xu (2016), Fardella and Prodi (2017) and Karkanis (2018). The Czech Republic and Hungary recorded the highest export gaps for three out of the top five commodities. For these landlocked countries, new railway connections within the BRI represent an important stimulus for the growth of exports to China (Fardella and Prodi 2017; Karkanis 2018; Li, Bolton, and Westphal 2018).

Conclusions

Currently, the high-tech industry plays a crucial role in international business, particularly for economic powers striving to be leaders in the global economy while maintaining their own competitiveness. In this sector, the EU and its member countries achieve comparative advantages, with Germany and France being the most competitive, as the article showed. Despite steadily increasing the production and exports of high-tech products, China remains a significant importer of a variety of high-tech products, particularly in the fields of electrical and optical devices. This study identified the untapped potential for high-tech exports of selected EU countries in trade with China and evaluated the benefits of the BRI in utilising this potential.

We revealed export potential in the high-tech industry, amounting to US$151,500,000 for all EU countries analysed. Companies from countries such as Germany and France, which have a dominant position in the high-tech sector within the EU and are also its largest economies, fully use their comparative advantages, particularly in the fields of aviation, pharmaceuticals, and optical devices. They can meet the demand of the world's most populous country because of sufficient production capacities. This was confirmed by the existence of a relatively small export gap (especially when considering the size of the economies). Nonetheless, these nations have long been sceptical of strengthening ties with China under the framework of the BRI initiative.

By contrast, we showed that Greece and Italy, which have the most extensive collaboration with China under the BRI, both the value of the export gap and their competitiveness in the export of high-tech products is relatively minor. We conclude that BRI does not have the potential to facilitate the export of high-tech products to China for these countries. Therefore, a "win-win" cooperation cannot be achieved in this sector.

Electrical machinery and equipment had the largest export gaps (e.g., HS 853224 for the Czech Republic, HS 853400 for Hungary, and HS 853222 for the Netherlands). For most commodities with an export gap, China prefers geographically closer suppliers. Emerging rail connections and modernised transport within the BRI could help mainly the CEE countries with the highest untapped export potential to accelerate the delivery of high-tech products to Chinese customers. However, this is challenged by the current situation surrounding the Russian invasion of Ukraine, as many trains moving from Europe to China pass through Russia, and transport on these lines was suspended in February and March 2022. China is attempting to use routes along the southern branch of the BRI, which passes via Kazakhstan, Azerbaijan, Georgia, Romania, Hungary, Slovakia, and the Czech Republic before reaching Mannheim, Germany.

Even though most investigated commodities with an export gap are not subject to Chinese customs duties, the conclusion of a modern trade agreement between the EU and China would help the EU exploit its untapped export potential. It would be a significant milestone in improving the long-term strained relations between the EU and China, which may help shift China's attention away from importing American or Australian goods, for instance, towards European ones.

The findings of this study, particularly the identification of specific high-tech goods with export potential to China, can be used by European businesses in their decision-making. They can also help institutions in the studied countries adjust their economic and trade policies, particularly vis-à-vis China and the BRI initiative, within the field of supporting infrastructure projects, as well as high-tech industries. From an academic point of view, the study contributes to the existing literature on the potential of EU export growth to China, which has not been sufficiently explored yet. Considering the limitations of the methodology used, we recommend verifying the results by implementing an alternative methodological approach. We also recommend including more EU countries in the research.

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Potencjał eksportu produktów zaawansowanych technologicznie z wybranych państw członkowskich UE do Chin i związane z nim możliwości wynikające z inicjatywy Pasa i Szlaku

Stosunki gospodarcze UE z Chinami charakteryzują się znacznym deficytem handlowym. Zwiększenie unijnego eksportu produktów zaawansowanych technologicznie, w szczególności do Chin, jest najlepszym sposobem wyjścia z tej nierównowagi. W ten sposób kraje UE mogą skorzystać z możliwości oferowanych przez Inicjatywę Pasa i Szlaku (BRI), która ma na celu poprawę łączności między Europą a Azją.
Cel: Niniejsze opracowanie ma na celu identyfikację niewykorzystanego potencjału eksportowego produktów zaawansowanych technologicznie wybranych krajów UE w handlu z Chinami oraz ocenę możliwości wynikających z BRI w zakresie wykorzystania tego potencjału.
Metody badawcze: Aby ocenić ogólny potencjał w zakresie eksportu produktów zaawansowanych technologii wybranych krajów UE do Chin, dokonano kalkulacji luki eksportowej przy użyciu koncepcji ujawnionych przewag komparatywnych.
Ustalenia: Spośród badanych krajów UE największy potencjał wzrostu eksportu produktów zaawansowanych technologicznie do Chin mają Węgry i Czechy. Największe luki eksportowe odnotowano w przypadku maszyn i urządzeń elektrycznych.

Implikacje i zalecenia: Wyniki badań mogą być wykorzystane przez europejskie przedsiębiorstwa do dostosowania swoich strategii eksportowych. Mogą być również wykorzystywane przez instytucje rządowe badanych państw przy projektowaniu ich polityki gospodarczej i handlowej, szczególnie wobec Chin i inicjatywy BRI, w zakresie wspierania projektów infrastrukturalnych, a także branż high-tech.
Wkład i wartość dodana: Opracowanie wnosi wkład do literatury na temat potencjału wzrostu eksportu UE do Chin, który nie został jeszcze wystarczająco zbadany. Nowością przeprowadzonych badań jest identyfikacja konkretnych produktów zaawansowanych technologicznie o najwyższym potencjale eksportowym do Chin.

Słowa kluczowe: Unia Europejska, Chiny, potencjał eksportowy, produkty high-tech

Appendix 1. Top 10 export gaps of high-tech products of selected EU countries in trade with China (in 2020) with additional data

Country	HS Code	Commodity Group	The country's average share of world imports in 2016–2020 (%)	The country's share of China's imports in 2020 (%)	The country's exports to China in 2020 (million US$)	The country's export gap in 2020 (million US$)	Average tariff (estimated) applied by China	Tariffs on products from the EU	The average RCA index of a country between 2016 and 2020	The average IS index of China between 2016 and 2020	Concentration of supplying countries	The average distance between China and its import partners (km)	Average distance between a country and all its import markets (km)	The number of requirements related to the import of the commodity
The Czech Republic	853224	Fixed electrical capacitors, ceramic dielectric, multilayer (excluding power capacitors)	1.35	0.00	0.33	21.69	0%	0%	1.45	3.66	0.24	2199	906	38
Hungary	853400	Printed circuits	0.64	0.02	2.30	11.54	2.69%	0%	1.00	2.16	0.24	1740	1227	41
The Netherlands	853222	Fixed electrical capacitors, aluminium electrolytic (excluding power capacitors)	3.33	0.05	0.82	9.77	0.28%	0%	1.180	2.677	0.22	3143	1020	38
The Czech Republic	853221	Fixed electrical capacitors, tantalum (excluding power capacitors)	7.44	0.26	1.86	8.91	1.29%	0%	7.44	2.93	0.16	5414	4521	38
The Netherlands	902750	Instruments and apparatus for physical or chemical analysis, using UV ...	4.38	0.54	12.62	7.90	0.95%	0%	1.44	1.93	0.17	6554	3154	N/A
Germany	840130	Fuel elements "cartridges", non-irradiated, in casing with handling fixtures ...	10.21	0.00	0.00	7.37	1.50%	2%	1.17	1.27	0.72	8371	584	35
The Czech Republic	851830	Headphones and earphones, whether or not combined with microphone, and sets ...	2.14	0.00	0.00	5.99	2.80%	0%	2.34	1.24	0.68	2517	995	40
The Czech Republic	902710	Gas or smoke analysis apparatus	3.50	0.06	0.51	5.85	3.75%	4%	3.20	1.33	0.17	6296	2370	40
France	284420	Uranium enriched in U 235 and its compounds: plutonium and its compounds; alloys, dispersions, ...	12.59	0.00	0.00	4.93	4.70%	5%	9.41	1.23	0.38	5466	5232	17
Hungary	300432	Medicaments containing corticosteroid hormones, heir derivatives ...	1.45	0.00	0.00	4.69	0%	0%	2.27	1.43	0.18	8127	933	117

Source: processed based on own calculations of data from International Trade Center 2022a.

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Consumer and Professional Inflation Expectations – Properties and Mutual Dependencies

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Abstract

Inflation expectations are a crucial variable for central banks. However, empirically examining their properties is challenging. This paper juxtaposes the properties of consumer and professional expectations. It also assesses the degree of forward- and backward-lookingness and the information content of expectations. We apply entropy-based measures (common information and mutual common information) to capture nonlinear dependencies and dynamic time warping to account for different lags in the relationships. The study covers 12 inflation-targeting economies from the European region. The results suggest that in most countries, professionals are more forward-looking, and consumers follow professionals. Both groups of economic agents present expectations that are aligned in terms of information content. However, cross-country differences occur. These results imply that, from the central bank's point of view, communication and practices designed to shape expectations, even if understood mostly by specialists, are effective also for consumers. The novelty of this study

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lies in its use of alternative methods to tackle the formation and dependencies between heterogeneous expectations. This avoids the drawbacks of a standard approach and allows broader conclusions to be drawn.

Keywords: inflation expectation, mutual information, dynamic time warping

JEL: C82, D84, E31

Introduction

Empirical studies have shown that expectations vary across different groups of economic agents, and they display different properties (Gerberding 2001; Łyziak and Mackiewicz-Łyziak 2014; Łyziak and Sheng 2023). Even within the same group of economic agents, there is a dispersion of expectations due to different cognitive abilities (D'Acunto et al. 2019), personality traits (Abildgren and Kuchler 2021) or economic characteristics (Zhao 2022). Macromodels assume homogeneity of expectations, although this assumption does not hold when expectations are studied empirically. The question of whose expectations matter more for the evolution of inflation remains unanswered. Coibion and Gorodnichenko (2015) found that consumer expectations are more important for the economy's price-setting patterns than those of specialists. When expectations are disaggregated according to socioeconomic or demographic characteristics, high-income, college-educated, male, and working people play a larger role in inflation dynamics than other consumers or professional forecasters' expectations (Binder 2015).

This study highlights the limitations of current methods for assessing expectation properties. These methods often ignore time series characteristics like non-stationarity and non-linearity of dependencies when estimating regressions. Additionally, they assume a constant lag structure of inflation and inflation expectations. We address these issues in Section 2. Standard econometric methods used to measure forward-lookingness, backward-lookingness, and co-movements of expectations suffer from practical application problems. The residuals from the estimated regressions rarely meet the assumptions. To overcome these limitations, we apply a novel methodology based on dynamic time warping distance using distance measures rather than regression estimates and common information measures to capture linear and nonlinear dependencies. The proposed method offers deeper insights into the dependencies between time series studied than standard methods by providing a more comprehensive analysis.

This study investigates the relationship between consumer and professional expectations of inflation. We analyse the co-movements and information content of these expectations, along with their forward- and backward-looking nature. Utilizing a unique data set on consumer and professional expectations, we also examine how inflation expectations co-move. This study addresses the following questions:

Q1: Do the inflation expectations of professionals carry the same information content as consumer expectations?

Q2: Is the common information between consumer and professional expectations the effect of a transfer of inflation information?

Q3: Are consumers more backward- or forward-looking?

Q4: Are professionals more backward- or forward-looking?

The study employs a novel method utilizing entropy-based and distance measures. To assess the degree of backward- or forward-lookingness of expectations, we use the dynamic time warping (DTW) algorithm, incorporating the windowing technique proposed by Rutkowska and Szyszko (2022). Additionally, to assess information carried by the inflation expectations of professionals and consumers, we use mutual information that can be interpreted as the "amount of information" obtained about one random variable by observing another.

The sample includes Albania, Czechia, Hungary, Kazakhstan, Norway, Poland, Romania, Russia, Serbia, Sweden, Turkey and the UK. We selected small open economies from the Eurasia region because they conduct independent monetary policy, and their central banks implement inflation targeting (IT) as a monetary policy framework. This strategy focuses on managing expectations. Thus, the issue of expectation formation and co-movements is crucial from a central bank perspective. The research period varies depending on the year each country adopted IT adoption and ends for all countries in June 2019.

Professional expectations are measured using Consensus Forecasts from Consensus Economics data, which are transformed into fixed-horizon forecasts. Consumer expectations for European Union Member States and Albania (complemented by central banks' data before May 2016), Serbia, Turkey, and the UK are derived from Business and Consumer Surveys. For Kazakhstan, Norway and Russia, we use survey results published by their national central banks.

DTW is often used to overcome distortions by aligning and classifying time series and helping to classify it (El Amouri et al. 2022). It has attracted significant research attention in economics because it imposes no specific conditions on time series or lags. DTW has been used to detect recessions (Raihan 2017), the clustering of business cycles (Franses and Wiemann 2020), and pattern recognition in stock markets (Han et al. 2020). The work most closely related to ours is Rutkowska and Szyszko's (2022) first attempt to analyse the forward- and backward-lookingness of consumer expectations for seven small open economies: Croatia, Czechia, Hungary, Poland, Romania, Sweden, and the UK. Our paper builds on this previous study in three key ways:

1. We test the properties of two groups of economic agents (consumers and professionals).
2. We expand the sample to include 12 economies that have implemented IT.
3. We consider the co-movement of consumer and professional expectations.

The second method applied – mutual information and conditional mutual information – allows us to determine how much information can be obtained about the expectations of one group of agents by observing another group. This methodology has already been used to find information flow between economic and financial variables, including asset prices (Lahmiri and Bekiros 2020; Będowska-Sójka, Kliber, and Rutkowska 2021; Ferreira and Morais 2023).

The remainder of this paper proceeds as follows: The next section briefly reviews standard methods to assess expectations properties, and the third section describes the methods and data used in the study. The fourth section presents the results. The paper ends with conclusions.

The standard method to assess properties of expectations

This paper focuses on the forward- and backward-lookingness of inflation expectations. These characteristics describe the degree to which inflation expectations are shaped by past inflation trends (backward-lookingness, BL) or future inflation trends (forward-lookingness, FL). When economic agents forecast inflation, they may consider only past inflation (BL) or base their forecasts on numerous forward-looking factors (FL).

Pure forward-looking behaviour is one of the characteristics of rational expectations, as presented by Muth (1961) and introduced to macroeconomic models by Lucas Jr. (1972; 1976)[1]. However, neither rationality of expectations nor pure forward-lookingness hold empirically. Thus, expectations regarding their degree of FL or BL (hybrid) are studied.

The standard procedure to assess the degree of BL and FL involves identifying the forward-looking component of expectations and the backward-looking component. The backward-looking component refers to the adaptive expectations hypothesis[2]

1 Rational expectations exhibit several features, unbiassedness and orthogonality being the most important. We refrain from their detailed description in this paper, as our intentions are mostly about a novel method.

2 Assumes that past inflation, past expectations presented and expectation errors drive inflation.

(Eq. 1) or static expectations[3] (Eq. 2eq:2). Two specifications of the hybrid nature of expectations are presented below.

$$\pi^e_{t+12|t} = \alpha_1 + \alpha_2 \pi_{t+12} + \\ (1-\alpha_2)\left[\pi^e_{t-2|t-14} + \alpha_3\left(\pi^e_{t-2|t-14} - \pi_{t-2}\right)\right] + \varepsilon_t, \quad (1)$$

$$\pi^e_{t+12|t} = \alpha_1 + \alpha_2 \pi_{t+12} + (1-\alpha_2)\pi_{t-2} + \varepsilon_t, \quad (2)$$

where:

$\pi^e_{t+12|t}$ is the expected inflation rate at time $t+12$ formed at time t,

π_{t+12} is the actual inflation at $t+12$ (analogous to the meaning of other subindices), and

ε_t is the white noise error.

For both models, the expectations are entirely forward-looking if $\alpha_1 = 0$ and $\alpha_2 = 1$.

Equations 1 and 2 differ in terms of how they understand a non-forward-looking component of expectations. The second model (Eq. 2) – the static specification – is more intuitive and aligned with the method applied in this study. It simply assesses the degree to which expectations incorporate past inflation (BL) and future inflation (FL). Both methods should be applied to stationary time series. However, in practice, neither inflation nor expectations are stationary, especially when in emerging or transition economies. Despite this, most studies do not report stationarity or unit root tests. It is often assumed that time series are stationary over the medium and long term, as forming unbiased expectations in a nonstationary environment would, in many circumstances, be an implausibly demanding task (Evans and Gulamani 1984).

The estimator is a separate element on which the results depend; it is somewhat arbitrary and must be selected before analysis. The endogeneity problem makes ordinary least squares (OLS) estimations inconsistent. Therefore, a common solution is the regression of instrumental variables (two-stage least squares (2SLS) estimation). However, this choice is associated with inaccuracy due to large standard errors, bias when the sample size is small, and bias in large samples if one of the assumptions is only slightly violated (Martens et al. 2006). The issue of weak instruments and their consequences has been extensively discussed in the literature (Staiger and Stock 1994; Stock and Wright 2000; Hahn, Hausman, and Kuersteiner 2004).

3 Assume that past inflation drives expectations.

The standard specification imposes a fixed structure of lags, as reflected in the subindices of our equations. The $T+12$-month horizon of expectations relates to the survey questions where consumers were asked about their price level estimates for the next 12 months. Their expectations are juxtaposed with actual inflation over a one-year horizon and past inflation. Past inflation from two months before the survey is considered ($t-2$) because this is the most recent inflation available for consumers due to the survey schedule and macroeconomic data publication calendar. For instance, if we use the June survey as an example, the respondents could be aware of April inflation (published at the end of May). Moreover, consumers need time to process economic information. Thus, a two-month lag is the shortest period that seems justified.

When examining the alignment of disagreement between different groups of economic agents, the traditional approach offers limited procedures. One of them is to run standard Granger causality tests, as presented by Łyziak (2013). These tests are often incorporated into theoretical models, such as Carroll's (2002) epidemiological theory of expectations, to assess the dependencies between the expectations of different groups of economic agents. The epidemiological theory of expectations posits that consumers form their expectations based on media news spread by professionals. Empirical testing of this model often reveals that consumers are influenced by professionals. Specifically, Granger causality from the professional forecasts (presented in the media) to consumer expectations exists, but the reverse is not true. To identify the long-run relationship between the expectations of different groups of economic agents, vector error correction models are estimated and impulse responses are tested. Drager (2015) applied a similar procedure to identify dependencies between consumer and professional expectations.

An alternative, theory-consistent approach to comparing the expectations of consumers and professionals involves estimating the New-Keynesian Phillips curve to determine which group's expectations enhance its accuracy. The Phillips curve represents inflation equations in new neoclassical synthesis models. It links inflation to expected inflation, lagged inflation, and the output gap (or another measure of economic slack). The baseline version of the model assumes heterogeneous, rational economic agents. Nonetheless, more empirically consistent versions allow for different specifications of expectations (forward- or backward-looking) and heterogenous economic agents. The heterogeneity in expectations representation can indicate whether one group of economic agents (as presented by Coibi- on and Gorodnichenko (2015; 2018)) or a subgroup with specific features (as presented by Binder (2015)) augments the Phillips curve specification.

Methodology

The empirical section consists of two parts. In the first part, we use different entropy measures to assess the common information carried by the expectations of different agents. In the second part, we compare the properties of their inflation expectations using DTW. We briefly introduce basic concepts and notions from the information theory used in the first step and DTW. In the next step, we present the study sample in detail.

Mutual information, conditional mutual information, and the global correlation coefficient

To analyse the connection between variables, we use entropy-based measures: mutual information, conditional mutual information, and the global correlation coefficient. Let us consider two random variables, X and Y, each described by its probability distributions (P_x and P_y, respectively). The entropy measures the expected uncertainty in X. We can also say that $H(X)$ is approximately equal to how much information we learn on average from one instance of random variable X (see Eq. 3).

$$H(X) -= \sum_{x_i \in X} P_x(X = x_i) \log\left(P_x(X = x_i)\right). \quad (3)$$

Joint entropy measures the uncertainty when jointly considering two random variables, following Eq. 4.

$$H(X,Y) = -H(X,Y) = -\sum_{x_i \in X} \quad (4)$$

Mutual information (Eq. 5) measures the information about one random variable contained in another random variable. It can also be interpreted as the reduction in uncertainty of a random variable if another variable is known. Importantly, it captures the overall dependence, both linear and nonlinear, between X and Y.

$$I(X,Y) = H(X) + H(Y) - H(X,Y). \quad (5)$$

Mutual information is always positive $I(X;Y) \geq 0$ and equals 0 only if X and Y are independent. To normalise mutual information to take values from 0 to 1 (and be an alternative measure to the linear correlation coefficient), it can be transformed into the global correlation coefficient λ (as proposed in (Dionisio, Menezes, and Mendes 2004):

$$\lambda(X,Y) = \sqrt{1 - \exp\left(-2I(X,Y)\right)}. \quad (6)$$

Conditional entropy quantifies the amount of information required to describe a random variable X given knowledge of a random variable Y, and is defined as follows:

$$H(X\,|\,Y) = H(X,Y) - H(Y). \tag{7}$$

For a clear view of entropy measures and the relationship between them, see Figure 1. Assume that X represents consumer expectations and Y represents professional expectation. Then, $H(X\,|\,Y)$ describes the remaining uncertainty about X given Y, i.e., what new information about X remains after knowing the professionals' expectations.

Conditional mutual information, proposed by Dobrushin (1963) and Wyner (1978), quantifies the average mutual information between random variables X and Y given knowledge of a third variable, Z. Conditioning on a third random variable may either increase or decrease the mutual information. For random variables X and Y, Z is defined according to Eq. 8

$$I(X,Y|Z) = H(X,Z) + H(Y,Z) - H(Z) - H(X,Y,Z). \tag{8}$$

If Y only reveals information about X that Z already reveals, it holds $I(X,Y\,|\,Z) = 0$. If X and Y are independent but $Z = X + Y$, then $I(X,Y\,|\,Z) = 1$. That means that Y only reveals useful information about X after observing Z. The relationships among the three variables are presented in Figure 2. Equation 8 can be rewritten to show its relationship to mutual information as:

$$I(X,Y\,|\,Z) = I(X,Y,Z) - I(X,Z). \tag{9}$$

Assume again that X represents consumer expectations and Y represents professional expectations, while Z is inflation two months ago, that is, it was known and published at the time of surveying expectations. $I(X,Y\,|\,Z)$ is the common part of the information carried by the expectations of professionals and consumers but not the part that consumers have in common with inflation.

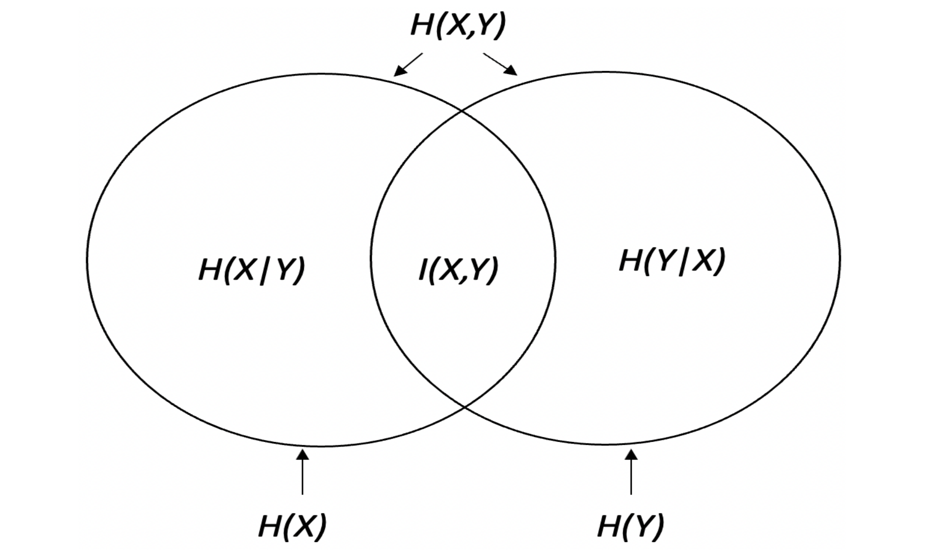

Figure 1. Visualisation of mutual information and entropy relationships

Source: own elaboration.

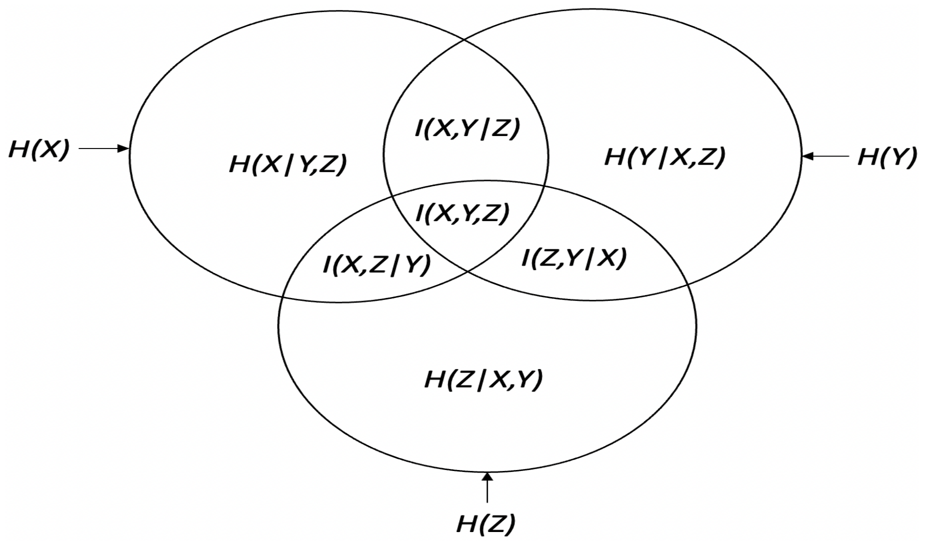

Figure 2. Visualisation of conditional mutual information and multivariate entropy relationships

Source: own elaboration.

Dynamic time warping

DTW is an algorithm for measuring the similarity/distance between two temporal sequences, which may vary in time or speed. Let us assume that we have two time series: a test, or query, $X = (x_1, \ldots, x_N)$, and a reference $Y = (y_1, \ldots, y_M)$. f is a non-negative, local dissimilarity function defined between any pair of elements x_n and y_m with the shortcut $d(n,m) = f(x_n, y_m) \geq 0$. In the first step, the accumulated distance (cost) matrix is calculated. Matrix D satisfies the following identities:

- $D(n,1)=\sum_{k=1}^{n} d(x_k,y_1)$, for $n\in[1:N]$,
- $D(1,m)=\sum_{k=1}^{m} d(x_1,y_k)$, for $m\in[1:M]$,
- $D(n,m)=min\{D(n-1,m-1),D(n-1,m),\ D(n,m-1)\}+d(n,m)$,

for $1<n\leq N$ and $1<m\leq M$.

The optimal path $p^*=(p_1,\ldots,p_L)$ is computed in the reverse order of the indices, starting with $p_L=(N,M)$. Suppose that $p_l=(n,m)$ has been computed. If $(n,m)=(1,1)$ then $l=1$, and we are finished. Otherwise,

$$p_{l-1}:=\begin{cases}(1,m-1), & \text{if } n=1\\ (n-1,1), & \text{if } m=1\\ argmin\{D(n-1,m-1),D(n-1,m), & \\ D(n,m-1)\}, & \text{otherwise,}\end{cases}$$

where we take the lexicographically smallest pair in case "argmin" is not unique. At the core of the technique lies the warping curve $\phi(k),k=1,\ldots,T$:

$$\phi(k)=(\phi_x(k),\phi_y(k)) \tag{10}$$

with $\phi_x(k)\in 1,\ldots,N$ and $\phi_y(k)\in 1,\ldots,M$, with assumptions $\phi_x(k+1)\geq\phi_x(k)$ and $\phi_y(k+1)\geq\phi_y(k)$.

The warping functions $\phi_x(x)$ and $\phi(y)$ remap the time indices of X and Y, respectively.

$$DTW=\sum_{k=1}^{T} d(\phi(k)). \tag{11}$$

To normalise DTW, we use Equation (12):

$$d_\phi(X,Y)=\sum_{k=1}^{T}\frac{d(\phi_x(k),\phi_y(k))m_\phi(k)}{M_\phi}, \tag{12}$$

where $m_\phi(k)$ is a per-step weighting coefficient and M_ϕ is the corresponding normalisation constant The idea underlying DTW is to find the optimal alignment that minimises the distance between two time series, as presented in Figure 3, according to Equation (13).

$$D(X,Y)=min_\phi d_\phi(X,Y). \tag{13}$$

In other words, one selects the deformation of the time axes of X and Y that brings the two time series as close as possible to each other. To make this alignment meaningful for a particular use, a global constraint, or window, explicitly forbids warping curves from entering some region of the (i, j) plane.

$$\left|\phi_x(k) - \phi_y(k)\right| \leq T_0, \tag{14}$$

where the warping curve $\phi(k), k = 1, \ldots, T$ and T_0 is the maximum allowable absolute time deviation between two matched elements. Windows for forward and backward-lookingness were first presented by Rutkowska and Szyszko (2022). Forward refers to the upper triangular part of the distance matrix, while backward refers to the lower part, as shown in Figure In our study, DTW inference is performed in the following steps:

1. Calculate DTW distance with forward-looking windows.
2. Calculate DTW distance with backward-looking windows.
3. Compare distances – the lower the distance, the stronger the properties.

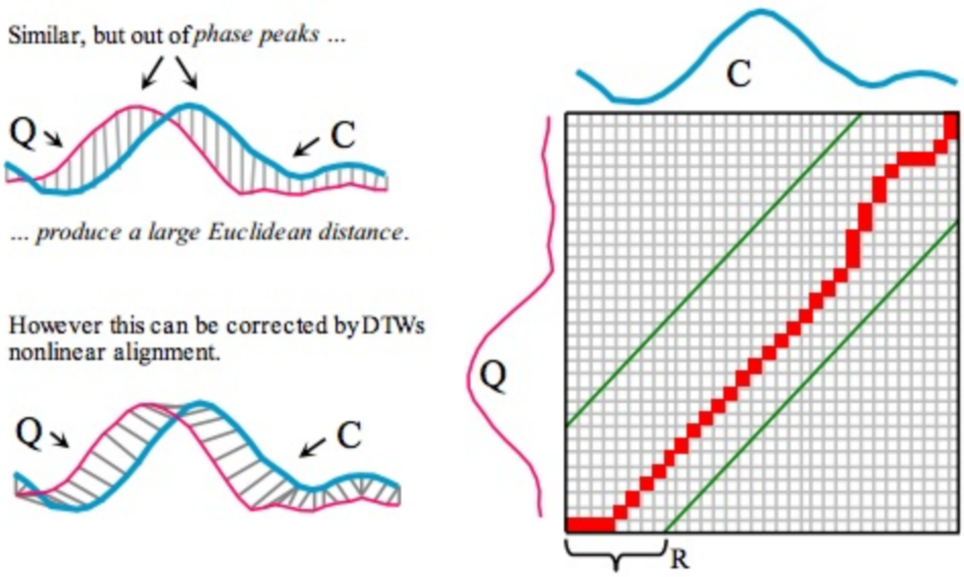

Figure 3. The idea of time-series alignment in the DTW algorithm

Source: Rakthanmanon et al. 2012.

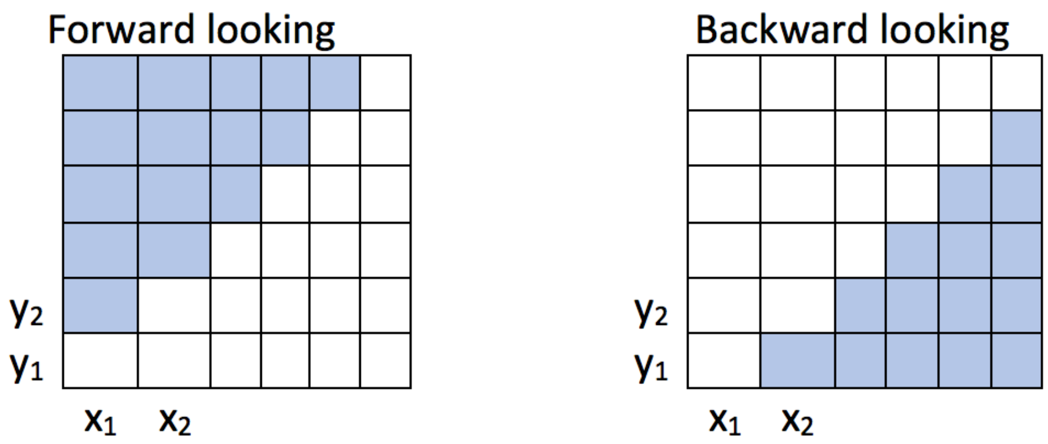

Figure 4. Backward- and forward-looking windows

Source: Rutkowska and Szyszko 2022.

Data and study steps

The sample covers 12 small open economies classified as European and implementing IT: Albania, Czechia, Hungary, Kazakhstan, Norway, Poland, Romania, Russia, Serbia, Sweden, Turkey, and the UK. We selected these countries because they run independent monetary policies under similar IT frameworks, which clearly demonstrates the need to focus monetary policy on the expectations of private agents. Despite the common IT frameworks, the sample is diverse in terms of economic development, which enables the recognition of the dependencies and co-movements of expectations among the different economies. The coverage of this study constitutes a novelty because most previous studies are about world-leading economies. The sample is suitable for testing a new method, and the study provides new insights into the economies covered. The research period varies according to the year each country adopted IT, as presented in Table 1.

Table 1. Research sample

Country	No. of observations	First observation
Albania	138	Jan. 2008
Czechia	222	Jan. 2001
Hungary	199	Dec. 2002
Kazakhstan	46	Sep. 2015
Norway	222	Jan. 2001
Poland	196	Mar. 2003
Romania	174	Jan. 2005
Russia	69	Oct. 2013
Serbia	90	Jan. 2009

Country	No. of observations	First observation
Sweden	222	Jan. 2001
Turkey	162	Jan. 2006
UK	222	Jan. 2001

Source: own elaboration.

In this study, we use three main series: (i) survey-based proxies for consumer inflation expectations, (ii) Consensus Economics' Consensus Forecast data on professional expectations, and (iii) the inflation rate (standard CPI-based inflation measure published by national statistical offices).

Consumer expectations are derived from Business and Consumer Surveys for European (European Commission 2016), Union Member States and Albania (complemented by central bank's data before May 2016), Serbia, Turkey, and the UK. The surveys do not cover Kazakhstan, Norway, or Russia, so we used survey data provided by the central banks of these economies. All surveys, except for those from Russia, are qualitative. Consumers are asked about the direction and strength of the price change compared to current inflation[4]. Expectations are quantified with the probabilistic method by Carlson and Parkin (1975) adjusted for the polychotomous (five response) survey as presented by Batchelor and Orr (1988). The method and procedure are widely accepted, so a detailed description is not provided here. For the dataset provided by the Business and Consumer Surveys, we applied a subjectified version of the quantification that assumes that perceived inflation is first quantified and then used as a scaling factor to quantify expectations. We applied a 36-month moving average of past inflation as a scaling factor for inflation perceptions. This two-step procedure weakens the relationship between expectations and inflation.

Professional expectations are derived from Consensus Economics' Consensus Forecast data. As these forecasts are fixed-event forecasts, we apply a method to transform them into fixed-horizon (12-month) forecasts (as Dovern, Fritsche, and Slacalek 2012). We investigate the dependencies of 12-month forecasts of consumers and professionals because this is the only horizon available for consumers. Consensus Forecast survey participants present the inflation forecast at the end of the current and the next calendar year. We approximate fixed-horizon forecasts as a weighted average of fixed-event forecasts. $F^{e}_{y_0,m,y_1}(x)$ denotes the fixed event forecast of variable x for year y_1 formulated in month m

4 The survey question for perceived inflation is as follows: 'How do you think consumer prices have developed over the last 12 months?' The answers to choose from include the following: 'They have… risen a lot, risen moderately, risen slightly, stayed about the same, fallen, don't know'. The survey question for the expected inflation rate is as follows: 'When compared to the past 12 months, how do you expect consumer prices to develop in the next 12 months?' The answers to choose from included the following: 'They will… increase more rapidly, increase at the same rate, increase at a slower rate, stay about the same, fall, don't know'.

of the previous year, $y_0 = y_1 - 1$. Let $F^h_{y_0,m,12}(x)$ be the fixed horizon, twelve-month-ahead forecast made at the same time. The fixed horizon forecast for the next twelve months is approximated as an average of the forecasts for the current and next calendar year weighted by their share in the forecasting horizon (Dovern, Fritsche, and Slacalek 2012):

$$F^h_{y_0,m,12}(x) = \frac{12 - m + 1}{12} \cdot F^e_{y_0,m,y_0}(x) + \frac{m-1}{12} \cdot F^e_{y_0,m,y_1}(x). \tag{15}$$

Results

Common information in expectations and past inflation

Mutual information analysis addresses the common information embedded within the expectations of both economic agents and past inflation. Conditional mutual information provides an overview of the alignment within a conditional context, specifically when past inflation is excluded as coordinating information. Table 2 presents the normalized mutual information between professional and consumer expectations, as well as the normalized mutual information between expectations of both groups and lagged inflation.

Romania exhibits the highest mutual information for professionals and consumers' inflation expectations, while the UK and Czechia show the lowest values. In the context of expectations, the economic interpretation of the common information suggests that professional and consumer expectations contain the same information or are aligned, as represented by the normalised mutual information coefficient (for example, approximately 76% for Poland).

This measure shows how much the expectations of one type of economic agent tell us about those of another. However, mutual information does not allow us to conclude about causality. Thus, the results can only be interpreted in terms of alignment. Mutual information is also referred to in terms of reducing the uncertainty of a random variable if another is known. In this case, it is more intuitive to refer to the reduction in consumer expectation uncertainty due to knowledge of professional expectations. This approach aligns with Carroll's epidemiological theory of expectations. However, the measure applied need not be applied only in one direction.

The strongest alignment of expectations between professionals and consumers occurs in our sample of countries with disturbed disinflation processes. This suggests that, under such circumstances, past inflation is a major factor that affects expectations for both groups of economic agents. The central banks of Czechia and the UK, for which the time series behave the most independently, conduct forward-looking (inflation forecast-based) monetary policies. They were successful at keeping inflation at the targeted level during the period studied.

Table 2 also presents common information between expectations and inflation for both professionals and consumers. It contributes to the debate about the backward-lookingness of expectations, as it presents the common information in the expectations series and realised inflation (again lagged by two months). The case of Czechia and the UK, the two economies with the lowest mutual expectation information, is worth noting. In the UK, professionals exhibit low common information with past inflation, while that of consumers is high. Conversely, the opposite is true for Czechia. Our findings for most other sample countries except Norway mirror those of Czechia – lower mutual information between consumer expectations and past inflation than for professionals and inflation. The results of past studies suggest that consumers are more backward-looking than professionals, and they rely more on past inflation when formulating their expectations. Thus, we might expect greater alignment of expectations with past inflation for consumers, which is not true for this sample. However, this result does not necessarily mean that consumers are more forward-looking. It could mean that households ignore economic information when forming their expectations or are driven by their inflation perceptions, which normally differ substantially from actual inflation, as is well documented in the economic literature.

Table 2. Normalised mutual (I) information between professionals, consumers, and past and current inflation

Country	Professionals vs consumers	Professionals vs inflation (lag2)	Consumers vs inflation (lag2)
Albania	0.6994	0.7714	0.6636
Czechia	0.5279	0.7947	0.4418
Hungary	0.8423	0.9013	0.8058
Kazakhstan	0.6069	0.9184	0.6069
Norway	0.6729	0.6890	0.9331
Poland	0.7598	0.8911	0.7149
Romania	0.8701	0.8947	0.8178
Russia	0.5206	0.6779	0.5448
Serbia	0.8298	0.7456	0.6411
Sweden	0.6392	0.7283	0.6474
Turkey	0.7041	0.7527	0.6519
UK	0.4977	0.4976	0.7645

Source: own calculations.

Table 3. Mutual information (I) between professionals and consumers conditioned by two-month lagged inflation

Country	I (professionals, consumers)	I (professionals, consumers) conditioned inflation (lag2))
Albania	0.3358	0.3443
Czechia	0.1634	0.3100
Hungary	0.6180	0.2480
Kazakhstan	0.2297	0.0402
Norway	0.3015	0.1311
Poland	0.4305	0.2643
Romania	0.7075	0.2697
Russia	0.1580	0.1530
Serbia	0.5834	0.5199
Sweden	0.2626	0.3055
Turkey	0.3424	0.2881
UK	0.1423	0.3290

Source: own calculations.

The conditional mutual information analysis presented in Table 3 sheds light on the information content of expectations among different groups of economic agents.

First, the mutual information between the three time series – the expectations of both groups of economic agents and inflation – varies from 14% for the UK to 71% for Romania. It reveals the cross-country differences between the alignment of expectations and inflation.

Second, conditional mutual information is analysed. It represents the common information incorporated into the expectations of consumers and professionals, assuming that the information incorporated in past inflation is excluded (i.e., it is not a factor that coordinates the time series). The conditional mutual information coefficient represents the common information about inflation drivers based on other information. This coefficient reflects a more specific alignment of expectations, conditional on excluding one variable. In our sample, this alignment varies from 4% in Kazakhstan to 52% in Serbia. When the content of information incorporated into past inflation is excluded, the alignment between series is, on average, lower. This means that an important portion of the common information is about past inflation.

Third, comparing mutual information and conditional mutual information reveals that, for all cases, mutual information is greater than conditional mutual information. This suggests that the common information shared between professional and consumer expectations is based on the information content of past inflation. As both groups of economic agents are partially backward-looking, the results confirm the importance of past inflation in shaping expectations.

Fourth, comparing mutual information among professionals, consumers, and past inflation and conditional mutual information (excluding information incorporated into past inflation) reveals two distinct cases:

1. In Hungary, Kazakhstan, Norway, Poland, Romania, Russia, Serbia and Turkey, is when common information for three variables is greater than conditional common information. This situation is standard: knowing past inflation reduces the uncertainty of inflation expectations and strengthens the alignment between series.
2. In Albania, Czechia, Sweden and the UK, conditional mutual information outperforms mutual information, meaning that knowing past inflation does not reduce uncertainty; the information content in expectations differs from past inflation.

The forward- and backward-lookingness of expectations

We used a DTW algorithm to approximate the degree of forward- and backward-lookingness of expectations. Note that the notions of FL and BL replicate the theoretical approach as described in Section 2; nonetheless, they do not bear the same meaning. The important difference is that we do not compare expectations with past or future inflation for a fixed horizon. Table 4 presents results for professionals, while those for consumers are shown in Table 5.

Table 4. Professional inflation expectations, forward- and backward-lookingness

Country	$Forward_{dist}$	$Backward_{dist}$	$Backward_{dist} - forward_{dist}$
Albania	0.1466	0.2128	0.0662
Czechia	0.2258	0.3057	0.0799
Hungary	0.2766	0.4032	0.1267
Kazakhstan	0.2785	0.8283	0.5497
Norway	0.1079	0.2897	0.1818
Poland	0.1621	0.3095	0.1474
Romania	0.3694	0.5096	0.1403
Russia	0.5287	0.7002	0.1715
Serbia	0.5475	0.4945	−0.0529
Sweden	0.1315	0.1267	−0.0049
Turkey	0.3372	0.5045	0.1674
UK	0.1893	0.2942	0.1049

Source: own calculations.

Table 5. Consumer inflation expectation properties

Country	$Forward_{dist}$	$Backward_{dist}$	$Backward_{dist}$ – $forward_{dist}$
Albania	0.0499	0.3302	0.2803
Czechia	0.2354	0.5318	0.2964
Hungary	0.4674	0.3466	–0.1208
Kazakhstan	0.8799	1.1500	0.2701
Norway	0.1906	0.1244	–0.0662
Poland	0.1764	0.3578	0.1814
Romania	1.1675	0.4702	–0.6973
Russia	2.2784	2.5133	0.2349
Serbia	0.7550	0.4661	–0.2888
Sweden	0.1984	0.3714	0.1730
Turkey	1.6659	0.7909	–0.8750
UK	0.2110	0.2067	–0.0042

Source: own calculations.

Comparing $Forward_{dist}$ and $Backward_{dist}$ is the first step in presenting the results. When the forward-looking distance is lower than the backward-looking distance, we consider expectations to be based more on the future evolution of inflation (compared to rational expectations). Professional expectations (see Table 4) are more forward-looking for almost all countries except Serbia and Sweden. In Kazakhstan, the distance between professionals' expectations and future inflation and expectations and past inflation is the greatest, which suggests the most forward-looking expectations in the sample.

When consumers are considered (see Table 5), in six out of the twelve economies (Albania, Czechia, Kazakhstan, Poland, Russia, Sweden), consumers are more forward-looking than backward-looking. However, the distance between expectations and past inflation is lower in Hungary, Norway, Romania, Serbia, Turkey and the UK. Note that in the case of Norway and the UK, the difference between FL and BL distances is negligible, making these cases inconclusive.

When comparing the FL or BL distances reported for professionals and consumers, both distances are higher for consumers. This means that they exhibit a lower ability to recognise past or future economic situations. Consumer expectations in Turkey, Russia and Kazakhstan are much further from actual inflation than in other countries. In these economies, the disinflation process was interrupted. Russia and Kazakhstan are also the most recent adopters of IT (see Table 1). Moreover, these economies are characterized by a relatively weak institutional environment where political factors have a strong influence on the economy. The formation of inflation expectations in such an environment is disrupted.

Alignment of expectations among professionals and consumers

Finally, this section presents the DTW-based result that reports co-movements of expectations between the two groups of economic agents. Table 6 shows the dependencies, which we understand as follows:

Consumer (professional) expectations follow professional (consumer) expectations if the distance between consumer (professional) expectations and future (forward) professional (consumer) forecasts is lower than between consumer (professional) expectations and past (lagged) professional (consumer) expectations.

In most cases, professional expectations preceded those of consumers. The situation when professional expectations precede those of consumers could be considered a standard: more educated economic agents – professionals – present their forecasts and discuss them in media. It is more likely that households use professional forecasts as drivers of their forecasts than vice versa. This is the case for most countries in our sample. In Romania and Turkey, the difference between the "consumers follow professionals" and "professionals follow consumers" cases is the most visible.

In Albania, Czechia, and Sweden, consumers do not follow professionals when following is represented by the shortest distance between professional and consumer expectations considered at different lags. The situation in Poland and the UK is inconclusive, as the difference between distances is negligible.

The most significant distances occur in Russia, regardless of which time series is considered first. This coincides with one of the lowest mutual information values for this economy between time series. However, in most cases, mutual information does not translate into lower distances between time series.

Table 6. Professional vs. consumer distances according to DTW

Country	$Forward_{dist}$	$Backward_{dist}$	$Backward_{dist} - forward_{dist}$
Albania	0.4091	0.1971	−0.2120
Czechia	0.5711	0.2467	−0.3243
Hungary	0.3128	0.5901	0.2773
Kazakhstan	0.5532	0.9844	0.4313
Norway	0.0817	0.2122	0.1304
Poland	0.2152	0.3053	0.0900

Country	$Forward_{dist}$	$Backward_{dist}$	$Backward_{dist} - forward_{dist}$
Romania	0.2545	1.3904	1.1359
Russia	2.2324	2.5541	0.3217
Serbia	0.3552	0.5806	0.2254
Sweden	0.3351	0.2332	–0.1019
Turkey	0.3865	1.3225	0.9360
UK	0.3813	0.4346	0.0532

Note: $Forward_{dist}$ (first column) presents the distance between consumer expectations and (forward) professional expectations. $Backward_{dist}$ (second column) presents the distance between consumer expectations and (lagged) professional expectations. A smaller forward distance means that consumers follow professionals – a positive value in the third column.
Source: own calculations.

Conclusion

This paper presented an empirical study employing a novel combination of mutual information measures and the DTW algorithm, thanks to which we were able to obtain interesting conclusions. Mutual information captures all dependencies (including non-linear dependencies) and quantifies how much we can learn about one variable from knowing the values of another variable. The DTW algorithm does not require any assumption about time series, and because we do not assume a time shift between them, we redefine forward- and backward-lookingness without specifying a particular lag. However, it is difficult to draw any specific conclusions if the results of distance differences or different configurations of mutual information are small. This study's novelty also concerns the empirical results provided. The applied method allows us to investigate expectations from different perspectives than the standard method by accounting for non-linearities and non-stationarity in time series.

Our findings and responses to the research questions can be summarised as follows. The strongest alignment of expectations between professionals and consumers occurs in countries with disrupted disinflation processes over time (Romania and Turkey). Nonetheless, informational coordination between both groups of economic agents exists, ranging from 50% to almost 90% (Q1). A significant portion of the common information is about past inflation, regardless of whether professionals or consumers are studied. In all cases, mutual information is greater than conditional mutual information (Q2). Our sample is balanced considering consumers' forward- or backwards-lookingness (Q3). In six countries, the distance between expectations and future inflation is lower than between expectations and past inflation. Expectations mimic past inflation more than future inflation in four economies, while the results for two countries are inconclusive. Professional expectations display a lower distance to future inflation in ten out of the twelve economies (Q4).

In terms of future research, a country-level examination that considers local monetary policies and economic circumstances would shed more light on the reported relationships. Given this study's focus on methodology, the results are only presented with a general commentary.

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Oczekiwania inflacyjne konsumentów i profesjonalistów – własności i wzajemne zależności

Oczekiwania inflacyjne są kluczową zmienną dla banków centralnych. Jednak empiryczne badanie ich właściwości stanowi wyzwanie. Celem tego badania jest porównanie właściwości oczekiwań konsumentów i profesjonalistów oraz ocena nastawienia na przyszłość i informacji zawartej w oczekiwaniach tych grup uczestników rynku. W badaniu zastosowano miary oparte na entropii, aby uchwycić nieliniowe zależności między zmiennymi i algorytm dynamicznej transformaty czasowej (DTW) oraz uwzględnić różne opóźnienia w relacjach. Badanie obejmuje 12 gospodarek regionu europejskiego, w których realizowana jest strategia celu inflacyjnego. Wyniki sugerują, że w większości krajów profesjonaliści bardziej wybiegają w przyszłość, a konsumenci podążają za profesjonalistami. Obie grupy podmiotów gospodarczych prezentują oczekiwania zgodne pod względem zawartości informacyjnej. Występują różnice między krajami. Wyniki badań potwierdzają, że komunikacja i inne działania banków centralnych, nakierowane na kształtowanie oczekiwań, nawet jeśli skierowane są głównie do specjalistów, nie pozostają bez znaczenia dla konsumentów. Wartość dodana badania wynika z zastosowania alternatywnej metody oceny oczekiwań, pozwalającej na uniknięcie wad metod standardowych oraz na wyciągnięcie szerszych wniosków na temat zależności.

Słowa kluczowe: oczekiwania inflacyjne, wzajemna informacja, algorytm DTW

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Levels of Renewable Energy Use in Selected European Union Countries – Statistical Assessment of Changes and Prospects for Development

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Abstract

The search for and use of green energy sources is an important course of action for the European Union (EU). The paper compares the 13 EU countries that acceded to the EU in 2004 and afterwards in terms of the level of renewable energy use. The primary indicator used to assess the use of renewable energy sources (RES) was the share of renewable energy in gross final energy consumption from 2007 to 2021. Statistical data were sourced from the Eurostat database. The results of the study confirm that between 2007 and 2021, there were positive changes in the use of renewable energy in most of the countries. The prospects for renewable energy development in these countries were assessed by constructing forecasts of the indicator concerning the share of renewable energy in gross final energy consumption

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for 2022–2024. For most of the countries, the forecasts were highly and sufficiently precise, meaning the countries have a chance of meeting the RES targets set out in EU directives.

Keywords: renewable energy, European Union, forecasting methods, development perspectives

JEL: O39, O40

Introduction

The progress of world civilisation is significantly affecting the environment, as well as the living environment of humans and animals, increasing the demand for electricity. In the nineteenth century, energy consumption was mainly based on coal and lignite; in the twentieth century, the fuel was oil (Johansson 2013). When fossil fuels are burnt, gaseous pollutants are emitted into the atmosphere, and significant amounts of solid waste are released into the environment, causing its degradation. In view of this, the combustion of these fuels contributes significantly to exacerbating the greenhouse effect (Latkowska, Fitko, and Stelmach 2011; Kruk 2012; Daroń and Wilk 2021). Coal combustion causes a significant deterioration of air quality through the emission of toxic substances, harmful dust and heavy metals (Ociepa-Kubicka 2015). Such structure of primary fuel consumption causes the development of increasingly stringent environmental protection standards (Frątczak 2015, p. 202).

Today, in the 21st century, given the economic and environmental aspects, humanity is forced to search for new, non-conventional energy sources (Latkowska, Fitko, and Stelmach 2011). The continued growth in global energy demand and the prospect of depleting fossil fuel stocks are significantly increasing interest in renewable energy sources and how they can be used. This course of action is part of the global trend of searching for and diversifying green energy sources.

Electricity generation is one of the most important elements of the global economy. It is also important for individual regions and is a factor that significantly influences their economic development. In modern times, energy determines the growth of industrial production, innovation, the creation of workplaces, the development of society, inflation, and poverty status, including housing affordability, a topic that resonates in many European countries today (Łuczak and Kalinowski 2022). The use of raw materials of natural origin for energy production is closely correlated with legal regulations at the European Union (EU) level. This has important implications for the supply of raw materials for energy production from renewable energy sources (RES) (Molo 2016).

The natural limitations to RES development in individual EU countries are mainly climatic and natural conditions, including too little sunshine, light winds, and a lack of geothermal water deposits. Restrictions are also placed on established forms of nature conservation (including landscape parks, national parks, nature reserves, Natura 2000 network areas, and bird migration routes), where, for example, wind energy cannot be developed (Kruk 2012).

Some authors, such as Stec and Grzebyk (2022), have drawn attention to several important energy-related issues that have been under consideration in the EU in recent years, such as oil price volatility, disruptions in energy supply from non-EU countries, and difficulties in accessing the market for gas and electricity suppliers. These issues have made the topic of energy one of the main political agendas in Europe, especially after 24th February 2022 (i.e., the beginning of the war in Ukraine). Thus, the use of renewable energy sources is seen as a key element of energy policy, including energy security. Energy security issues were also highlighted by Żuk and Żuk (2022) and Mišík (2022), who showed how the last three years have clearly changed the outlook for shaping and evaluating energy mixes. The sense of threat associated with the COVID–19 pandemic and war in Ukraine has intensified the need for security, and the issue of ensuring energy supply for individual countries is now a prerequisite for the smooth functioning of European economies. Individual EU countries are expected to increasingly base their development on their own renewable energy resources and gradually move away from dependence on major fossil fuel exporters such as Russia and Saudi Arabia (Van de Graaf 2018). It is, therefore, recognised that energy independence and security of the energy supply are major key factors in economic growth and development (Kryszk et al. 2023). The development of renewable energy is important for implementing the fundamental climate and energy policy objectives of the EU as a whole, as well as of its constituent countries. Increasing the use of renewable energy sources offers opportunities for increased energy efficiency and economic independence (Gaigalis and Katinas 2020).

This article assesses the changes in renewable energy use in selected EU countries between 2007 and 2021 and identifies the prospects for its development between 2022 and 2024. The research subjects are the following countries, which acceded to the EU in 2004 and later: Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia (hereinafter: the EU–13). A measure that assesses renewable energy use in selected countries is the share of renewable energy in gross final energy consumption. The article provides an extensive statistical analysis of this ratio, and the prospects for renewable energy use in the EU–13 between 2022 and 2024 are assessed using selected forecasting methods, including linear and non-linear trend functions.

The article seeks to answer the following questions:

- How did the share of renewable energy in gross final energy consumption evolve in the EU–13 between 2007 and 2021?

- Which of the EU–13 are leaders in the use of renewable energy, and which are low achievers?
- Are the EU–13 likely to meet their individual RES energy production targets in accordance with existing EU directives?

Guidelines for the development of renewable energy in EU documents

Renewable energy refers to energy derived from recurring natural processes from renewable, non-fossil energy sources (i.e., water, wind, solar, geothermal, wave power, current and tidal flows) and energy generated from solid biofuels, biogas and liquid biofuels, as well as ambient (environmental) energy from heat pumps (Daroń and Wilk 2021). In the 1990s, interest in RES significantly increased. As Devine-Wright (2019) and Papież, Śmiech, and Frodyma (2018) noted, renewable energy sources have undergone an evolution from a technological novelty to a viable tool used to produce energy to meet the growing needs of the world's population.

Renewable energy sources are an alternative to traditional, primary, non-renewable energy carriers (fossil fuels). Their resources are replenished through natural processes, making it possible to treat them as practically inexhaustible. Furthermore, obtaining energy from these sources is, when compared to traditional (fossil) sources, more environmentally friendly. The use of RES significantly reduces the harmful impact of energy on the environment, mainly by reducing emissions of harmful substances, especially greenhouse gases (Rajchel and Walawender 2018).

The EU's energy policy is based on respect for natural resources and independence from fuel imports from non-EU economic areas, including a move away from fossil fuels towards the production of energy from renewable sources (Directive 2009/28/EC; Wawrzyniak 2016). This is particularly relevant now with the ongoing war in Ukraine. The extent of renewable energy use in the EU member states is regulated by the relevant EU normative documents and acts that set general and specific targets concerning the obligation to achieve set indicators for the share of renewable energy in gross final energy consumption (Rajchel and Walawender 2018).

Higher-level EU legislation promoting the use of energy from renewable sources has existed since 2001, when the first directive on the promotion of electricity produced from renewable energy sources in the internal market was adopted (Directive 2001), followed by the directive of 2003 (Directive 2003/30/EC) on the use of biofuels and other renewable energy sources in transport (Papież, Śmiech, and Frodyma 2018). The enlargement in 2004 forced an update of the RES energy share targets to

21% and it included targets for candidate countries. However, these demands were non-binding and did not result in consequences for member states if they were not met (Olczak 2016). The subsequent 2009 directive aimed to establish a common framework for the promotion of energy from renewable sources by setting mandatory targets for Member States. The directive stipulated that by 2020, 20% of the EU's total energy consumption had to come from renewable sources, with this target being broken down into binding sub-targets for the Member States.

In the transport sector, Member States had to achieve a 10% share of fuels from renewable sources by 2020. The directive sets out the mechanisms that the Member States could use to achieve their targets (support schemes, guarantees of origin, joint projects, co-operation between Member States and third countries), as well as sustainability criteria for biofuels (Directive 2009/28/EC; Molo 2016). The target, defined as the share of RES energy in total energy consumption, is defined as the quotient of the gross final energy consumption from RES and the gross final energy consumption from all sources, expressed as a percentage (Ustawa z dnia 20 lutego 2015 r. o odnawialnych źródłach energii). Gross final energy consumption means energy commodities supplied for energy purposes to industry, the transport sector, households, the tertiary sector (including public services), agriculture, forestry and fisheries. It also includes the consumption of electricity and heat by the energy industry for electricity and heat generation, as well as losses of electricity and heat during distribution and transmission (Directive 2009/28/EC).

Further changes came in December 2018, when a more stringent framework was introduced for the share of energy from renewable sources as part of the 'Clean Energy for all Europeans' package (Directive 2018/2001/EU; Hoicka et al. 2021). The purpose of the package was to maintain the Union's position as a global leader in renewables and, more broadly, to help the EU meet its emissions reduction commitments made under the Paris Agreement. The directive set a binding target of at least 32% of the final energy consumed in the EU to be derived from renewable sources by 2030. It also includes a clause to bring this target forward to 2023 and to increase the target to a 14% share of renewable energy in transport by 2030. Additionally, an increase in the share of RES in heating and cooling will also be required (by 1.3% and 1.1%, respectively, each year) relative to the annual average calculated for the periods 2021–2025 and 2026–2030.

The Member States were required to incorporate the changes into their national law by June 2021, with effect from 1st July 2021. If the changes had not taken place, the national renewable energy targets for 2020 should be each Member State's minimum contribution for the year 2030. Each state was obliged to propose a national energy target and establish ten-year national energy and climate plans under the program 'Horizon 2030'. As Hoicka et al. (2021) noted, if the changes are effectively implemented and transposed into national laws, it could accelerate a more equitable and sustainable energy transition by facilitating the widespread implementation of 'Renewable Energy Communities' (RECs).

Under the 2018 directive, Member States have to report on their progress in this scope every two years. The commission will assess the plans and may take measures at the EU level to ensure that the plans are consistent with overall EU objectives.

Discussions on the post–2030 energy policy framework are currently underway (Wiśniewska, Pusz, and Rogalski 2020). The European Green Deal is a new growth strategy that aims to transform the EU into a sustainable, fair and prosperous society, resource-efficient and with no net greenhouse gas emissions by 2050, i.e. working towards the goal of achieving EU energy neutrality. The strategy outlines ways to accelerate the development and deployment of low-carbon technologies considering the targets set for 2030 and 2050 (Communication… 2019).

The EU aims to develop its strategy and infrastructure for the further decarbonisation of the energy system by 2050, including an 80–95% reduction in greenhouse gas emissions compared to 1990 levels. It also aims to further increase the share of RES in gross final energy consumption (up to 55% in 2050) and other measures to increase energy efficiency while taking into account the objectives of supply security and competitiveness (Bekirsky et al. 2022).

Materials and methods

An indicator for the share of renewable energy in gross final energy consumption was used to assess renewable energy use in the EU–13 using statistical data from 2007–2021 taken from the Eurostat database. The research methods used were measures to describe the structure of collectivity (arithmetic mean, coefficient of variation, asymmetry coefficient), measures of dynamics, and selected forecasting methods. A description of the statistical measures and forecasting methods used in this paper can be found in Aczel (2000), Cieślak (2001), Zeliaś, Pawełek, and Wanat (2003), and Frątczak (2015).

The simplest measure of dynamism is absolute growth, which is the difference between the magnitude of a phenomenon in the period under study and the baseline (base) period:

$$\Delta y_t = y_t - y_0, \qquad (1)$$

where: y_t – the magnitude of the phenomenon during the period considered, y_0 – the magnitude of the phenomenon in the base period.

Absolute increments indicate by how much the phenomenon increased (decreased) during the study period compared to its level during the base period. The average rate of change is defined by the following equation:

$$\overline{y}_g = \sqrt[n-1]{\frac{y_n}{y_1}}, \quad (2)$$

where: y_n, y_1 – absolute levels of the phenomenon from the last and the first period.

The average rate of change, expressed as a percentage, indicates the average periodic percentage increase in the phenomenon over the time interval under consideration.

Forecasting economic processes is one way of anticipating the future. It involves rational, scientific predictions of future events (Cieślak 2004) and facilitates decision-making, with the quality largely depending on the accuracy of the forecast.

The academic literature contains many time series forecasting methods, and the choice of the right one depends on the course of the phenomenon under study in time. By visually assessing the time series values, the appropriate analytical form of the model can be selected. Furthermore, assessing the model's quality involves assessing measures of how well the model fits the empirical data and conducting relevant statistical tests. The acceptability of the designated forecasts is typically judged based on forecast error values.

When the time series shows a developmental trend and random fluctuations, analytical models (linear or non-linear trend function) can be used for forecasting.

The linear development trend model takes the following general form:

$$y_t = \alpha_0 + \alpha_1 t + \varepsilon, \quad (3)$$

where: t – time variable, ε – random component.

The parameters of the linear trend functions a_0 and a_1 are determined using the Least Squares Method from the following equations:

$$a_1 = \frac{\sum_{t=1}^{n}(y_t - \overline{y})(t - \overline{t})}{\sum_{t=1}^{n}(t - \overline{t})^2}, \quad (4)$$

$$a_0 = \overline{y} - a_1\overline{t}. \quad (5)$$

The estimated linear trend model takes the following form:

$$\hat{y}_t = a_0 + a_1 t. \quad (6)$$

Of the many forms of non-linear trend functions, this paper uses second and third-degree polynomial functions.

The general form of a polynomial of the second degree is as follows:

$$y_t = \alpha_0 + \alpha_1 t + \alpha_2 \ t^2 + \varepsilon. \tag{7}$$

This function is transformed into a linear model by introducing replacement variables: $Z_1 = t$ and $Z_2 = t^2$. When substituted into the general form (equation 7), the following linear model is obtained:

$$y_t = \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_2 + \varepsilon. \tag{8}$$

Structural parameter estimates are determined by the Least Squares Method using the following vector:

$$a = (Z^T Z)^{-1} Z^T y. \tag{9}$$

The general form of the trend function as a polynomial of the third degree is defined by the following equation:

$$y_t = \alpha_0 + \alpha_1 t + \alpha_2 \ t^2 + \alpha_3 \ t^3 + \varepsilon. \tag{10}$$

The function is transformed into a linear model using replacement variables: $Z_1 = t$, $Z_2 = t^2$ and $Z_3 = t^3$.

Structural parameter estimates are determined using the following vector:

$$a = (Z^T Z)^{-1} Z^T y. \tag{11}$$

Once the structural parameters of the trend models have been estimated, it is important to validate the resulting models.

The fitness of models to the empirical data can be assessed using the coefficient of determination and coefficient of random variation.

The coefficient of determination, R^2, has the following form:

$$R^2 = 1 - \frac{\sum_{t=1}^{n} (y_t - \hat{y}_t)^2}{\sum_{t=1}^{n} (y_t - \bar{y})^2}. \tag{12}$$

The closer the value of the coefficient of determination is to one, the better the model fits the empirical data.

On the other hand, the coefficient of random variation, W_e, is determined based on the following equation:

$$W_e = \frac{S_e}{\bar{y}} \cdot 100, \tag{13}$$

where: S_e – standard deviation of the residual component, $\bar{y}$ – average value of the explained variable.

The coefficient indicates what percentage of the arithmetic mean of the explained variable of the model constitutes the standard deviation of the residuals. The smaller the W_e coefficient, the better the fitness of the model to the data.

The standard deviation of the residual component is calculated using the following equation:

$$Se = \sqrt{\frac{\sum_{t=1}^{n}(y_t - \hat{y}_t)^2}{n-2}}. \tag{14}$$

It indicates by how much, on average, the empirical values deviate from the theoretical values of the model.

In the process of verifying linear development trend models, it is also worth checking the significance of structural parameter estimates. The relevant statistical hypotheses are of the following form:

$$\mathrm{H}_0 : \alpha_i = 0 \, H_1 : \alpha_i \neq 0 .$$

Hypothesis H_0 assumes that parameter α_i is not statistically different from 0, while the alternative hypothesis H_1 assumes otherwise.

The test statistic is defined by the following equation:

$$t_i = \frac{|a_i|}{S(a_i)}. \tag{15}$$

If $t_i \leq t_\alpha$, there are no grounds to reject the H_0 hypothesis. Conversely, when $t_i > t_\alpha$, the H_0 hypothesis should be rejected in favour of the alternative hypothesis H_1.

The critical value t_α is determined from the t-test distribution tables for the chosen significance level α (usually 0.05) and $n - 2$ degrees of freedom.

In practical applications based on computer programmes, the p-value (test probability level) is often used to assess the significance of structural parameters. If the p-value is lower than the accepted significance level α (usually 0.05), the H_0 hypothesis should be rejected, indicating that the parameter under study differs from zero in a statistically significant manner.

A correctly verified model can be used as the basis for building forecasts of a phenomenon for subsequent years.

Determining the forecast of a phenomenon based on a linear trend model can be done by extrapolating it:

$$y_T^* = a_0 + a_1 T, \tag{16}$$

where: y_T^* – point forecast for Y variable, T – forecasting period.

The average forecast error (S_{pT}) for the linear trend function is determined using the following equation:

$$S_{pT} = Se\sqrt{\left[\frac{(T-\bar{t})^2}{\sum_{t=1}^{n}(t-\bar{t})^2} + \frac{1}{n} + 1\right]}. \tag{17}$$

In order to express the average forecast error in percentage terms, the average relative ex-ante forecast error is calculated using the following equation:

$$V_T = \frac{S_{pT}}{y_T^*} \cdot 100. \tag{18}$$

The following criteria are adopted to assess the quality of a forecast (Cieślak 2001):

$V_T \leq 5\%$, high-precision forecast,

$5\% < V_T \leq 10\%$, sufficiently precise forecast,

$V_T > 10\%$, insufficiently precise forecast.

In the case of a trend of the phenomenon under study with a polynomial of the second and third degree, the average forecast error (S_{pT}) is determined using the following equation:

$$S_{pT} = S_e\sqrt{X_T\left(Z^T Z\right)^{-1} X_T^T + 1}, \tag{19}$$

where: X_T – vector of time variable value.

The vector of time variable value contains the following components:

$X_T = [1\,T\,T^2]$ for a trend function in the form of a polynomial of the second degree,

$X_T = [1\,T\,T^2\,T^3]$ for a trend function in the form of a polynomial of the third degree.

Results and discussion

The study of the level of use of renewable energy covered the EU–13 countries, which acceded to the EU in 2004 and later. Table 1 contains a general characterisation of the study group with key statistical indicators about the countries for 2021.

Table 1. Basic statistical indicators of selected EU countries, 2021

Country	Area in km²	Population in millions	GDP per capita in €	Investment rate (% GDP)	GERD*	Unemployment rate (%)	Gini coefficient	Persons at risk of poverty or social exclusion (%)
Bulgaria	110,910	6.88	10,330	16.3	0.85	5.3	39.7	32.1
Croatia	56,594	3.96	14,720	20.7	1.24	7.6	29.2	23.2
Cyprus	9,251	0.90	26,680	19.5	0.84	7.5	29.4	21.3
Czechia	78,870	10.51	22,270	26.0	1.99	2.8	24.8	11.9
Estonia	45,228	1.33	23,640	28.9	1.75	6.2	30.6	23.2
Hungary	93,025	9.71	15,840	27.2	1.59	4.1	27.6	17.8
Latvia	64,573	1.88	17,890	22.3	0.69	7.6	35.7	26.0
Lithuania	65,300	2.80	20,000	21.4	1.14	7.1	35.4	24.8
Malta	316	0.52	28,890	20.3	0.65	3.4	31.2	19.0
Poland	312,696	37.75	15,060	17.0	1.39	3.4	26.8	17.3
Romania	238,397	19.12	12,620	23.7	0.47	5.6	34.3	30.4
Slovakia	49,035	5.45	18,110	18.9	0.9	6.8	20.9	14.8
Slovenia	20,273	2.11	24,770	20.3	2.14	4.8	23.0	15.0
Mean	88,036	7.92	19,294	21.73	1.20	5.6	29.9	21.3
CV**	0.98	1.26	0.28	0.17	0.43	0.30	0.17	0.27
CA***	1.76	2.32	0.18	0.56	0.46	−0.26	0.10	0.31

* GERD (gross domestic expenditure on R&D) – percentage of GDP in 2020; ** CV – coefficient of variation; *** CA – coefficient of asymmetry.

Source: own compilation based on Eurostat n.d.

The EU–13 are strongly differentiated in terms of their area. The following countries are the largest: Poland (312,696 km^2), Romania (238,397 km^2) and Bulgaria (110,910 km^2). In contrast, the smallest are Malta (316 km^2), Cyprus (9,251 km^2) and Slovenia (20,273 km^2). In terms of population, the leaders are Poland (37.75 million people), Romania (19.12 million) and Czechia (10.51 million). The least populated are Malta (0.52 million), Cyprus (0.9 million) and Estonia (1.33 million). The variation between countries in terms of population can be considered strong, with a variation coefficient of 1.26. However, the vast majority of countries have populations below the group average.

One of the most important indicators of a country's socio-economic development is GDP per capita. The countries with the highest levels are Malta (EUR 28,890 per capita), Cyprus (26,680) and Slovenia (24,770). Conversely, those with the lowest levels are Bulgaria (EUR 10,330 per capita), Romania (12,620) and Croatia (14,720). The variation coefficient, at the 0.28 level, indicates a weak variation among the EU–13.

Another economic indicator is the investment rate (% of GDP), which ranges from 16.3% in Bulgaria to 28.9 in Estonia. Thus, the diversity of countries can be considered weak.

One measure of a country's innovativeness is GERD (gross domestic expenditure on R&D) as a percentage of GDP. The leaders are Slovenia (2.14%), Czechia (1.99%) and Estonia (1.75%). In contrast, Romania (0.47%), Malta (0.65%) and Latvia (0.69%) have the lowest share of R&D expenditure in their GDP.

The EU–13 have a good labour market situation. The unemployment rate is relatively low, ranging from 2.8% (Czechia) to 7.6% (Latvia). On average, it stood at 5.6%, with six countries above the average (weak negative asymmetry).

Several indicators that define social development were also assessed. The Gini coefficient shows income disparity in a given society; the higher it is, the greater the disparity of incomes. The lowest values are found in Slovakia (20.9%), Slovenia (23.0%) and Czechia (24.8%). In contrast, the largest income disparities can be observed in Bulgaria (39.7%), Latvia (35.7%) and Lithuania (35.4%). The average value of the Gini coefficient was 29.9%.

The countries are also characterised by poor diversification in terms of the ratio of persons at risk of poverty or social exclusion, ranging from 11.9% (Czechia) to 32.1% (Bulgaria). The weak right-handed asymmetry indicates that most of the countries have lower poverty levels than the group average (Table 1).

The general statistical characterisation of the EU–13 shows that they form a fairly homogeneous collective. The question arises as to whether renewable energy use is also similar. The values of the share of renewable energy in gross final energy consumption between 2007 and 2021 are given in Table 2.

Table 2. Values of the share of renewable energy in gross final energy consumption (%) in selected EU countries, 2007–2021

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Bulgaria	9.10	10.35	12.01	13.93	14.15	15.84	18.90	18.05	18.26	18.76	18.70	20.58	21.55	23.32	17.02
Croatia	22.16	21.99	23.60	25.10	25.39	26.76	28.04	27.82	28.97	28.27	27.28	28.05	28.47	31.02	31.33
Cyprus	4.00	5.13	5.92	6.16	6.25	7.11	8.43	9.14	9.90	9.83	10.48	13.87	13.78	16.88	18.42
Czechia	7.90	8.67	9.98	10.51	10.95	12.81	13.93	15.07	15.07	14.93	14.80	15.14	16.24	17.30	17.67
Estonia	17.14	18.81	23.01	24.58	25.52	25.59	25.36	26.13	28.99	29.23	29.54	29.97	31.73	30.07	38.01
Hungary	8.58	8.56	11.67	12.74	13.97	15.53	16.21	14.62	14.50	14.38	13.56	12.55	12.63	13.85	14.12
Latvia	29.62	29.81	34.32	30.38	33.48	35.71	37.04	38.63	37.54	37.14	39.01	40.02	40.93	42.13	42.11
Lithuania	16.48	17.82	19.80	19.64	19.94	21.44	22.69	23.59	25.75	25.61	26.04	24.70	25.47	26.77	28.23
Malta	0.18	0.20	0.22	0.98	1.85	2.86	3.76	4.74	5.12	6.21	7.22	7.91	8.23	10.71	12.15
Poland	6.90	7.69	8.68	9.28	10.34	10.96	11.45	11.61	11.88	11.40	11.06	14.94	15.38	16.10	15.62
Romania	18.20	20.20	22.16	22.83	21.74	22.83	23.89	24.85	24.79	25.03	24.45	23.88	24.29	24.48	23.60
Slovakia	7.77	7.72	9.37	9.10	10.35	10.45	10.13	11.71	12.88	12.03	11.47	11.90	16.89	17.35	17.41
Slovenia	19.68	18.65	20.77	21.08	20.94	21.55	23.16	22.46	22.88	21.98	21.66	21.38	21.97	25.00	25.00
UE–27	11.75	12.55	13.85	14.41	14.55	16.00	16.66	17.42	17.82	17.98	18.41	19.10	19.89	22.04	21.78

Source: own compilation based on Eurostat n.d.

Even a cursory assessment of the share of renewable energy in gross final energy consumption shows quite significant differences between the countries. In 2007, the indicator ranged from 0.18% (Malta) to 29.62% (Latvia). The European average (EU–27) was 11.75%, exceeded by six of the EU–13 (Latvia, Croatia, Slovenia, Romania, Estonia and Lithuania). However, by 2021, there were some significant changes in the level of renewable energy share in gross final energy consumption compared to 2007. There was a noticeable increase in all of the countries. In 2021, it ranged from 12.15% in Malta to 42.11% in Latvia, with an EU–27 average of 21.78%. RES leaders were Latvia, Estonia and Croatia. The bottom three countries in the ranking were Malta, Hungary and Poland, where the share of renewable energy in gross final energy consumption was almost one-third that of Estonia. Estonia saw the largest increase in 2021 compared to 2007 (by 20.87%), followed by Cyprus (14.42%) and Latvia (12.49%). In the study period, the ranking of the EU–13 in terms of the share of renewable energy in gross final energy consumption showed that four countries had improved by two places (Cyprus, Estonia, Lithuania, and Slovakia). Six countries (Bulgaria, Croatia, Czechia, Latvia, Malta and Poland) remained unchanged, while Romania and Slovenia fell by two places, and Hungary fell by four.

Changes in the share of renewable energy in gross final energy consumption in the EU–13 in 2007 and 2021 are presented in Figure 1.

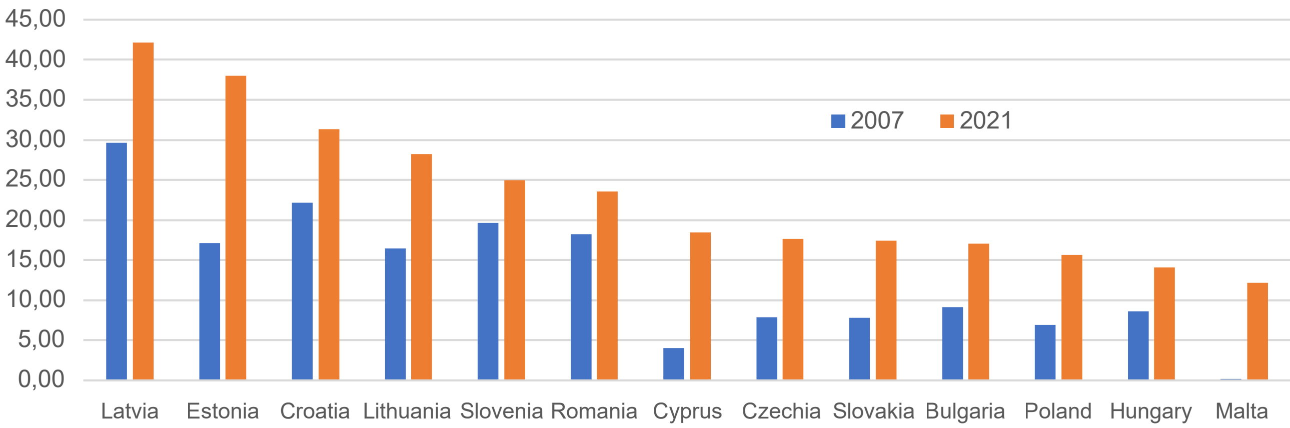

Figure 1. Values of the share of renewable energy in gross final energy consumption (%) in selected EU countries, 2007 and 2021

Source: own compilation based on own compilation based on Eurostat n.d.

The data in Figure 1 show that in 2021, compared to 2007, there had been significant progress in the use of renewable energy in all the countries studied. Pérez, Scholten, and Smith Stegen (2019) pointed out that Central and Eastern European countries are among those with similar energy experiences. Furthermore, similar political and economic conditions, including the period of recent economic transition, continue to influence the energy policy-making principles they have adopted. Nevertheless, as the results of the study show, despite such advances, the energy transition remains a huge challenge for them, both technologically and economically. This can also be seen in the debates and negotiations on EU energy policy. Central and Eastern European countries often criticise renewable energy sources for their instability and high sourcing costs while also arguing that these sources cannot fully replace fossil fuels.

Examining the entire research period of 15 years shows the average rate of change of the share of renewable energy in gross final energy consumption for the EU–13 and EU–27 countries. The results of the calculations, according to equation (2), are shown in Figure 2.

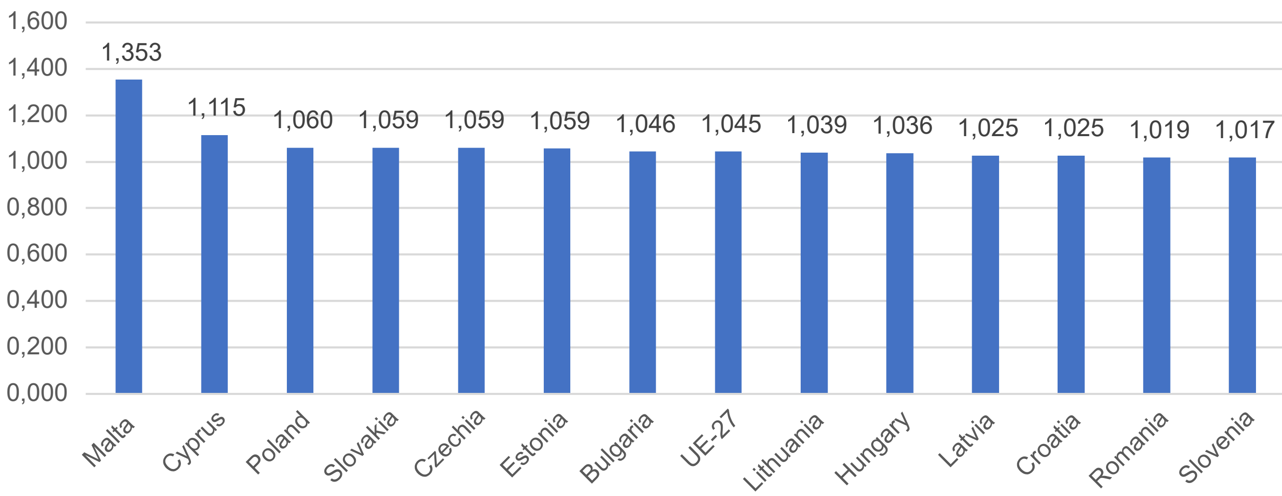

Figure 2. Average rate of change of the share of renewable energy in gross final energy consumption (%), 2007–2015

Source: own compilation based on Eurostat n.d.

Figure 2 shows that the rate of change in the share of renewable energy in gross final energy consumption was positive in all the countries studied. The highest rate of growth was achieved by Malta (a 35.3% average annual increase) and Cyprus (11.5%). Poland, Slovakia, Czechia, Estonia and Bulgaria also had growth rates higher than the EU–27 average. Nonetheless, the countries which stand out in terms of the rate of change of the share of renewable energy in gross final energy consumption are catching up but still far from the current RES leaders (Latvia, Estonia, Croatia).

The issues of energy transition in southeast European countries and the related problems were highlighted by Anastasiu et al. (2018), Năstase et al. (2018), and Koltsaklis et al. (2020). Using Romania as an example, they showed that countries in the region have great potential to diversify their energy sources, including the use of renewable sources. Romania can and does use a variety of renewable energy sources, including wind, solar, geothermal and hydropower. However, making full use of the sources requires investment and an appropriate, well-thought-out operational strategy.

Romanian energy policy, just like that of other countries in the region, is dominated by the use of non-renewable energy sources, primarily coal.

To ascertain whether the upward trend observed in the share of renewable energy in gross final energy consumption between 2007 and 2021 in the EU–13 will continue, an attempt was made to forecast it for the years 2022–2024. The time series of the variable from 2007 to 2021 showed an increasing trend for most of the countries and slight random fluctuations for some of them. An analytical approach using linear and non-linear trend functions may then be an appropriate forecasting method, assuming this trend of changes continues. Using the least squares method, the structural parameters of the linear trend function of the indicator of the share of renewable energy in gross final energy consumption over the period 2007–2021 were estimated for each of the 13 countries separately, determined by equation (3). The structural parameters were determined using equations (4) and (5), and the models were verified using the statistical measures and tests defined by equations (12)–(15).

If the verification of the estimated linear trend functions did not meet the desired criteria, non-linear trend functions, i.e. a second-degree polynomial model (equation (7)) or a third-degree polynomial model (equation (10)), were used. The final results of the trend model estimations for the EU–13 and EU–27 are presented in Table 3.

Table 3. Trend functions of the share of renewable energy in gross final energy consumption in the years 2007–2021 for selected EU countries

Country	Trend function equation	Standard Error	t-Stat	p-Value	R^2	We (%)
Bulgaria	$\hat{y}_t = 10.23 + 0.81\ t$	$S_{(a0)} = 1.08$ $S_{(a1)} = 0.12$	$t_0 = 9.43$ $t_1 = 6.78$	0.000000 0.000013	0.779	11.96
Croatia	$\hat{y}_t = 22.26 + 0.59\ t$	$S_{(a0)} = 0.59$ $S_{(a1)} = 0.07$	$t_0 = 37.39$ $t_1 = 8.95$	0.000000 0.000000	0.860	4.07
Cyprus	$\hat{y}_t = 2.23 + 0.93\ t$	$S_{(a0)} = 0.66$ $S_{(a1)} = 0.07$	$t_0 = 3.35$ $t_1 = 12.78$	0.005194 0.000000	0.926	12.61
Czechia	$\hat{y}_t = 8.06 + 0.67\ t$	$S_{(a0)} = 0.45$ $S_{(a1)} = 0.05$	$t_0 = 17.86$ $t_1 = 13.46$	0.000000 0.000000	0.933	6.02
Estonia	$\hat{y}_t = 18.29 + 1.08\ t$	$S_{(a0)} = 1.02$ $S_{(a1)} = 0.11$	$t_0 = 17.98$ $t_1 = 9.64$	0.000000 0.000000	0.933	6.95
Hungary	$\hat{y}_t = 3.79 + 3.89\ t -$ $-0.43t^2 + 0.01t^3$	$S_{(a0)} = 1.17$ $S_{(a1)} = 0.61$ $S_{(a2)} = 0.09$ $S_{(a3)} = 0.004$	$t_0 = 3.25$ $t_1 = 6.37$ $t_2 = 4.91$ $t_3 = 3.96$	0.007748 0.000053 0.000468 0.002233	0.880	6.53
Latvia	$\hat{y}_t = 29.29 + 0.90\ t$	$S_{(a0)} = 0.73$ $S_{(a1)} = 0.08$	$t_0 = 40.18$ $t_1 = 11.27$	0.000000 0.000000	0.907	3.67

Country	Trend function equation	Standard Error	t-Stat	p-Value	R^2	We (%)
Lithuania	$\hat{y}_t = 16.81 + 0.77\ t$	$S_{(a0)} = 0.55$ $S_{(a1)} = 0.06$	$t_0 = 30.62$ $t_1 = 12.67$	0.000000 0.000000	0.925	4.41
Malta	$\hat{y}_t = -2.00 + 0.85\ t$	$S_{(a0)} = 0.38$ $S_{(a1)} = 0.04$	$t_0 = 5.29$ $t_1 = 20.49$	0.000146 0.000000	0.970	14.44
Poland	$\hat{y}_t = 6.66 + 0.61\ t$	$S_{(a0)} = 0.50$ $S_{(a1)} = 0.05$	$t_0 = 13.35$ $t_1 = 11.14$	0.000000 0.000000	0.905	7.95
Romania	$\hat{y}_t = 17.66 + 0.58\ t - 0.06\ t^2$	$S_{(a0)} = 0.58$ $S_{(a1)} = 0.17$ $S_{(a2)} = 0.01$	$t_0 = 30.60$ $t_1 = 8.05$ $t_2 = 6.25$	0.000000 0.000004 0.000042	0.902	2.80
Slovakia	$\hat{y}_t = 6.53 + 0.65\ t$	$S_{(a0)} = 0.71$ $S_{(a1)} = 0.08$	$t_0 = 9.18$ $t_1 = 8.36$	0.000000 0.000000	0.843	11.13
Slovenia	$\hat{y}_t = 19.44 + 0.30\ t$	$S_{(a0)} = 0.58$ $S_{(a1)} = 0.06$	$t_0 = 33.36$ $t_1 = 4.75$	0.000000 0.000376	0.635	4.90
UE–27	$\hat{y}_t = 11.44 + 0.69\ t$	$S_{(a0)} = 0.27$ $S_{(a1)} = 0.03$	$t_0 = 43.03$ $t_1 = 23.54$	0.000000 0.000000	0.977	2.89

Source: own calculations using Excel and Statistica.

The data in Table 3 show that for most of the countries studied and for the EU–27, a linear function was the appropriate analytical form of modelling the development trend of the share of renewable energy in gross final energy consumption over the period 2007–2021. It correctly described the course of the phenomenon, as indicated by the values of the verification measures, i.e. the standard error, t-statistic, p-value, coefficient of determination (R^2) and coefficient of random variation (*We*). Only for two countries, i.e. Romania and Hungary, was it incorrect. Thus, for Romania, a second-degree polynomial trend function was used, while for Hungary, a third-degree polynomial trend function was used, which met the verification criteria. Subsequently, for all trend models, the values of the structural parameters of the estimated trend models were statistically significantly different from zero, the coefficient of determination was close to one, and the coefficient of random variation was within the recommended limits (less than 10–15%).

The correctly verified linear and non-linear trend functions of the share of renewable energy in gross final energy consumption provided the basis for forecasting its values for 2022–2024 for the EU–13 and the EU–27. The point forecast values, together with the forecast errors, are shown in Table 4.

Table 4. Point forecasts and forecast errors for the share of renewable energy in gross final energy consumption, 2022–2024

Country	2022			2023			2024		
	y_T^*	S_{pT}	V_T	y_T^*	S_{pT}	V_T	y_T^*	S_{pT}	V_T
Bulgaria	23.17	2.27	9.81	23.98	2.32	9.70	24.79	2.38	9.61
Croatia	31.64	1.25	3.94	32.22	1.28	3.96	32.81	1.31	3.98
Cyprus	17.15	1.39	8.11	18.08	1.42	7.87	19.01	1.46	7.66
Czechia	18.74	0.94	5.04	19.41	0.97	4.98	20.07	0.99	4.93
Estonia	35.54	2.13	5.99	36.31	2.08	5.95	37.69	2.23	5.92
Hungary	14.70	1.45	9.85	16.09	2.01	13.70	18.07	2.82	19.17
Latvia	43.75	1.53	3.49	44.65	1.56	3.50	45.56	1.60	3.51
Lithuania	29.05	1.15	3.96	29.82	1.18	3.95	30.58	1.21	3.94
Malta	11.65	0.79	6.81	12.50	0.81	6.49	13.36	0.83	6.22
Poland	16.44	1.05	6.36	17.05	1.07	6.27	17.66	1.10	6.20
Romania	22.91	0.87	3.80	22.16	0.98	4.42	21.29	1.13	5.31
Slovakia	17.01	1.49	8.77	17.66	1.53	8.64	18.32	1.56	8.53
Slovenia	24.31	1.22	5.02	24.62	1.25	5.07	24.92	1.28	5.13
UE–27	22.45	0.56	2.48	23.14	0.57	2.46	23.83	0.58	2.45

Source: own calculations.

The data in Table 4 show that increases in the share of renewable energy in gross final energy consumption in subsequent years can be predicted for Bulgaria, Czechia, Croatia, Latvia, Lithuania, Hungary, and Poland, we well as the EU–27. Several countries are projected to have a lower value of the indicator in 2022 compared to the previous year (Estonia, Cyprus, Malta, Romania, Slovenia, Slovakia). In the following years, the share of renewable energy in gross final energy consumption is expected to increase again in these countries. Only for Romania is a slight decline projected.

Measures of forecast quality include absolute and relative ex-ante forecast errors (S_{pT} and V_T). For most countries, the relative error of the forecasts did not exceed 10%, indicating high precision. However, caution is advised for the forecast of the share of renewable energy in gross final energy consumption for Hungary in 2023 and 2024, where the forecast error limit was exceeded.

Interesting conclusions can be made when comparing the achieved share of renewable energy in gross final energy consumption in 2020 (Table 1) with and the projections for 2022–2024 (Table 4), alongside the national RES targets to be achieved in 2020 and 2030 (Table 5) for each of the 13 countries. Under current directives, each EU country is mandated to transition away from fossil fuels towards energy generation from RES. Each country is tasked with meeting specific RES energy production targets, depending on regional capacity and prior RES development.

Table 5. National commitments as to the RES share in gross final consumption of energy (%)

Country	National target/contribution for renewable energy: Share of energy from renewable sources in gross final consumption of energy (%)	
	2020	2030
Bulgaria	21.4	27.09
Croatia	20.0	36.4
Cyprus	13.0	22.9
Czechia	13.0	22.0
Estonia	25.0	42.0
Hungary	13.0	21.0
Latvia	40.0	50.0
Lithuania	23.0	45.0
Malta	10.0	11.5
Poland	15.0	21.0–23.0
Romania	24.0	30.7
Slovakia	14.0	19.2
Slovenia	25.0	27.0
UE–27	20.0	32.0

Source: own research based on European Commission 2020.

Based on the data in Tables 1, 4 and 5, it can be concluded that all the countries studied and the EU–27 achieved the 2020 target share of renewable energy in gross final energy consumption. However, the 13 countries studied and the EU–27 also set their own national targets, ranging from 10% in Malta to as high as 40% in Latvia. A major challenge for the EU as a whole, as well as the EU–13, will be to meet the national targets adopted for 2030. The increasing forecast values for the share of renewable energy in gross final energy consumption for 2022–2024 for most of the countries provide grounds for optimism, although there are concerns about Romania and Slovenia meeting the 2030 RES targets.

Conclusions

The management of renewable energy sources is now one of the most important branches of a country's economy, determining its socio-economic development. The volume and structure of production and energy consumption is an important element of the economic strategy pursued. It indicates the degree of modernity of technological, production and consumption solutions adopted in terms of the rationality of energy consumption and the pro-ecological orientation of a country's economic development (Gorczyca 2011).

The development of RES in many regions of the world contributes to their economic development while also improving environmental conditions. However, there are also some adverse effects, including the conversion of agricultural and forest land for energy crop production and environmental impacts through noise and landscape changes in the case of wind farms (Kruk 2012). Nevertheless, RES development is a kind of bridge linking economic, environmental and energy issues (Załuska, Piekutin, and Magrel 2018).

The article evaluated the 13 countries admitted to the EU in 2004 and later, i.e. Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia in terms of the level of renewable energy use. The indicator of the share of renewable energy in gross final energy consumption for the period 2007–2021 was assessed.

The results of the research, as well as those of other authors (e.g., Papież, Śmiech, and Frodyma 2018; Gaigalis and Katinas 2020; Koltsaklis et al. 2020; Daroń and Wilk 2021; Mišík 2022; Stec and Grzebyk 2022) confirm that the EU–13 countries attach great importance to obtaining and using energy from renewable sources. Over the 15-year research period, the use of renewable energy showed an increasing trend in most of the countries. In 2021, the leaders were Latvia (42.11%), Estonia (38.01%) and Croatia (31.33%). However, a lot of work still needs to be done by Malta, Hungary and Poland. In all of the countries, the change in the indicator of the share of renewable energy in gross final energy consumption between 2007 and 2021 was positive.

To assess whether the upward trend in the indicator will continue, we forecast it for 2022–2024 using linear and non-linear trend models. The forecasting method was an effective tool for building a forecast for the indicator, as indicated by the verification measures used. For most of the countries, the forecasts were highly and sufficiently precise, meaning the countries had a chance of meeting the RES targets set out in the EU directives. A comparison of the set forecasts of the indicator of the share of renewable energy in gross final energy consumption for 2022–2024 with the targets set by individual countries for 2020 shows that they have already been met, and the targets for 2030 also appear realistic.

The research is of great practical relevance, providing an overview of the RES situation in selected EU countries and the prospects for future years. It is becoming crucial to monitor development in this area and to set directions for the development of renewable energy sources. The level of development should be assessed as part of a long-term plan for the EU on how to increase the competitiveness of individual countries and the EU as a whole on the international stage. Using our analyses and calculations, it is possible to illustrate in detail the state of progress to date, as well as the prospects for further development.

The results of the research can also be useful, enabling the authorities or other decision-makers in these countries to identify which areas need to be improved to meet the targets set for the increasing use of RES. Countries that fall short of the targets could, for example, apply for assistance funds under EU cohesion policy or other programmes supporting RES. They could also benefit from the experiences of countries that are RES leaders.

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Poziom wykorzystania energii odnawialnej w wybranych krajach Unii Europejskiej – statystyczna ocena zmian i perspektyw rozwoju

Poszukiwanie i wykorzystywanie ekologicznych źródeł energii to ważne kierunki działań Unii Europejskiej. W pracy dokonano porównania 13 wybranych krajów, przyjętych do UE w 2004 roku i później, w zakresie poziomu wykorzystania energii odnawialnej. Podstawowym wskaźnikiem oceniającym poziom wykorzystania OZE w wybranych krajach był udział energii odnawialnej w końcowym zużyciu energii brutto w latach 2007–2021. Dane statystyczne pobrano z bazy Eurostatu. Wyniki przeprowadzonych badań potwierdzają, że w latach 2007–2021 w większości badanych krajów UE nastąpiły pozytywne zmiany w zakresie wykorzystania energii odnawialnej. We wszystkich badanych krajach tempo zmian wskaźnika udziału energii odnawialnej w końcowym zużyciu energii brutto w latach 2007–2021 było dodatnie. Perspektywy rozwoju energii odnawialnej w badanej grupie krajów oceniono poprzez budowę prognoz wskaźnika udziału energii odnawialnej w końcowym zużyciu energii brutto na lata 2022–2024. Dla większości badanych krajów prognozy okazały się wysoce i dostatecznie precyzyjne, co daje szansę realizacji założonych celów OZE zawartych w dyrektywach unijnych.

Słowa kluczowe: energia odnawialna, Unia Europejska, metody prognozowania, perspektywy rozwoju

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Lost in Transition? Market Failure in the Implementation of the Circular Economy. A Comparative Analysis of the Netherlands and Poland

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Abstract

It is necessary for economies to transition to a circular economy (CE). What particularly inhibits the implementation of the CE in linear economies is market failures, whose theoretical principles are embedded in modern welfare economics and neoclassical economics. Market failures shape the functioning of different areas of the markets, including the allocation of and access to resources, competition, and cooperation, among others. Due to their presence in the market, opportunities for industrial symbiosis based on intersectoral cooperation and the creation of resource-efficient production systems are limited. It is crucial because the functioning of local actors within an industrial symbiosis significantly favours the promotion and development of a CE. The aim of the paper is to identify market failures that limit the implementation of CEs in traditional linear economies.

The article is based on focus group interviews (FGI) conducted with four groups of stakeholders in the Netherlands and Poland: academia, society, business and the government. The main findings show that one of the greatest barriers in Poland is stakeholders' low awareness of the CE, which influences their possibilities of cooperating and networking. Existing

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laws additionally limit opportunities to develop the CE. In contrast, in the Netherlands, where awareness is deeply embedded in the culture, education system and upbringing, the level of market failure is lower.

Keywords: circular economy, linear economy, transition to the CE, market failures

JEL: O18, Q56, R11

Introduction

The principles of the circular economy (CE) are challenging to implement. It is a complex and long-lasting process, but nowadays, it seems to be a necessity (Wysokińska 2016, p. 71; Kirchherr, Reike, and Hekkert 2017, pp. 228–230). Transitioning to the CE has been described as "a fundamental change in the structure, culture and practices of a societal (sub)system that is the result of a co-evolution of economic, technological, institutional, cultural and ecological developments at different scale levels" (Grin, Rotmans, and Schot 2010, p. 109; Bosman and Rotmans 2016, p. 3; van Langen et al. 2021, p. 2; Wysokińska 2020, p. 159). Although many steps have already been taken for the transition to the CE, we are still a long way from the full implementation of CE principles (Haas et al. 2015, p. 775; Donner and de Vries 2020, p. 1932; Ghisellini and Ulgiati 2020, pp. 144–145; Towa, Zeller, and Achten 2021, pp. 844–845). The transition towards the CE is inhibited by many barriers, the most common of which are technological, economic, institutional and social (De Jesus and Mendonça 2018, pp. 75–89; Kinnunen and Kaksonen 2019, pp. 153–154).

The transition is especially challenging for countries and regions with linear economies. What can limit the implementation of the CE in these territories is market failures. The theoretical principles of market failures can be found in modern welfare economics and neoclassical economics. Market failures are usually defined as the non-efficient and non-Pareto-optimal allocation of resources (Ledyard 1989, p. 185; Stiglitz 2004, pp. 90–105). However, Cunningham (2011, p. 13) states that market failure does not mean that a market is not working at all, but that it is not working efficiently because it is not delivering desirable products and services. In the literature, many types of market failures are distinguished (Cowen and Crampton 2002; Andrew 2008, pp. 394–396; Jackson and Jabbie 2019, pp. 3–8). In this paper, we adapt the most common types: public goods, externalities, imperfect competition, incompleteness of the market, and information asymmetry.

The market failures described in neoclassical economics can also be identified when implementing the CE (van Ewijk 2018, pp. 12–14; Ghisellini, Passaro, and Ulgiati 2021, pp. 149–150, 156–157; Barteková and Börkey 2022, pp. 18–20). In principle, while the types of market failures remain the same, regardless of economic development and the principles on which this development is based, there is differentiation within particular market failures. Figure 1 presents our approach to market failures in individual areas of the CE.

Market failures are natural and inevitable within a market economy. What is important, however, is their scale and the intensity with which they affect the market, limiting its efficient functioning and the development of the entities operating in it. That is why this paper aims to identify market failures that limit the implementation of CEs in traditional economies. To achieve this aim, we conducted Focus Group Interviews (FGIs). The study was conducted with four stakeholder groups: academia, society, business, and the government, who we consider to be the main actors in the market.

The remainder of this paper is organised as follows. Section 2 outlines the theoretical backgrounds, including the definitions of market failures and CE barriers. It shows the connection between classical market failures distinguished in the neo-classical economy and typical barriers observed when implementing the CE. Section 3 presents the materials and methods. We also indicate the main principles of our research and the reasons for conducting it. Section 4 concentrates on the results. We show the differences not only between the groups of respondents but also between the researched regions. Section 5 includes a discussion and conclusion where we answer the research questions and sum up the results of our investigation.

Theoretical background

The concept of market failure is rooted in modern welfare economics. As Ledyard indicated, to understand market failure, one should understand market success, which is explained by Pareto optimality. It could be defined as the ability of idealised competitive markets to achieve an equilibrium allocation of resources (Ledyard 1989, p. 185). Market success is described by the First Fundamental Theorem of welfare economics (Arrow 1951, p. 507):

- there are enough markets,
- all consumers and producers behave competitively,
- an equilibrium exists.

In such a case, the allocation of resources in equilibrium is Pareto optimal (Bator 1958, pp. 353–355; Randall 1983, pp. 131–132; Ledyard 1989, pp. 185–189; Moreau 2004, pp. 849–850; Phelan and Rustichini 2018, pp. 979–981; Bimpizas-Pinis et al. 2021, p. 1). So, market failure arises when allocation in markets is neither efficient nor Pareto-optimal. Market failure was defined in this way by, among others, Bator (1958, pp. 351–379), Klaassen and Opschoor (1991, pp. 93–95), Winston

(2006, p. 2), and Conrad (2020, pp. 176–177). A similar definition was presented by Samuelson and Nordhaus (1992, p. 741), who also referred to the inefficient allocation of resources but in the context of an imperfection in the price system. Pearce (1986, p. 13) described it as "The inability of a system of private markets to provide certain goods either at all or at the most desirable or 'optimal' level". Lines, Marcouse, and Martin (2006, p. 167) indicated that market failure is represented by the forms of growth of monopolistic firms and other non-competitive organisations, and it happens when factors of production stand idle. As Cunningham (2011, p. 13) stated, the term "market failure" does not mean that a market is not working at all, but that it is not working efficiently because it is not producing desirable goods. The concept of market failure is often treated as a general justification for government intervention (e.g., Zerbe and McCurdy 1999, pp. 559–560; Bleda and Del Río 2013, pp. 1039–1040, Alvarez, Barney, and Newman 2015, p. 25).

The most common categories of market failures are public goods, externalities, imperfect competition, incompleteness of the market, and asymmetrical information (Randal 1983, p. 137; Moreau 2004, pp. 849–850; Stiglitz 2004, pp. 90–105; Jackson and Jabbie 2019; pp. 3–6). Other authors also add incomplete property rights to this list (e.g., Perman et al. 2003, p. 10; Acheson 2006, p. 121). Redmond (2018, pp. 417–418) presented market failure from a different point of view. He proposed a systems approach in contrast to earlier, classic research, where market failure was analysed with a transactional approach. It let him distinguish one more category of market failure – transaction costs. This category appears in the New Institutional Economy (NIE), which looks at the organisation of exchange from a market or hierarchical perspective. In NIE markets, when market conditions threaten to increase transaction costs, hierarchies (i.e., firms) are created to minimise these costs. This can be perceived as a reaction to market conditions to maximise profits, although from a neoclassical perspective, it constitutes a market failure (Chang 2002, pp. 544–546).

A different approach was presented in the evolutionary economy, where the market is seen as dynamic, chaotic, and constantly changing rather than tending to a state of equilibrium (Nelson and Winter 2002, pp. 24–25; Nelson 2008, pp. 1–12, 20; Schmidt 2018, pp. 792–797). From this point of view, market failures that are typical of a neoclassic economy are not failures. As Bleda and del Río (2013, p. 1049) indicated, common problems in the evolutionary economy, such as uncertainty, agents' limited knowledge, and difficulties in coordinating knowledge and its carriers, are sources of coordinator failure. In evolutionary markets, failures are explained by undeveloped or ineffective mechanisms and constituent markets.

In this paper, we look at market failure from the CE perspective (cf. van Ewijk 2018, pp. 11–14; Compagnoni and Stadler 2021, pp. 18–19; Cong and Thomsen 2021, p. 3;

Ghisellini, Passaro, and Ulgiati 2021, pp. 151–158; Barteková and Börkey 2022, pp. 8–11; Fullerton and He 2022, pp. 3–7). A CE is more likely to identify the barriers that derail or slow the transition towards a CE (Kirchherr, Reike, and Hekkert 2017, pp. 228–230; Neves and Marques 2022, pp. 2–4). The issue of barriers to implementing CE has been raised by many authors (see Tab. 1).

Table 1. Categories of barriers to implementing CE occurred in the literature

Author(s)	Category of barriers to implementing the CE								
	technological	market/economic	political/ institutional	legal/regulatory	social/cultural	organisational	supply chain	infrastructural	lack of information/ knowledge
Preston 2012	+	+	+		+	+	+	+	
Vanner et al. 2014	+	+	+		+		+	+	+
Rizos et al. 2015	+	+	+	+	+		+		+
Ritzén and Sandström 2017	+	+			+	+		+	
Agyemang et al. 2019	+	+	+		+		+	+	
De Jesus and Mendonça 2018	+	+	+		+				
Galvão et al. 2018	+	+	+	+					
Geng and Doberstein 2008	+		+		+				
Kirchherr et al. 2018	+	+		+	+				
Mahpour 2018	+		+	+	+		+		
Mangla et al. 2018	+	+		+	+	+	+		+
Masi et al. 2018	+	+	+		+			+	
Ranta et al. 2018				+	+				
Tura et al. 2019	+	+			+	+	+		
Kinnunen and Kaksonen 2019	+	+		+			+		+
Grafström and Aasma 2021	+	+	+		+				

Source: own compilation.

The listed categories of barriers correspond to the problems that emerge during the transition to the CE. The most common categories are technological, economic, institutional, and social. De Jesus and Mendonça (2018, p. 77) introduced an additional classification, dividing them into hard and soft barriers. Hard barriers are related to techno-economic issues, and soft ones are related to regulatory and social issues.

Although the neoclassical economy and circular economy represent different approaches to the market and its imperfections, there is a link between them. The barriers that occurred in the CE can be identified with classic market failures (see Figure 1). For example, with social barriers, community members' lack of (or limited) willingness to cooperate reduces or even prevents the creation of an effective CE value chain. This case can be attributed to the imperfect competition type of market failure. Society's limited awareness of public goods associated with the CE, i.e., the benefits of operating and developing the territory based on CE principles, falls into the category of market failure. Society's lack of awareness of the CE that results from gaps in their knowledge leads to market failures in the area of market incompleteness. An ineffective and inefficient system of information for citizens about the CE also does not favour the development of awareness, as manifested by market failures in information asymmetry. These barriers also promote the free rider effect, which is a market failure in the area of externalities. Thus, there is a clear connection between market failures and CE barriers. This was the starting point for our research. Individual categories of threats in classical market failures are also assigned to individual barriers in the CE (see Figure 1).

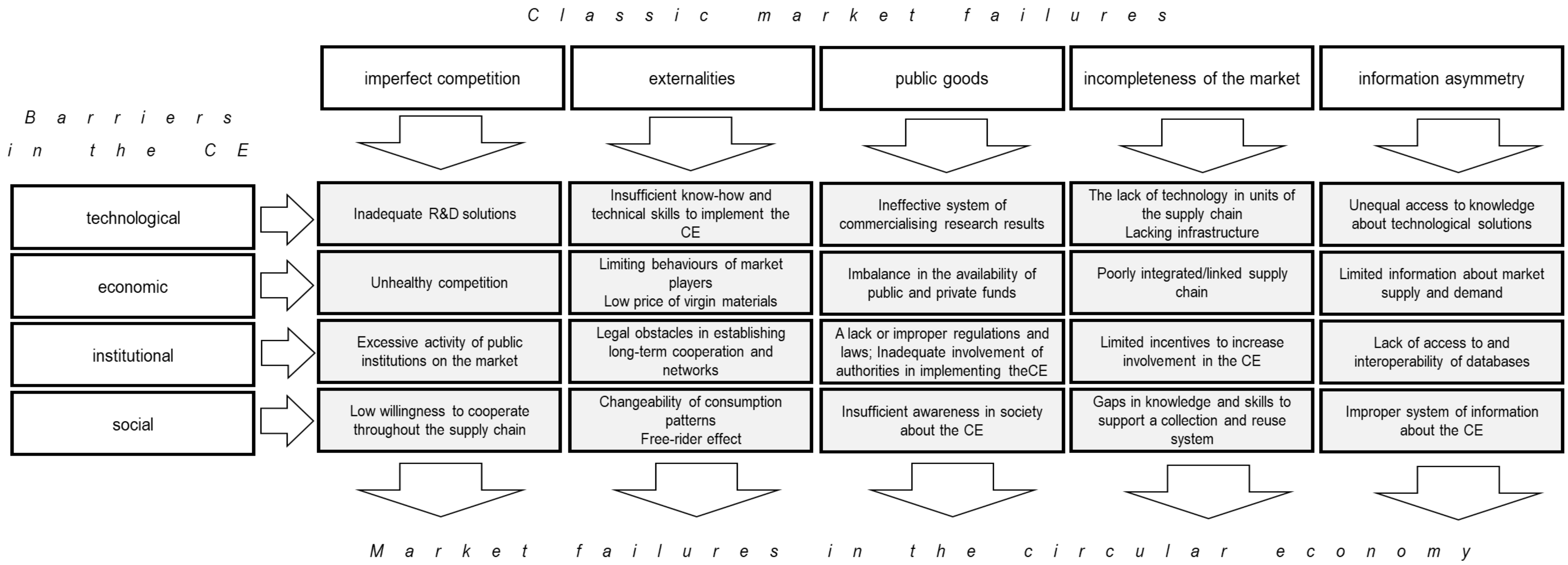


Figure 1. Categories and interpretation of market failures in the circular economy

Sources: own compilation based on Galvão et al. 2018, Grafström and Aasma 2021.

Materials and methods

The dynamics of change toward the CE vary depending on the maturity of a country's economy and communities. These differences are most noticeable between the countries of Western Europe and Central and Eastern Europe. Therefore, two purposefully selected regions were included in the study. The first, Friesland (the Netherlands), can be considered a reference point regarding the degree of advancement of the CE. It is becoming one of the most circular regions in Europe and should be treated as a template for other regions (Interreg Europe 2020). The second case study is the Lodz Region.

Friesland has approximately 650,000 inhabitants and covers an area of 5,748.77 km^2, divided into 18 municipalities. It is a regional authority and the governing body of one of the twelve provinces in the Netherlands. The capital and largest city is Leeuwarden. Economically, it is well known for its strong water and agriculture clusters and technology. In recent years, the main economic focus has been on transitioning towards a CE. Friesland strives to be the most circular EU region in 2025. Thus, the regional authority cooperates strongly in public-private partnerships with partners across the quarduple helix. On a European level, the region is a member of Association of Cities and Regions for Sustainable Resource Management (ACR+) (Circulair Friesland n.d.; Frontship n.d.; International Welcome Center North n.d.).

The Lodz Region is a regional self-governing administrative unit located in central Poland. It is inhabited by about 2.4 million people, and the seat of the local authorities is the city of Lodz. It is divided into 177 municipalities with an area of 18,218.95 km^2. Due to its central location in Poland and Europe, it has an excellent transport connection, and as a result, it has become a significant national and international logistics centre. For many years, the region has been striving to build its potential and become a bioeconomy leader in Poland and Central and Eastern Europe (e.g., innovative agriculture and food processing; medicine, pharmaceuticals, and cosmetics; green energy; the textile industry; biotechnology). The region has also taken significant steps toward actively participating in the EU's Circular Economy and wastes policy debates (Frontship n.d.; Województwo łódzkie n.d.). As the European Observation Network for Territorial Development and Cohesion (ESPON) report indicates, the implementation of CE solutions in the Lodz Region is at a fairly good level, as evidenced by indicators such as the national extraction of natural resources and waste generation (excluding major mineral waste) as a share of national material consumption. However, an indicator that should be improved is the turnover generated by CE companies (van Herwijnen et al. 2022). Challenges to CE implementation arise primarily at the local level and relate to closing circular value chains. It is also a challenge to monitor the implementation of CE measures at the local and regional levels, as well as the achievement of sustainable development goals.

This research aims to identify market failures that limit the implementation of the CE and to assess their level in the Lodz Region. The following research questions were posed:

Q1. Which market failures have the most significant negative impact on implementing the CE?

Q2. Are there differences in the level of market failures among the different stakeholder groups?

Q3. What are the reasons for market failures that limit the implementation of the CE?

Q4. What changes should be introduced to reduce market failures that limit the possibility of implementing the CE?

The research was conducted among four groups (business, government, academia, and society) that we consider to be the main actors in the market. Our choice is based on the quadruple helix model (Carayannis and Campbell 2009). For each group, we created matrixes to show the market failures from Figure 1 in detail.

To achieve this aim, we conducted two-stage research:

1. An online survey was conducted with people from each of the four groups (in total, there were eight surveys: four in Poland and four in the Netherlands). A separate survey was prepared for each group (4 in the English-language version and 4 in the Polish-language version). The selection of respondents was purposeful – they were specialists in the CE (academia, government and businesses) and local civic leaders (society), who then took part in an FGI, which was the second stage of our research. The respondents rated market failures on a five-point scale.
2. The results of the survey were the basis for the scenario and discussion during the FGI. An FGI was conducted with the same respondents (in total, there were 8 FGIs: four in Poland and four in the Netherlands).

The research involved:

- 20 government and local government members (10 in Poland and 10 in the Netherlands),
- 18 academics (10 in Poland and 8 in the Netherlands),
- 15 businesspeople (8 in Poland and 7 in the Netherlands),
- 18 members of society (10 in Poland and 8 in the Netherlands).

The research was conducted from April to September 2022. Gathering data let us compare the level of market failure in a region just beginning to implement the CE (i.e., the Lodz Region) with the template region (i.e., Friesland).

Results

The collected research material is presented in the form of matrices. The layout of the matrices was determined by the principles of CE market failures in Figure 1. The results of the survey formed the basis of the evaluations in the matrices for individual CE market actors, and they were verified during the FGIs. Thus, the occurrence of market failures in both regions and the disproportions between them were determined.

Market failure in the CE from the business perspective

The surveys conducted among companies indicated that the most noticeable market failure in the Lodz Region was public goods (with a rating of 5.0, Figure 2). The least noticeable problem was information asymmetry (3.3, Figure 2), which also saw the smallest gap between the two regions.

Business owners from the Lodz Region stated that the biggest problem was the existing legislation and how it was interpreted and applied by public institutions (PG). One respondent spoke of "beating their head against a wall due to legislative absurdities". According to the respondents, public entities are favoured during tenders, making it difficult for private entities to compete with them. Another problem was regulations that obstruct the treatment of waste as a secondary raw material (PG). Additionally, the highly formalised procedures mean that a lot of time must be spent dealing with official matters.

It was often mentioned that there is "collusion among companies" when they participate in public procurement tenders (IC). As a result, a given market may be serviced by only one or two enterprises, which creates barriers to other entities from entering the sector. There is a lobby of current business owners that blocks other entities from entering the market. The other barrier to entering the market is the high costs of technology, which are demanded in, e.g., the secondary raw materials sector (IM).

The interviewees indicated that the cost-effectiveness of using secondary raw materials depends on the type. Firstly, virgin materials with simple ingredients are cheaper than secondary raw materials. Secondly, the availability of secondary raw materials with more complicated ingredients is limited (EX). The business owners noticed that nowadays, it is impossible to act without cooperation. Of course, such cooperation should be beneficial for partners and primarily involves the exchange of benefits, including information. One company owner said, "If there is business to be done, we cooperate." However, someone else said, "We cooperate, but do not share knowledge and experience." The business owners from the Lodz Region stated that incomplete and unreliable databases are not conducive to networking and cooperation (IA). It is difficult to establish needs and monitor what other companies that could enter cooperation are doing and what raw materials they have. Underreported information in databases contributes to further difficulties in planning the volume of waste, which does not always have much to do with reality. For example, waste processing installations may only be created as indicated in the plan, which may be insufficient.

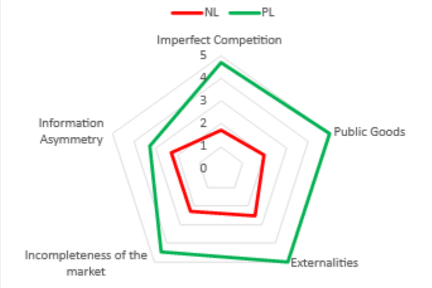
Market participant:	BUSINESS	
Characteristics of the FGI research target group:	Companies from Circular Systematic Solutions (CSSs): wood, plastic, water, food and other companies involved in the CE (i.e., waste collection and recycling)	
TYPE OF MARKET FAILURES	**MAJOR INTERPRETATION OF MARKET FAILURE IN THE CE**	**SYNTHETIC ASSESSMENT OF MARKET FAILURE OCCURRENCE**
Imperfect Competition [IC]	– number of entities on the market – type of relationship between market players (openness to cooperate) – the activity of public institutions in the market	PL 4.3 NL 1.7
Public Goods [PG]	– evaluation of the regulations related to the activities of secondary raw materials market operators	PL 5.0 NL 2.0
Externalities [EX]	– consumption patterns – cost-effectiveness of using secondary raw materials	PL 4.5 NL 2.5
The incompleteness of the market [IM]	– number of secondary raw material suppliers on the market – availability of secondary raw materials on the market – the complexity of the value chain – entry barriers to the market	PL 4.3 NL 2.3
Information Asymmetry [IA]	– utilities of data on the secondary raw materials market – access to information on new techniques and technologies – the willingness of / secondary raw material market actors to share knowledge and information	PL 3.3 NL 2.3

Figure 2. Market failures matrix – companies

Source: own compilation.

The situation seems better for companies in Friesland. First of all, there are accelerators to help small and medium-sized enterprises that operate within the CE framework stay in business. Although operating in the CE market "is not cheaper, it is easier to get public funding." The business owners noticed that networking (formal and informal), especially in the region or even on a smaller scale, is important in the way their entities function and develop. Each company belongs to several associations and transparent platforms, which helps them to exchange information and contacts (IC). There is a high level of knowledge exchange and knowledge sharing among competitors (IA). In the respondents' opinion, financial or non-financial profit does not have to be visible immediately; such an attitude brings long-term benefits. The business owners pointed to a noticeable barrier to entering the secondary raw materials market, i.e., incomplete information on raw materials (e.g., quantity, availability, or quality at a specific time).

Market failure in the CE from the academic perspective

Academics in the Lodz Region identified externalities and incompleteness of the market as the most common market failures (3.5 and 3.3, respectively, Figure 3). Imperfect competition was considered the least problematic (2.3, Figure 3). Importantly, in this research group, the results in both regions were the least divergent.

The respondents from the Lodz Region indicated that CE themes are very popular and topical, and that undertaking research in this area guarantees cooperation between R&D institutions and enterprises (IC). They also stated that it is easy to obtain funding (grants) for research in the field of CE or to publish an article on this topic. According to the respondents, CE research requires interdisciplinarity, which necessitates cooperation, both between researchers from different academic fields but also with business owners and members of local governments. While cooperation with private entities was rated quite high, cooperation with local governments was rated low (it often finished at discussions and plans). Waiting for offers of cooperation was considered a weakness of the academic units, which rarely initiate R&D cooperation on their own (EX). Other problems faced by academic institutions in the Lodz Region are the lack of interdisciplinarity in CE research and the fact that researchers specialise in narrow research fields (IC). Knowledge transfer was also considered an important element in CE research, as exchanging knowledge, data, and information increases the chances of finding and implementing new measures. Unfortunately, its effectiveness was not rated highly (EX).

The Friesland researchers also mentioned the interdisciplinarity of CE research. They also considered themselves to be interdisciplinary and saw their strength in this, as this feature makes them an attractive partner for businesses (IC). In addition, their attractiveness for business is strengthened by their extensive networks of formal and informal contacts. One effect of these contacts is the temporary transfer of academics into the business sector. According to the researchers, the essence of the CE is to identify CE challenges, not only technological ones, but also those of a social, managerial or economic nature (again, interdisciplinarity is important). Knowledge transfer, which creates cooperation networks and allows the exchange of data and information, was also considered important (EX). In contrast to the Lodz Region, cooperation with the local government was assessed positively. In Friesland, local and regional governments are much more active;

they play the role of facilitator and indicate and encourage involvement in CE projects (IM). Importantly, the academics try to meet the needs of the local government and local business owners in both research and teaching activities (IA).

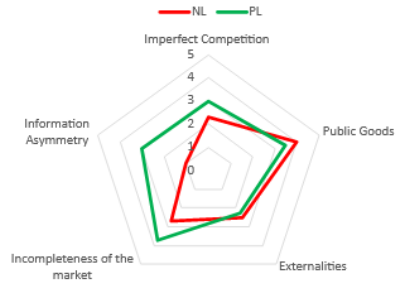
Market participant:	ACADEMIA	
Characteristics of the FGI research target group:	Academics involved in researching the CE in terms of the CSS scope Administrative officer of R&D units in terms of the CSS scope	
TYPE OF MARKET FAILURES	**MAJOR INTERPRETATION OF MARKET FAILURE IN THE CE**	**SYNTHETIC ASSESSMENT OF MARKET FAILURE OCCURRENCE**
Imperfect Competition [IC]	– competitiveness assessment of CE research – participation in CE projects in the activities of the R&D units – attractiveness of R&D units for business	PL 2.3 NL 2.0
Public Goods [PG]	– public funds crowding out private finance – the scope for commercialising research from public funds	PL 3.0 NL 3.5
Externalities [EX]	– formal barriers to commercialisation – CE projects carried out in partnerships vs individual projects – synergy effects of partnership – effectiveness of knowledge and technology transfer – profitability of CE projects – staff transfer	PL 3.5 NL 2.0
The incompleteness of the market [IM]	– implementation possibilities of projects – the level of interest and absorption of the proposed solutions in the regional market – absorption of R&D projects related to the CE in the region	PL 3.3 NL 2.3
Information Asymmetry [IA]	– monitoring market needs – monitoring business partners	PL 3.0 NL 1.0

Figure 3. Market failures matrix – academia

Source: own compilation.

Market failure in the CE from the society perspective

A study among members of society showed that in the Lodz Region, the key market failures were incompleteness of the market and information asymmetry (both scored 4.0, Figure 4). Externalities were the least problematic (2.7). The smallest gap between the two regions was noticed in this area.

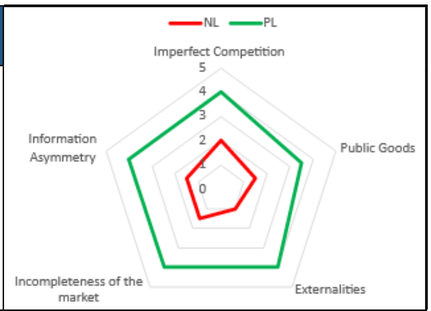
Market participant:	SOCIETY	
Characteristics of the FGI research target group:	– members of NGOs – members of the social enterprise – local social leaders	
TYPE OF MARKET FAILURES	**MAJOR INTERPRETATION OF MARKET FAILURE IN THE CE**	**SYNTHETIC ASSESSMENT OF MARKET FAILURE OCCURRENCE**
Imperfect Competition	– awareness of being a link in the value chain of industrial symbiosis – cooperation between residents in the CE	PL 3.5 NL 1.5
Public Goods	– the social responsibility of residents as producers of waste – evaluation of regulations on the collection and use of waste	PL 3.5 NL 1.5
Externalities	– benefits of participating in a recycling management system – willingness to buy goods made from secondary raw materials – free-rider effect – gaps in the system of motivation and control of waste management	PL 2.7 NL 1.7
The incompleteness of the market	– the incompleteness of municipal recycling collection infrastructure – gaps in the involvement of residents in waste management processes	PL 4.0 NL 1.5
Information Asymmetry	– completeness of information on the waste collection system – completeness of information on the waste reuse system	PL 4.0 NL 1.5

Figure 4. Market failures matrix – society

Source: own compilation.

Citizens in the Lodz Region are mostly aware that they are part of a supply chain and are often and eagerly involved in additional ecological initiatives (including Earth Day, Cleaning the World, and collecting bottle caps and paper). They evaluated themselves as aware consumers (IC). The major factors that influence their attitude are children and their future. On the other hand, the respondents stated that they do not have complete knowledge regarding the CE, e.g., how to segregate waste. They also indicated that the behaviour of neighbours who do not care about the environment can be demotivating. They expressed concern that anonymity in crowded places (especially in a block of flats) exempts some residents from being responsible and complying with the rules (EX). According to one respondent, "An attitude persists in a large part of society: Why make an effort if others don't do it anyway?" A lack of information about the benefits of participating in waste segregation and recycling, as well as incomplete information about it (e.g., collection dates and location), was also noted (IA).

Frisian society is very dutiful when it comes to waste management issues (PG). Awareness of the need to take care of the environment, which includes sorting waste, is something that the Dutch "suck from their mother's milk" (IC). Their awareness translates into openness and involvement in CE initiatives and activities proposed by public authorities or NGOs. Especially among the younger generations, it is popular to use second-hand products (e.g., clothes and furniture) bought in shops or online (EX). Older people, on the other hand, are more involved in socio-educational activities, in which they try to share their knowledge and experiences of pro-environmental attitudes. This is important because, according to the survey, "people think that using secondary raw materials results in a higher price for the products made from them". This has often been true, but it will certainly change in the long term.

Market failure in the CE from the government perspective

From the perspective of the region and local government, the research found that in the Lodz Region, key market failures were externalities (5.0, Figure 5). The least problematic areas were imperfect competition and incompleteness of the market (3.2 and 3.3, respectively). In these cases, the smallest gap between the two regions was noticed.

Members of the Friesland authorities see themselves as a booster for the functioning and development of the CE in the region (PG), encouraging business owners to be more circular. They are also a key link between the different actors in the CE market, creating a network and a platform for cooperation (IC). For example, the Circular Friesland Association and other dedicated information and education platforms were established to serve this purpose. In addition, the local government works to ensure that the green procurement system contributes as much as possible to the circular value chain (EX). The authorities identified more difficult and less precise regulations defining company waste as a problem (PG), although they also stated that high awareness in society can sometimes be a problem. As an example, they cited a decrease in the number of domestic tourists who chose not to stay in certain types of accommodation due to the lack of waste segregation. The regulations on the no of waste segregation in tourist accommodation are due to insufficient knowledge of the segregation rules among some tourists. An important element in creating a CE in the region is institutions that support the creation and development of circular businesses (IM). An example is BeStart, a startup accelerator that helps circular startups in the north of the Netherlands become successful.

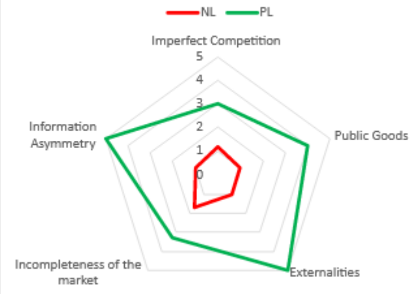
Market participant:	GOVERNMENT	
Characteristics of the FGI research target group:	– Members of the provincial and local government involved in planning, implementing and managing the CE – Members of an institution that supports and controls CE processes in the province	
TYPE OF MARKET FAILURES	MAJOR INTERPRETATION OF MARKET FAILURE IN THE CE	SYNTHETIC ASSESSMENT OF MARKET FAILURE OCCURRENCE
Imperfect Competition [IC]	– number of operators in the municipal and industrial waste market – competitiveness of public enterprises – type of relationship between market players (openness to cooperate) – public compliance with current waste management rules – society's openness to new CE solutions	PL 3.2 NL 1.2
Public Goods [PG]	– the authorities' role in the market – the authorities' flexibility in decision-making – evaluating laws and regulations on the market of secondary raw materials	PL 4.0 NL 1.3
Externalities [EX]	– the authorities support entering and existing market players – market players' behaviour as a market barrier – the impact of existing regulations on establishing long-term cooperation and networks	PL 5.0 NL 1.0
The incompleteness of the market [IM]	– number and type of market actors vs meeting their needs – adequacy of R&D solutions on the market (e.g., availability) – the possibility of greater citizen participation in the market	PL 3.3 NL 1.3
Information Asymmetry [IA]	– the willingness of secondary raw material market actors to share knowledge and information – database interoperability	PL 4.5 NL 1.0

Figure 5. Market failures matrix – government

Source: own compilation.

Members of the public authorities from the Lodz Region pointed to the problem of inadequate regulations governing the control of waste flows, which has resulted in the so-called

“Polish-utilisation”, i.e., abandoning waste in warehouses, illegally burning it or dumping it in mine pits (IC/PG). In addition, the respondents pointed to the poor quality, inaccessibility and lack of interoperability of databases (IA). For this reason, it is difficult for the public authorities to produce planning and strategic documents that meet real needs. An insufficient number of well-qualified staff in public institutions who deal with the CE is also a problem. According to the respondents, the creation of a CE system is not facilitated by the fact that there is a monopoly of waste management actors who are not open to sharing knowledge or information with others. The cooperation between public authorities and R&D entities is also noteworthy (IC/IA). The authorities lack funding to subsidise CE research, and they suggest that academia needs to be opened up to local governments and other public institutions (IM).

Discussion and conclusions

Based on the research, in the vast majority of cases, Friesland performed better than the Lodz Region, with the Dutch members of the public and local government evaluating the market failures close to the optimum (i.e., the ratings were close to 1).

Referring to research question 1, it can be concluded that the Lodz Region is only at the beginning of building a CE, so all types of market failures were identified, and they occur at a similar level. The most significant market failures were externalities and public goods (see Figure 6). What this means is that inadequate laws (PG) and immature cooperation (EX) are the region’s weaknesses. The legal weaknesses are due to their high variability and lack of precision, which allows for a great deal of arbitrary interpretation. Regarding cooperation, if it does occur, it tends to be traditional and forced rather than the result of a well-thought-out strategy based on the benefits for the market actors. As observed in Friesland, networking is crucial for the construction and effective functioning of a CE.

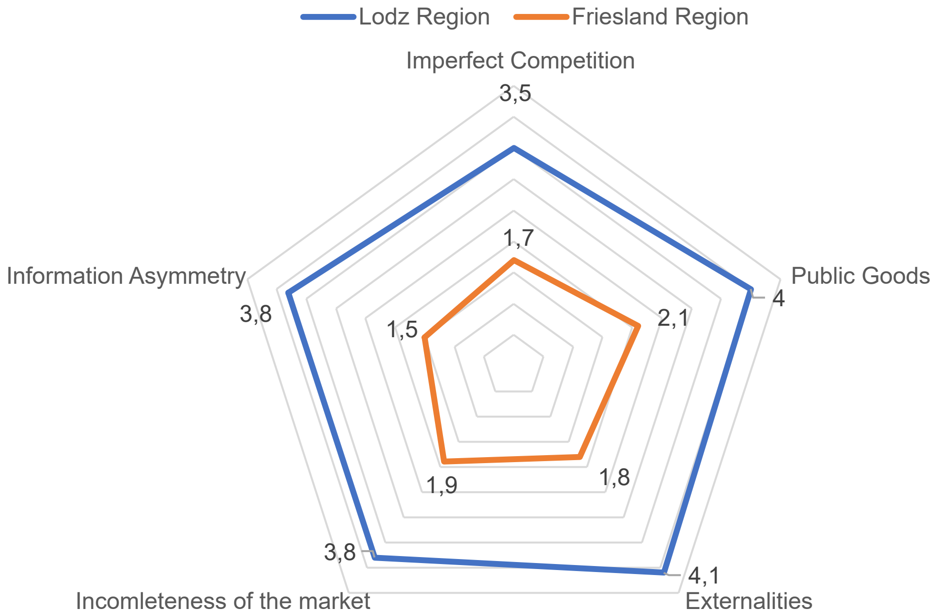


Figure 6. Level of CE market failures in the researched regions

Source: own compilation.

Regarding research question 2, there were clear differences in how the groups assessed market failures, although they are not very significant. The group of business owners gave the highest ratings, while the academics gave the lowest ratings (Tab. 2).

Table 2. Compilation of market failures by research group

Research group	NL	PL
Company	2.16	4.28
Academics	2.16	3.02
Society	1.54	3.54
Government	1.16	4.00
Regional average	1.76	3.71

Source: own compilation.

These differences are mainly due to the different roles assigned to each market actor and the resulting level of market activity. Business owners comprise the group that creates the foundations of the market, and they are the most active participants in it, which is why they see the most market failures. At the same time, they are most exposed to them every day from all other market actors, and they are the least protected from the effects of market failures.

On the other hand, the academics showed minor activity in the market, focusing primarily on their research and teaching activities. However, it does not necessarily mean that this activity is the least important. Additionally, academics face unfair competition at the regional level.

Concerning research question 3, in the Lodz Region, the high occurrence of market failures is primarily due to the stage that the economy is currently at, i.e., transitioning from a traditional economy to a circular one. The main market failures that limit the possibilities or slow down this process include the following:

- regulations that do not encourage and even discourage potential actors from implementing CE rules (PG);
- low awareness of potential actors in the CE market, especially members of the public/residents of the region (IC/PG). However, it should be remembered that changes in awareness take time and awareness-raising activities, and the effects are sometimes visible with a generational change;
- the lack of awareness and developed solutions for cooperating with other actors in the CE market results in a network of limited connections to ensure effective and globally beneficial cooperation (IC/EX).

In order to limit market failures and their effects on the CE market, multidimensional and consistent changes are necessary (research question 4). There should be a comprehensive process and not a set of disconnected, incidental activities. As part of this process, the following elements of the CE development support system should be prepared and implemented:

- an effective system of legal regulations and institutional solutions to encourage potential actors to take the right actions and punish them for breaking the rules (it will reduce the level in the scope of PG/EX market failure);
- a set of good practices linked to a system of cooperation within and between different categories of CE market actors (it will reduce the level in the scope of IC/IM market failure);
- a system for monitoring emerging market failures (it will reduce the level in the scope of IA market failure);
- an education system that continuously increases the awareness of all participants of the CE market (it will reduce the level in the scope of IC/EX market failure).

The main actor that should take charge of developing the above measures is the public authorities. It should be done at the local or regional level, as well as at the central level, since the legal regulations and the system of incentives are primarily the competence of the central level (it will reduce the level in the scope of PG market failure).

In Friesland, the low occurrence of market failures is a result of the awareness of all researched groups. Awareness of the need to move towards a CE is deeply rooted in the culture, education system and upbringing in the Netherlands. The awareness of society (understood as residents, business owners, academics and members of local and regional authorities or civil servants), which has built up over many years, led to the creation of high-quality social capital. Naturally, this social capital additionally enhances people's awareness, so it is a self-reinforcing process. The result of this capital and awareness is a mutual trust that fosters commitment to networking and building the CE. Networking is a key factor in Friesland's success in building a CE. If the Lodz Region is to increase its circularity, it could benefit from the experiences and solutions of the Friesland Region.

Many economists believe that it is not necessary to correct market failures because free markets correct themselves over time. However, there are many methods to reduce market failures, for example, laws and regulations, taxes, subsidies and trade restrictions. Amending market failures seems to be required in a CE. To achieve the United Nations' 2030 sustainable development goals, we must strive for the rapid implementation of the CE. It is, therefore, necessary to support its implementation by eliminating market failures. What makes the CE unique is that it is primarily based on awareness, networking, and the integrated cooperation of all market actors. Therefore, action is needed to make stakeholders change and start implementing a CE. Such actions might include education to boost awareness and incentives that trigger market actors' involvement in the CE. This involvement should not be limited to being a passive recipient. It should ultimately manifest itself in active participation, e.g., through prosumerism and/or being part of industrial symbiosis.

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Zagubieni w okresie przejściowym? Zawodności rynku we wdrażaniu gospodarki cyrkularnej. Analiza porównawcza Niderlandów i Polski

Obecnie transformacja gospodarek w kierunku obiegu zamkniętego i cyrkularności jest koniecznością. Tym, co szczególnie hamuje wdrażanie gospodarki cyrkularnej w gospodarkach liniowych, są zawodności rynku. Teoretyczne podstawy zawodności rynku są zakorzenione we współczesnej ekonomii dobrobytu i ekonomii neoklasycznej. Zawodności wpływają na funkcjonowanie różnych obszarów rynku, w tym alokację i dostęp do zasobów, konkurencję oraz współpracę między podmiotami. Zawodności rynku ograniczają również możliwość wdrożenia symbiozy przemysłowej opartej na międzysektorowej współpracy i tworzeniu efektywnych systemów produkcji. Jest to istotne, ponieważ funkcjonowanie lokalnych podmiotów w ramach symbiozy przemysłowej znacząco sprzyja promocji i wdrażaniu gospodarki cyrkularnej. Celem artykułu jest identyfikacja zawodności rynku ograniczających wdrożenie gospodarki cyrkularnej w tradycyjnych gospodarkach liniowych. Artykuł powstawał na podstawie zogniskowanych wywiadów grupowych (FGI) przeprowadzonych z reprezentantami czterech grup interesariuszy w Niderlandach i Polsce: środowiskiem akademickim, społeczeństwem, przedsiębiorcami oraz władzami. Przeprowadzone badania wykazały, że jedną z największych barier wdrażania gospodarki cyrkularnej w Polsce jest niska świadomość interesariuszy na jej temat. Wpływa to na ich możliwości współpracy i networkingu. Obowiązujące w Polsce przepisy prawne dodatkowo ograniczają możliwości rozwoju gospodarki cyrkularnej. Inaczej wygląda sytuacja w Niderlandach, gdzie – jak pokazały przeprowadzone badania – świadomość na temat gospodarki cyrkularnej jest głęboko zakorzeniona w kulturze, systemie edukacji i wychowaniu. Skutkuje to niższym poziomem występowania zawodności rynkowych.

Słowa kluczowe: gospodarka cyrkularna, gospodarka liniowa, tranzycja w kierunku gospodarki cyrkularnej, zawodności rynku

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In Search of Income Convergence and Ideal Distribution – the Case of European Union Regions

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Abstract

In the field of economics and regional research, income convergence between countries and regions has been analysed since the 1980s. At the beginning of the 21st century, a number of articles addressing income convergence of European Union (EU) countries were published, which was among many topics related to the accession of 12 countries to the EU between 2004 and 2007. The inspiration for this study was the variety of conclusions about convergence in various groups of EU regions.
The purpose of this article is to discuss the existing knowledge on the economic convergence of the EU regions and to expand it with the research results covering the period 2000–2021. The results confirm the convergence of incomes within EU regions, which translates into a change in the geographical distribution of income in the EU, slowly blurring the boundaries between the regions of the 2004/2007 enlargement countries and the countries located in the west and south of the EU. At the same time, no convergence within most of the biggest EU countries nor regions with well-developed knowledge-intensive sectors, were recorded.

Keywords: economic growth, sigma convergence, beta convergence, spatial autocorrelation, EU regions

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Introduction

One of the most closely monitored trends in economics is the pace of economic growth. Given that the basic measure of an economy's size is GDP (gross domestic product), it follows that the history of growth is the history of GDP Coyle (2014). By observing GDP we can identify periods of strong growth and significant slowdown. As a result, some economies are strengthening their position as global leaders while others are still trying to improve their economic fate. The inspiration for this study was the myriad conclusions about convergence in various groups of regions and levels of aggregation regarding territorial units, i.e., the state, region, and local units (a discussion on convergence research can be found in, among others, Johnson, Durlauf, and Temple (2005)). Such knowledge warrants a systematic organisation and a perspective approached with a degree of detachment.

When analysing income convergence in particular countries, it is crucial to consider situations when the assessment of a country's economy is influenced by the economies of regions with highly diversified economic conditions. The most developed regions of the European Union (EU), for instance, become part of a larger entity, and their competitive advantages are incorporated into a larger economic system, which, as a whole, may present different characteristics. This phenomenon is well known in spatial econometrics as MAUP (modifiable areal units problem) (Gehlke and Biehl 1934; Openshaw 1984; Wong 2004). As territorial units expand, the disparities between territories tend to blur. A good example of this is the assessment of the EU regions in terms of GDP pc (per capita). For years, Luxembourg[1] has been ranked first, among the EU countries with a value of 78,500 (pc PPS; per capita purchasing power standards) (year 2020). By comparison, in the ranking of NUTS–3 regions, Luxembourg comes 13th; first place goes to Wolfsburg, Kreisfreie Stadt (155,400 pc PPS). Overall, Luxembourg is preceded by eigh NUTS–3 regions from Germany, two form Ireland, and two from France.

The purpose of this article is to assess the income convergence of the EU at different levels of territorial units in the 21st century (2000–2021). The study is based on the assumption that common EU laws and values foster the reduction of disparities in regional development. The following research questions were formulated: (1) Do beta and sigma convergence occur simultaneously at all levels of the EU territorial units? (2) Is convergence observed within the regions that make up the largest EU economies (Germany, France, Spain, Italy, and Poland)? (3) Do convergence clubs, defined based on the level of innovation in the economy (reflecting a specific structure of human capital resources),

1 Luxembourg in the NUTS classification appears as a country (code: NUTS 0), major socio-economic regions (code: NUTS 1), basic regions for the application of regional policies (NUTS 2), and small regions for specific diagnoses (NUTS 3).

offer a better understanding of economic growth processes in the EU regions? These approaches are consistent with growth models that feature multiple steady states.

The analysis of convergence will be conducted for all the EU countries, NUTS–2 and NUTS–3 regions, as well as groups of regions defined by national borders or convergence clubs, which are identified based on the level of knowledge and technology-based economic structure.

Income convergence

Income convergence is often discussed in research that addresses the neoclassical growth model with exogenous technical progress (Solow 1956; Swan 1956) or its extended version with human capital (Mankiw, Romer, and Weil 1992). This concept involves regions with initially lower levels of income per capita achieving higher economic growth rates than regions with higher output per capita during the base period. This process is referred to as the catch-up effect.

The neoclassical growth theory explains the accelerated growth of underdeveloped regions through declining marginal factor productivity. A scarcity of capital is associated with a higher rate of return on capital, which encourages capital transfer from richer to poorer regions, thereby stimulating economic growth. In addition, less developed regions can more easily increase the technical reinforcement of labour. Meanwhile, in developed regions, a significant portion of investment goes into maintaining a large stock of tools (Czarny 2000).

A condition for the pursuit of convergence is for economies to have a common steady state where per capita output, capital stock, and consumption grow at a common constant rate, equalling the exogenously given rate of technological progress. It involves similar conditions and parameters that characterise a given group of economies where convergence is expected. This applies to short-term development, wherein capital accumulation can prompt convergence towards a common steady state. Eventually, economies reach the latest or most advanced stage of development, known as the cutting edge, where growth rates are zero. However, if human capital accumulation and related knowledge are present in the economy, a shift of a higher steady state occurs, propelled by the involvement of human capital capable of fostering innovations.

The use of knowledge and innovation resources in production yields endogenous technical progress, a result of deliberate investment in scientific and technical knowledge (Romer 1986; 1990) or human capital (Lucas 1988), increasing production efficiency. The long-term accumulation of human capital can lead to a new steady state (Cowen and Tabarrok 2015). Bernard and Jones (1996) and Bianco (2010) argued that empirical analyses of convergence exaggerate the role of capital accumulation in generating convergence at the expense of technology diffusion, i.e., the endogenous or Schumpeterian driver of growth.

Both the free flow of capital and the absence of restrictions on the diffusion of technical progress between regions serve as catalysts for convergence (Tokarski 2005). Physical and human capital in the region are prerequisites for absorbing and creating acquired technical progress, e.g., in the form of innovations. As Islam (1995) indicated, "persistent differences in technology level and institutions are a significant factor in understanding cross-country economic growth. It becomes clear that if there had been no such differences, and countries differed only in terms of capital per capita, convergence would have proceeded at a faster rate". Both physical and human capital are subject to diminishing returns (Cowen and Tabarrok 2015). While knowledge absorption appears to be an acceptable developmental incentive for low-level economies, moving to higher levels requires the capacity for creative work and the development of primary innovations characteristic of the leadership position in a given industry.

The concept of endogenous growth is consistent with the idea of convergence clubs. Following Galor (1996) and Johnson, Durlauf, and Temple (2005), if initial conditions play a role in shaping long-run outcomes, and countries with similar initial conditions exhibit similar long-run outcomes, then one can speak of convergence clubs. If two regions with different initial levels of income (development) pursue different steady states, they can achieve similar or even higher growth levels. Convergence clubs suggest that convergence occurs between regions equipped with immobile production factors to a similar extent, leading to long-term steady states. Regions grouped within individual convergence clubs may be approaching their long-term development paths, while simultaneously, divergence may occur between these clubs (Tokarski 2005).

This paper uses the concept of β (beta) and σ (sigma) convergence. β-convergence, also known as the catch-up effect, focuses on achieving higher rates of economic growth by regions with lower initial levels of development than the regions initially characterised by higher productivity (development). Meanwhile, σ convergence is defined as the equalisation of income levels between regions. σ-convergence is typically identified by examining the standard deviation of the logarithms of labour productivity (or GDP pc) between regions over successive periods. When considering these two types of convergence, it should be pointed out that while β-convergence is a necessary condition for σ-convergence, it is not sufficient (Sala-i-Martin 1996).

An overview of income convergence studies

As the source literature suggests, Baumol (1986) was one of the earliest studies to address absolute convergence in terms of productivity equalisation or the level of economic development measured by GDP pc. He confirmed the productivity convergence for 16 industrialised world economies between 1870 and 1979 (the Baumol-style OLS regression) and referred to these 16 industrialised economies as a convergence "club".

The literature review provides a general reflection that economic convergence is frequently observed across countries and regions (Schmidt 1997; Próchniak 2006; Batóg 2010; Bal-Domańska 2014; Chocholatá and Furková 2017), with the rate of convergence usually remaining at approx. 2–3% (Quah 1996). The research emphasised the sensitivity of convergence results to the assumptions made and the diversity of the analysed objects (Batóg 2010). In addition to sampling, contemporary authors also point out differences in the rate of convergence estimates that result from the method of data analysis (Caselli, Esquivel, and Lefort 1996; Bond, Hoeffler, and Temple 2001; Ciołek 2003), as well as differences in the data sets (Bernardelli, Próchniak, and Witkowski 2018).

Some studies assessed convergence at different levels of aggregation. For example, Gorzelak (2009) highlighted the difficulties in achieving convergence, noting that concentration often prevails over deconcentration between the two poles that represent opposing development trends. Some have indicated the increase in intra-regional disparities in EU countries, both those that show small income spreads (e.g., Sweden, Denmark, and the Netherlands) and those with traditionally large inter-regional differences (e.g., Italy and Hungary). A summary of research findings for groups of EU countries is available in the source literature (see, e.g., Batóg 2010; Kusideł 2013; Glawe and Wagner 2021). Most studies confirm convergence, although some highlight that convergence following a given model structure can only be confirmed for selected regions. For example, Baumont, Ertur, and Le Gallo (2003) demonstrated convergence in the spatial regimes model only for regions in southern Europe. The rate of income convergence across EU regional/country economies varies from 1% to 3%[2].

A frequent thread in convergence analyses is assessing the rate of convergence among groups of regions often conceptualised as clubs of regions that share common characteristics that approximate their development models. One such common thread is the division of countries into the "old" EU (i.e., the former EU15) and the "new" (after the enlargement in 2004 and 2007 (EU10/EU12)). The 2004 enlargement was noteworthy for the EU, as it included a large number of new countries, of which eight

2 The findings differ both in terms of estimates for the rate of convergence and the quality of meeting the model assumptions. A similar growth rate was also indicated for the rate of convergence of the European economies in terms of manufacturing productivity (Petrović and Gligorić Matić, 2023). The exception is the research conducted by Bernardelli, Próchniak, and Witkowski (2018), who presented findings at the level of 17.6% for the period 1996–2016.

had belonged to the communist bloc. It constituted a major challenge politically, organisationally, and economically. As Andor (2019) noted, "[The] 2004 enlargement was different because the income disparity between new and old Member States was much more significant than in any previous round. As a result, great imbalances have developed: capital flowed largely from West to East, while workers went mainly from East to West."

One frequent conclusion in convergence research into these two groups of countries is that convergence is faster in the new EU countries, and it favours the emergence of income beta convergence within the EU (Diaz del Hoyo et al. 2017; Cabral and Castellanos-Sosa 2019; Demertzis, Sapir, and Wolff 2019). Similar conclusions were reached not only regarding GDP pc but also household income (Muszyńska, Oczki, and Wędrowska 2018). However, Ingianni and Žd'árek (2009), who covered the period 1995–2006, confirmed β but not σ convergence. They also stated that the EU8[3] countries made rapid progress both in narrowing the gap and reducing income divergence within the group but not necessarily against the EU15.

The division into EU15 and EU10/EU12 does not exhaust the possibilities of searching for development patterns in EU regions. In particular, nowadays, almost 20 years after Central and Eastern European countries joined the EU, it is worth paying attention to the development models. Bal-Domańska (2011; 2016) has presented comprehensive analyses that considered the determinants of endogenous growth by: 1) including differences in the level of human capital in the model, and 2) dividing regions into clubs that have similar knowledge structures and uses of technology in the economy. Considering both human capital and knowledge accumulation in the models allows the long-term steady state to be shifted to a higher level. The inclusion of variables that represent human capital in the model structure allows differences in regional potential in workers' education and experience to be expressed. On the other hand, the division of economies into clubs with similar structures of knowledge sectors makes it possible to identify clubs with similar development models; thus, they are capable of pursuing the same steady state. The key findings from these studies, which covered the period between 2000 and 2011, can be summarised as follows:

1. Among the classifications grouping regions by criteria, the most robust models were developed for regions characterised by a significant presence of knowledge-intensive sectors, such as high and medium high-technology manufacturing, as well as knowledge-intensive services.
2. Regions with a lower share of knowledge sectors revealed clear unconditional beta convergence and, consequently, also σ-convergence.

3 EU8 – countries involved in the fifth European enlargement (year 2004), with the exception of Cyprus and Malta.

3. The results support the validity of the contradictory concept proposed by Gerschenkron (Barsby 1969; Kubielas 2009), which highlights the privileged role of regions with a high level of knowledge capital accumulation. These regions are, therefore, capable of creating and absorbing technology better, and as a result, they can achieve higher levels and growth rates of labour productivity.

4. Assessment of regional cohesion

Achieving territorial cohesion, understood as the absence of significant development disproportions in a functionally related area while allowing the existence of various local specialisations, remains one of the goals of regional policy. When formulating the purpose of the analysis presented below, the following assumptions were adopted:

- Implementing international standards and laws, as well as establishing a single market to guarantee the four freedoms (goods, capital, services, and people), constitute strong arguments for joint analyses of all EU regions. As Martin, Velazquez, and Funck (2001) stated, the main effect of European economic integration has been the diffusion of technologies, leading to converging capital/labour relations, which in turn has fostered real convergence.
- The existence of autonomous countries within the EU, which operate in accordance with unique historical, legal, structural, and political conditions, forms the basis for verifying the idea of regional convergence within their internal borders.
- As the size of a country increases, the likelihood of internal developmental disproportions increases. The territorial cohesion of higher-level units depends on the development level of the lower-level units. This aspect can be associated with the Friedman's Core-Periphery Model (1963). Based on the spatial distance from the core, it distinguishes four stages of regional development: from the initial state of inequalities (pre-industrial), disparities are reduced (transitional and further industrial stages with regional sub-centres) to a functionally integrated urban system (post-industrial).
- According to Kapeller, Gräbner-Radkowitsch, and Heimberger (2019), technological capabilities, which play a decisive role in a country's long-term economic development, continue to be very unevenly distributed among the Eurozone countries (this can be generalised for all EU economies). These inequalities in supplying regions with growth determinants constitute an important premise for defining convergence clubs striving for their proper steady state;
- Kijek, Kijek, and Matras-Bolibok (2022) stated that although technological progress and innovation diffusion create important macroeconomic benefits at the country level, they also make regional convergence even more challenging (Chapman and Meliciani 2017; Pina and Sicari 2021) as the concentration of knowledge-intensive

sectors gradually escalates at the regional level. Therefore, even though cross-country disparities may decrease, within-country divergence remains constant or even increases.

The presence of positive trends favouring the convergence of income levels in the EU economies carries the following implications:

1. There is a decrease in diversification in the value of generated income across different aggregation levels (NUTS–3 regions, NUTS–2 regions, countries), i.e., σ convergence.
2. Reducing differences in income between territorial units is possible in the presence of β convergence.
3. Political, historical and structural determinants imply a strong relationship between regions' level of economic development and their location. Clusters that bring together a large number of regions characterised by a similar, difficult economic situation enhance regional development disproportions. However, supporting regional and local economic centres, as well as their ability to create positive external effects (diffusion, transfer) at every level of territorial aggregation, strengthens β convergence and, consequently, σ convergence.

If we approach these processes as mutually reinforcing complementary phenomena suggests that the causal nature should be attributed to the factors listed in Implication 3 above. Creating appropriate political and legal conditions for the development of entrepreneurship, including the increase in its effectiveness, considering the potential inherent in individual regions, constitutes a developmental stimulus that may lead to the emergence of β convergence and, as a result, σ convergence.

Data and research procedure

The data come from the Eurostat database. Income was expressed by the value of gross domestic product per capita in the purchasing power standard (GDP pc in PPS). PPS is an artificial common reference currency unit developed by Eurostat. It expresses the same amount of goods and services in each country, allowing significant comparisons to be made in the volume of economic indicators between countries (Eurostat: Statistics Explained). GDP pc in PPS expresses the level of economic development of a region.

The study encompassed various levels of analysis, including countries and NUTS–2 regions, which are the basic unit of the EU regional policy. Twenty-seven EU Member States were included, and 242 NUTS–2 regions, with spatial analysis conducted on 234 NUTS–2 regions. To address data gaps in the employment structure, the examination within the convergence clubs framework focused on 220 NUTS–2 regions of the EU. Additionally, 1166 NUTS–3 regions were analysed (spatial analysis of 1150 NUTS–3 regions). Overseas regions of France and Portugal, as well as the Canary Islands, were excluded from the spatial analysis of regions. The analysis spanned from 2000 to 2021. However, due to data gaps for NUTS–3 regions, the time frame was narrowed to 2003–2020. To ensure comparability, selected results are presented for both time spans.

Spatial statistics, taxonometric, and econometric methods were applied to characterise development in the EU regions. These methods were based on the mutually reinforcing complementary phenomena outlined in the previous section.

Implication 1 was verified using the idea of σ-convergence based on the standard deviation of GDP pc (PPS) logarithms. Cross-sectional data (the Baumol-style OLS regression) were used to assess β-convergence (Implication 2). This approach allowed verifying the presence of convergence, and their graphic presentation. A broad description of the method for measuring convergence and the accompanying assumptions was presented by Sala-i-Martin (1996) and Batóg (2010). The Global and local Moran's I statistics (Moran 1950) were used to assess spatial correlations (Implication 3). The statistically significant values of Moran's I statistic indicate regional clusters with similar GDP pc (PPS) values in the cross-section of regions. The calculations used a row-normalised first-order adjacency matrix, in which units that share a common border were considered neighbours. The R CRAN program was used to perform the calculations.

The analysis of income convergence for convergence clubs was carried out for the NUTS–2 regions characterised by a similar economic structure, and the traditional Baumol-style OLS regression parameters were estimated for them. Grouping regions into classes that feature a similar structure was based on the data describing the percentage of people working in knowledge sectors, i.e., knowledge-intensive services (KIS) and also in high and medium high-technology manufacturing (MHTC). Due to data gaps for the NUTS–3 regions, the analysis was restricted to NUTS–2 regions. The classification was performed using the *k*-means method. The *k*-means algorithm (MacQueen 1967) aims to separate *n* regions in *k* non-overlapping groups to minimise the distances between the points and the centre of their group. The number of classes was determined based on a dendrogram created using Ward's hierarchical clustering method.

Characteristics of income convergence in the EU

The accession of 10 new Member States to the EU in 2004, followed by another 2 in 2007, resulted in a highly polarised economic landscape across EU regions. The newly admitted countries were achieving significantly lower incomes (GDP pc in PPS) that did not exceed 50% of the EU average. The following years of economic development, investment, and cooperation also carried out within the framework of the EU policy brought about a change in the economic picture of the EU regions. A comparison of the GDP pc in PPS expressed as the EU average in the EU NUTS–3 regions in 2000 and 2020 (Chart 1) reveals a blurring of divisions overlapping with state borders. In 2020, the picture of the EU NUTS–3 regions resembled centrically spreading waves from the most developed regions, whose income is close to or above the EU average, to the least developed regions. The richest regions include the regions of Germany (particularly the western part, northern Italy, Austria, Denmark, Belgium and the Netherlands, as well as Sweden). The regions with the lowest income are the western, southern and easternmost areas of the EU.

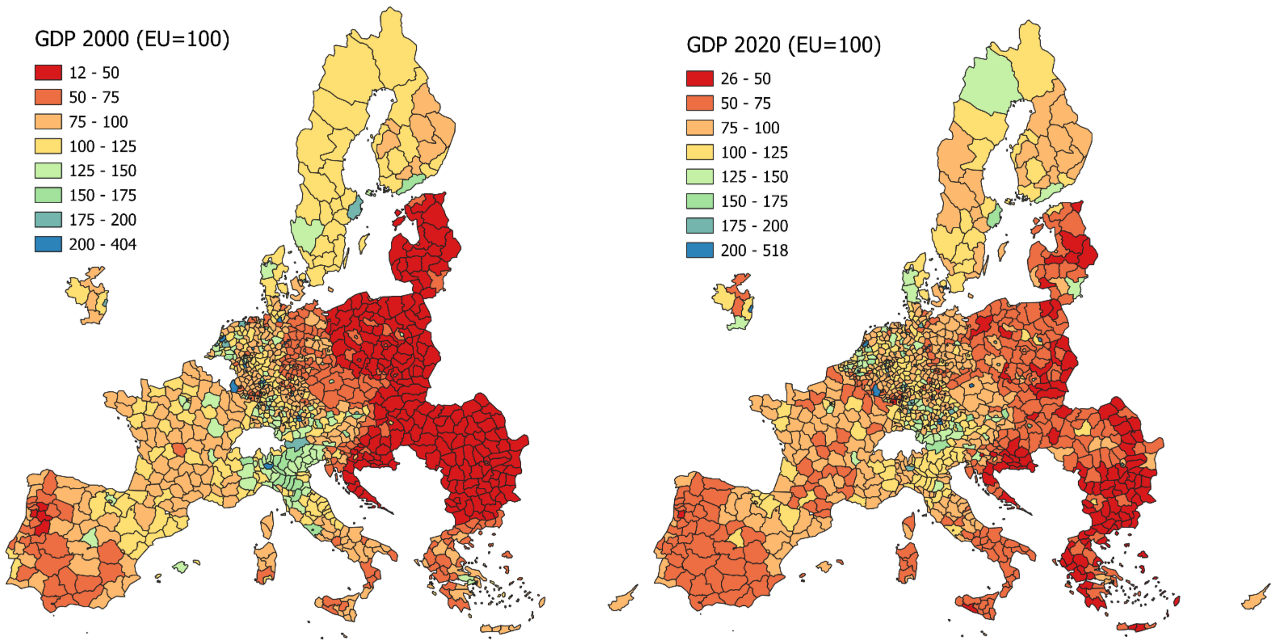

Chart 1. GDP pc in PPS as a percentage of the EU average in the EU NUTS–3 regions, 2000 and 2020

Source: author's compilation.

Twenty years of development saw significant economic progress in many of the new EU countries, including Poland, the Czech Republic, Hungary, Lithuania, Romania, and Estonia. Income levels in these regions approached 75% of the EU average. At the same time, many regions of Spain, France, southern Italy, and Greece recorded a relative decline in wealth, generating incomes below 75% of the EU average, with Greece falling below 50%. The change in the spatial wealth pattern of the EU regions and the disappearance of a clear geographical division into the Eastern Bloc and other Member States should also be assessed positively. These observations are confirmed by Moran's I spatial statistics (Chart 2), which assess the strength of income spatial autocorrelation. The decreasing values indicate a weakening tendency to concentrate regions with similar levels in one location in favour of an irregular income distribution. This trend is evident at both the NUTS–2 and NUTS–3 levels. In the NUTS–2 regions, the global Moran's I statistic decreased from 0.62 to 0.36. The disappearance of clear spatial regimes was accompanied by a decline in income differentiation between regions, thus confirming the emergence of σ-convergence at all levels of territorial aggregation. In the NUTS–2 regions, the σ-convergence measure dropped from 0.52 to 0.37 (Chart 2).

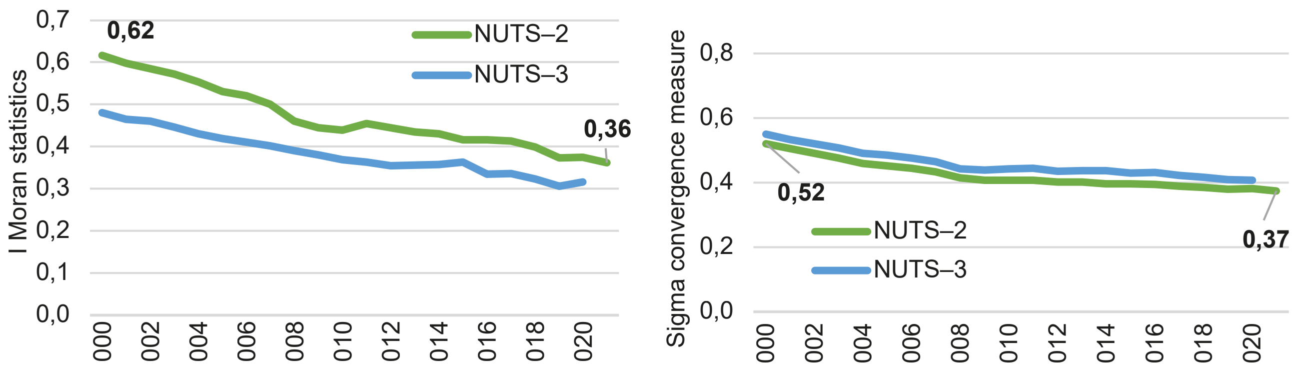

Chart 2. Global Moran's I statistics (left) and σ-convergence measures (right) for the EU NUTS–2 and NUTS–3 regions, 2001–2021.

Source: author's compilation.

The σ-convergence was the consequence of different income dynamics in individual regions. As the data in Chart 3 show, Romania saw the highest relative income increase in 2020 compared to 2003, where most regions recorded an increase of over 200%. Large increases were also observed for the NUTS–3 regions in Poland, Estonia, Lithuania, Latvia and Bulgaria. The relative growth in other EU countries did not exceed 50% (with a dynamics index of 1.5). At the same time, almost all Greek regions and selected Irish regions recorded a drop in income. Due to the COVID–19 pandemic in 2020, which affected regional economic results, Chart 3 presents both the dynamics of GDP pc in PPS in 2020 and in 2019, before the COVID–19 pandemic. The picture of changes against the base year 2003 is similar in both years. The differences arose in the dynamics observed in selected Italian and Spanish regions, where 2020 saw GDP pc in PPS income levels lower than those recorded 16 years earlier. These observations lead to the conclusion that σ-convergence is indeed ocurring at the EU level.

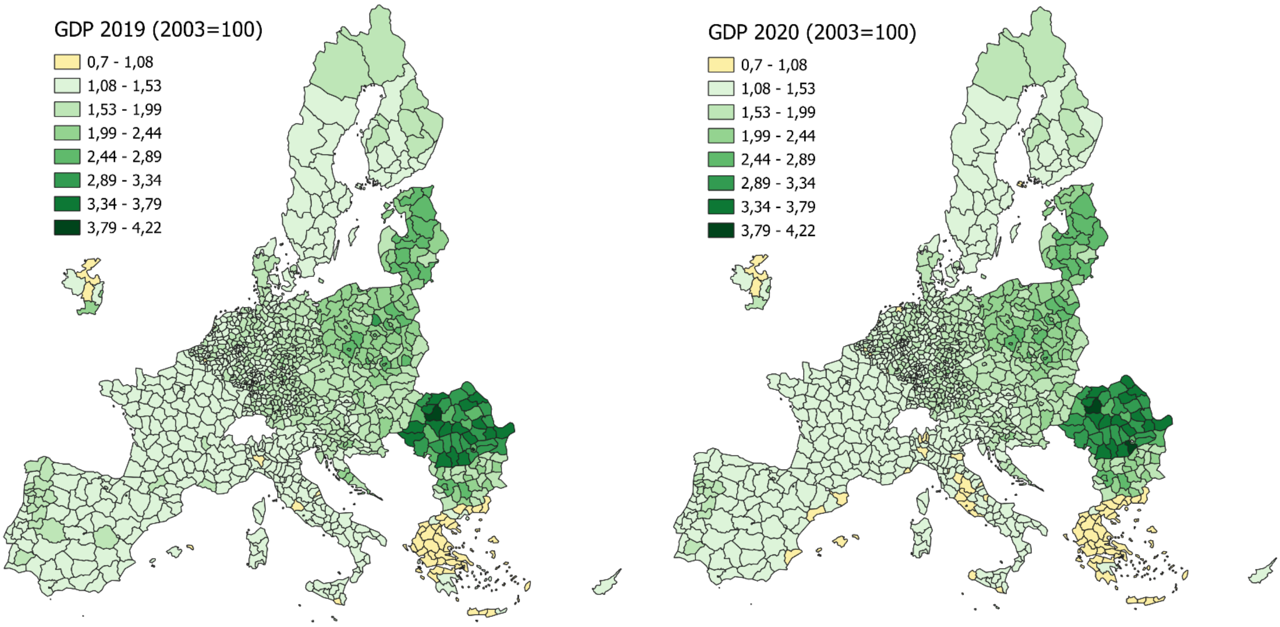

Chart 3. GDP pc in PPS dynamics indices for EU NUTS–3 regions

Source: author's compilation.

Chart 4 presents the income level of the EU NUTS–3 regions in 2003 and the dynamics indexes in 2020. This comparison allows the analysis of income β-convergence for NUTS–3 regions using the Baumol-style OLS regression. As evidenced by the data arrangement, the correlation is as expected, confirming β-convergence. Estimates of the corresponding power-form models at the NUTS–2 and NUTS–3 levels are presented in Table 1. The results confirm convergence both at the NUTS–3 and NUTS–2 levels, as well as in the group of 12 new countries. The estimated convergence rate at the NUTS–2 level is 2.5% per year, which gives a period of 27 years needed to cover half the distance to a common long-term steady state. In the NUTS–3 regions, the catching-up rate is slightly lower, at 2.2% per year (which gives a half-time of 32 years). In the group of regions from the new EU countries, catching up is characterised by lower dynamics, at approx. 2%. This means that within 34 years, the income generated by regions in this group should reduce the distance to the periodic steady state by half. However, in the old EU15 countries, no catching-up was observed. To understand this situation better, Chart 4 distinguishes observations for the EU15 and individual countries of the new EU12 enlargement.

The new EU countries, in particular Romania, Lithuania, Poland, and Bulgaria, are characterised by the highest growth rates, driving convergence. However, a small group of regions in the central part of the chart deviates from the convergence model, achieving an unexpectedly high growth rate (by 150%) along with a simultaneously high-income level in the initial period. These regions cover the rapidly developing capital regions of the EU12 countries, including Warsaw, Zagreb, Budapest, Bratyslavsky Kraj, as well as Dublin. Some of the regions with the highest income in 2003 (visible in the chart as the rightmost regions) also achieved a high growth rate (up to 100%), doubling their income in 17 years (GDP pc in PPS). These regions include the two previously mentioned German regions with the seat in Wolfsburg and Ingolstadt.

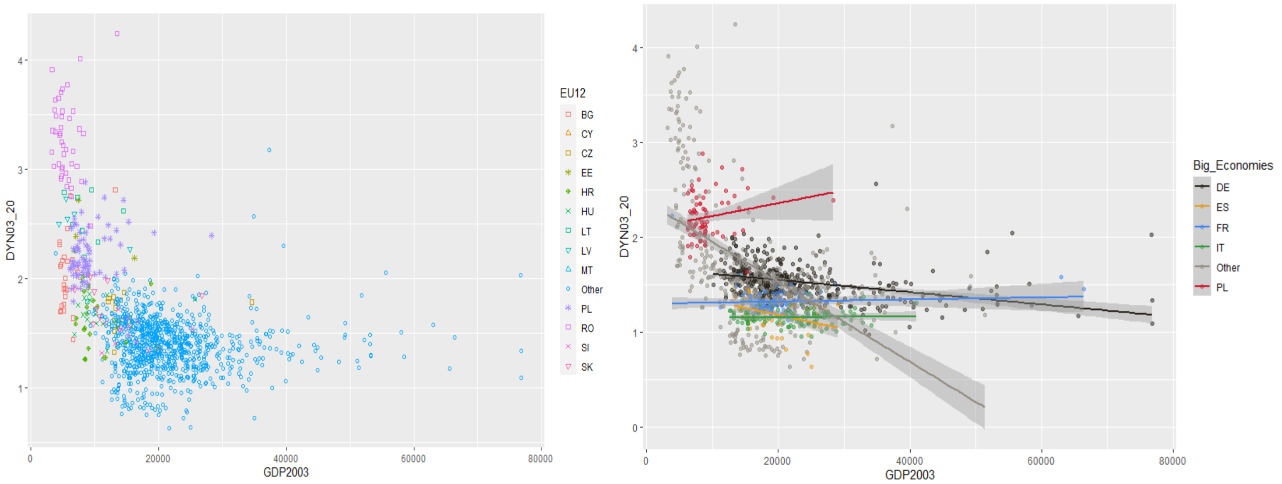

Chart 4. GDP pc in PPS and their dynamics in the EU NUTS–3 regions by country (left), and β-convergence models for selected countries (right)

Source: author's compilation in R CRAN.

Analysis of the regions of the EU15 countries shows that the regions are highly diversified. Some of the most affluent regions achieved a comparable high growth rate as the regions with an initially low level of wealth. At the same time, the regions with the lowest income in 2003 constitute a highly diversified group in terms of economic growth rate. In the initial income range, from 17,000 pc PPS (Purchasing Power Standard) to 30,000 pc PPS, the regions recorded income growth rates ranging from almost 0 to 100%. The results suggest different income growth models among the EU15 regions. To illustrate this, a β-convergence analysis was conducted for the five most populated EU economies (Chart 4; Table 1). This allowed us to closely examine the situation in four EU15 countries whose regions largely form the described cluster.

Germany and Spain had statistically significant negative estimates of convergence parameters, suggesting catch-up processes. However, the quality of the model expressed by the fit (determination) coefficient was very low, at 14%/20%, respectively. Low fit is a consequence of, among other things, the presence of regions that deviate from the convergence model determined by the traditional Baumol-style OLS regression. Spain's results were influenced by a group of regions that recorded an income decrease in 2020 compared to 2003.

Table 1. The traditional Baumol-style OLS regression results

	Coefficient	R^2	Speed of convergence	Half Time
EU27 NUTS–2 (2000–2021)	– 0.429***	0.492	2.5	27
EU27 NUTS–3 (2003–2020)	– 0.323***	0.358	2.2	32
EU12 NUTS–2 (2000–2021)	– 0.364***	0.340	2.1	34
EU12 NUTS–3 (2003–2020)	– 0.3***	0.280	2.0	35
EU15 NUTS–2 (2000–2021)	– 0.009	0.000	–	–
EU15 NUTS–3 (2003–2020)	– 0.043*	0.006	–	–
Five biggest EU countries (in terms of population) (NUTS–3, 2003–2020)				
Germany	– 0.147***	0.203	0.9	78
France	– 0.057	0.035	–	–
Spain	– 0.284***	0.139	1.9	37
Italy	– 0.001	0.002	–	–
Poland	0.072	0.041	–	–

R^2 – the coefficient of determination; *** – 0.001 level of statistical significance; ** – 0.01 level of statistical significance; * – 0.05 level of statistical significance.
Source: author's compilation.

Convergence is not a common phenomenon in the largest EU countries, including Germany. German regions stand out for their high income levels within the EU and the presence of convergence. The strong position of the German economy can be attributed to its diversified and frequently highly specialised economic structure of the economy based on high and medium high-technology manufacturing and innovation. As noted by Baccaro and Benassi (2017), the German growth model has transitioned from being driven by net exports and consumption to predominantly export-led growth.

For the three remaining countries (Poland, France and Italy), β-convergence could not be confirmed, which suggests the possibility of increasing income disparities between the regions. The absence of β-convergence in Italy was influenced by the low growth rate and even a decline in incomes in most regions (with income changes ranging from –5% to 40%). When all regions experience a low or negative rate of income change, it is not possible to observe catching-up processes according to the idea of β-convergence.

In France, most regions recorded a relatively moderate income growth (from 13% to 50%). Consequently, the poorer regions failed to narrow the gap with the richest ones, maintaining similar levels of regional wealth.

In Poland, the results were influenced by the relatively large group of regions which achieved the highest income in the initial period of the analysis (2003) and, at the same time, recorded the highest growth rate. These NUTS–3 regions, including Warsaw, Poznań, Kraków, Wrocław, and Łódź, now serve as significant development drivers, achieving positive economic results within their boundaries while also spreading these economic benefits to neighbouring areas (Chart 1). These regions attract foreign investments and, therefore, promote exports and foster innovation and productivity growth (OECD 2018). Overall, the economic growth rate of Polish NUTS–3 regions ranged from 65% to 190%.

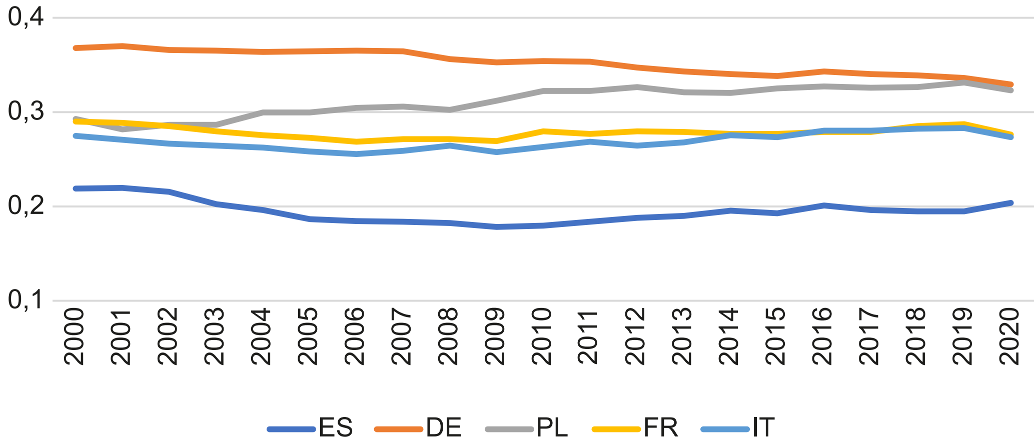

Chart 5. Sigma convergence in the selected EU countries (based on NUTS–3 regions)

Source: author's compilation.

To summarise, σ-convergence was recorded only in Germany (Chart 5), polarisation was visible in Poland, and income differences between NUTS–3 regions in France and Italy remained at a similar level. Meanwhile, in Spain, after initially seeing a decline in differences in regional wealth, recent years have seen the threat of increasing income polarisation.

Club convergence results

According to the neoclassical growth theory, one determinant of the pace of growth is the distance of an economy from its long-term steady state. The long-term steady-state point varies between economies characterised by different levels of efficiency and ability to adopt knowledge and technology. Chart 6 presents the key values of the Baumol-style model divided into three clubs of NUTS–2 regions, which were identified based on the economic structure in the knowledge-intensive sectors.

The Industry club comprises 107 regions with the highest percentage of people employed in high and medium high-technology manufacturing MHTC (with an average of 8.6%) and a relatively high percentage of people employed in knowledge-intensive services KIS (28%). The Services club is the smallest, covering 46 regions where, on average, 41% of employment is attributed to KIS, while approx. 5.8% is MHTC. The Other club comprises 67 regions with the lowest percentage of employment in knowledge-intensive sectors (MHTC 3.9%; KIS 19.2%).

The first observation drawn from the analysis of club data relates to the highest income level in the Services club regions (see also Cutrini and Mendez 2023). The average level ranged from 25,109 pc PPS in 2000 to 41,093 pc PPS in 2021. At the same time, the average income level in the Industry club ranged from 19,060 pc PPS to 31,060 pc PPS, respectively, while in the Other club, the range was narrower, spanning from 11,800 pc PPS to 21,607 pc PPS.

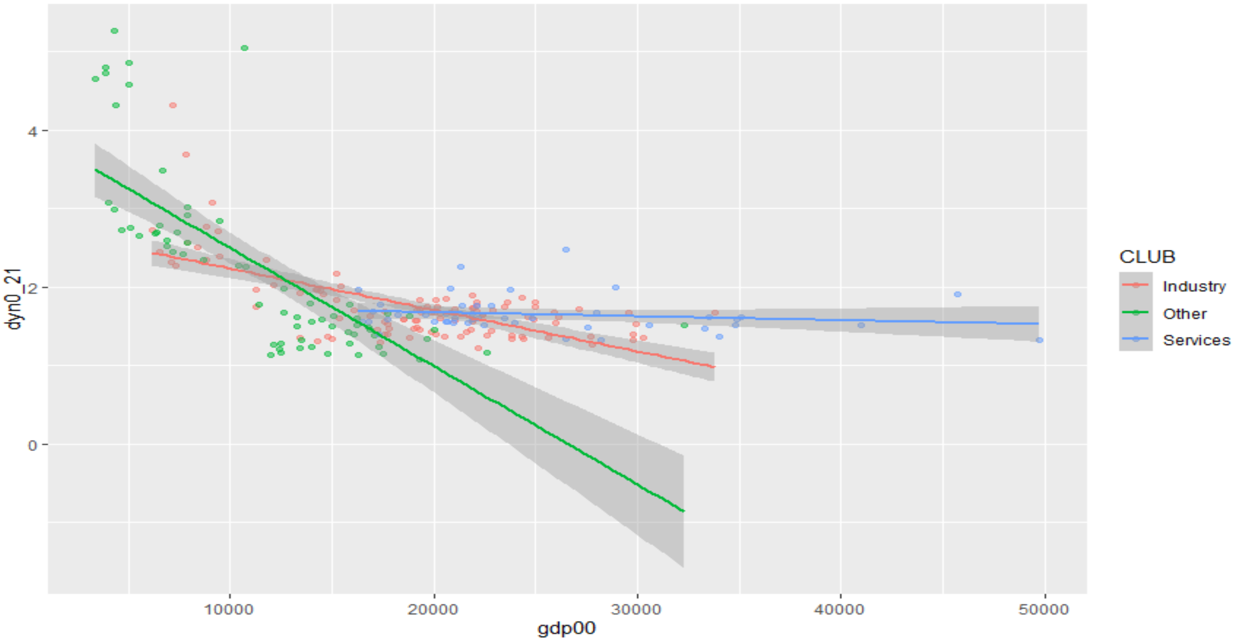

Chart 6. Income (GDP pc in PPS) and its dynamics in the EU NUTS–2 EU regions according to convergence clubs

Source: author's compilation in R CRAN.

Table 2. The Baumol-style OLS regression results for convergence clubs

	Coefficient	R^2	Speed of convergence	Half Time
2000–2021 (NUTS–2)				
All	−0.446***	0.550	2.7	26
Services	−0.09	0.038	–	–
Industry	−0.443***	0.557	2.7	26
Other	−0.74***	0.739	6.1	11

R^2 – the coefficient of determination; *** – 0.001 level of statistical significance; ** – 0.01 level of statistical significance; * – 0.05 level of statistical significance.
Source: author's compilation.

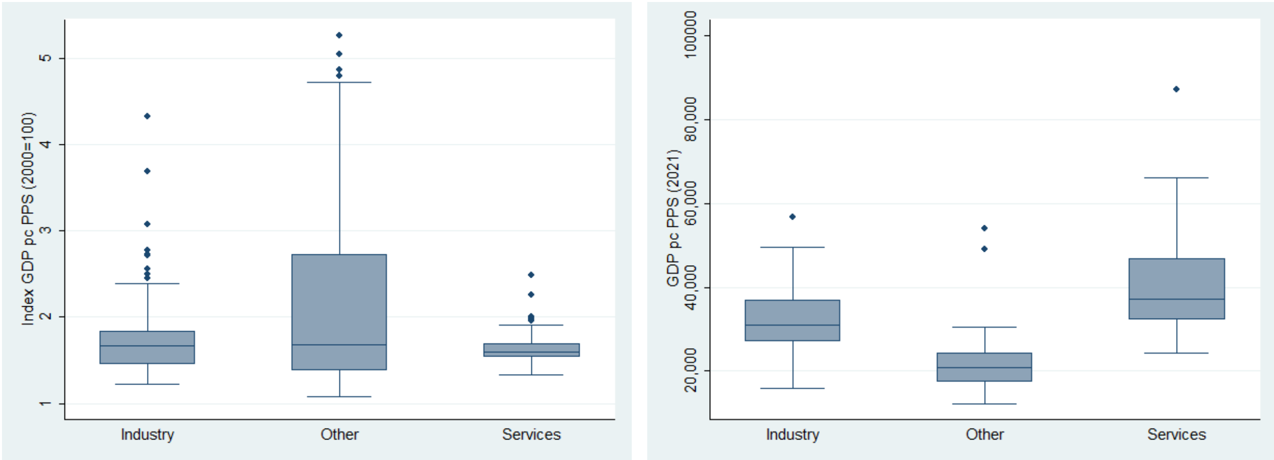

Chart 7. Dynamics indices GDP pc in PPS (2000 = 100) (left) and the level of regional GDP pc in PPS (right) among the EU NUTS–2 regions by convergence club in 2021

Source: author's compilation in STATA.

Absolute β-convergence was confirmed in two clubs, Industry and Other (Table 2). These convergence models are characterised by greater variance of the dependent variable, measured by the coefficient of determination (R^2), than the results presented earlier in Table 1. It can, therefore, be concluded that the division into clubs provides a better understanding of convergence within the EU NUTS–2 regions.

The Other club yielded the highest level of explanation and the highest convergence parameter. This indicates that the regions in this group are progressing towards a common long-term steady state at the fastest rate (5.7% per year). According to the estimates, it would take 12 years to halve the distance to the long-term steady-state shared by all regions within the club. In contrast, the Industry club demonstrates a convergence speed of only 2.7%, requiring 26 years to reduce the distance.

β-convergence was not observed in the Services club. The absence of convergence can be attributed to similar growth rates in these regions. As shown by the data presented in the box chart (Chart 7, left), the median of income dynamics indexes reached a similar level of 1.6 in all convergence clubs, with the Services club exhibiting the lowest deviations from this value (the coefficient of variation was only 14%). The lack of regions achieving high growth rates translated into the absence of convergence. Furthermore, the regions within the Services club are among those with the highest income levels, significantly exceeding the income achieved by the regions of the remaining two clubs (Chart 7, right). The results suggest that the Services club regions are approaching the growth limit at a given long-term steady state and within the existing economic model.

Conclusion

When answering the questions posed at the beginning of this article, it becomes apparent that income convergence was observed regardless of the level of analysis (i.e., NUTS–2 or NUTS–3 regions). The rate of convergence achieved by the EU regions is similar to the estimates in other studies, including those that focused on the EU, averaging around 2.5% per year. However, the situation becomes more complicated when examining smaller territorial systems rather than the entire EU. Catch-up processes were confirmed only within the regions of the new EU12, with no convergence observed in the EU15 regions. Convergence was also not common in the largest EU countries. Only in Germany were β and σ-convergence confirmed. Conversely, clear divergence was recorded in Poland.

These observations align with Pina and Sicari's (2021) assertion that the reduction of differences between countries in the first decade of the 21st century was more crucial for income convergence in the EU than the reduction of disproportions within countries. They also mentioned the lack of improvement in the EU15 countries and that there was even a tendency towards divergence and polarisation.

This situation is influenced by globalisation and changes in the political and economic systems in Europe. These dynamics determine the flows of financial resources, investments and employees between countries. The last EU enlargements (in 2004 and 2007) have driven strong economic growth, labour market improvements, and buoyant investment, including increases in FDI inflows in the EU12 countries (Borys, Polgár, and Zlate 2008). Additionally, the EU cohesion policy has also provided a positive stimulus for the economic growth of the new Member States (Savić, Drvenkar, and Drezgić 2023), resulting in the countries of Central and Eastern Europe improving their economic position in Europe. For example, when Poland joined the EU, it was ranked the 23rd economy in terms of GDP pc in PPS. By 2021, it had risen to 19th.

Maintaining this positive trend in the EU12 countries requires them to address further economic challenges to increase productivity and structural transformation (Borys, Polgár, and Zlate 2008; Pina and Sicari 2021). They must focus on accumulating capital, including the activation of human capital towards innovation and the development of modern economic sectors of international or supra-local importance. The transition to the next stage of development requires that these countries and regions develop industries and services based on the latest technical expertise and standards, extending far beyond the local markets.

While the inflow of investments, particularly foreign ones, into low-income regions may serve as an important incentive in the first period of development, it cannot constitute a target model. As noted by Gorzelak (2009), the "high" segment, which is based on research and development, as well as innovation, is not subject to relocation. In contrast, foreign investments that target foreign markets typically address industries with lower technological advancement. Consequently, at a certain stage of regional development, entrepreneurship must be established based on the latest knowledge achievements, broad coverage, and native roots in technical innovation and market ideas.

The observation of disruptions in convergence within countries can be linked to the findings drawn from the existing literature. As Pina and Sicari (2021) stated, "high-value added services have become more concentrated at the regional level. This has mainly benefited large cities since productivity in knowledge-intensive sectors has proved particularly sensitive to agglomeration economies." This is a problem not only for Europe but for economic geography in general.

Furthermore, businesses are more willing to invest in centres that already possess capital, have access to educational and scientific centres and housing resources, and are well-connected (Moretti 2021). Even though the concentration of enterprises, especially high technologies, results in an increase in wages and housing prices, it remains a common strategy among employers. The tendency to concentrate in selected locations is demonstrated, in particular, by the deployment of industry and services characterised by high technology and knowledge, deepening the division of the EU economy into "high" and "low" technology segments (Porter 1990; Gorzelak 2009).

This observation leads to the question of whether the existence of mechanisms that favour specific locations and that support capital accumulation in already developed regional centres results in convergence within clubs of regions that share a similar development model. The Services club regions, with a modern economic structure characterised by a large share of people working in knowledge-intensive services, as well as high and medium high-technology manufacturing sectors, do generate the highest incomes. However, the development they experience is characterised by a relatively moderate and similar growth rate.

Income convergence within EU regions is not accompanied by convergence within EU countries. In this scenario, development is dominated by the factors described in location theories. Going beyond the issues of convergence characteristics and formulating recommendations, it can be stated that the pursuit of income convergence, despite its somewhat utopian nature, has positive effects. Convergence, as a way of equalising disproportions in the level of regional economic prosperity, remains one of the dimensions of achieving economic cohesion. Economic cohesion, according to Gorzelak (2009), involves harmonising the entire complex economic system and maximising the potential inherent in its components. Even if convergence only leads to the disappearance of differences between countries and regions of the entire EU, it still brings us closer to the goal of an economically cohesive Europe. Furthermore, it paves the way for regional and local policy initiatives aimed at achieving economic cohesion within countries. This approach also capitalises on the positive externalities obtainable from economically stronger agglomerations. It fosters social and territorial cohesion and promotes employee mobility and remote work while strengthening local relationships, supporting local specialisations and seeking local comparative advantages.

By supporting networks of cooperation and mutual correlations between central areas and their peripheries, local and regional policies should consider the development of regional polycentric and balanced territorial structures. They should also develop less significant centres to create a more integrated hierarchy of cities and, consequently, interconnected and interdependent economic systems[4].

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4 The suggestions are consistent with the provisions in strategic documents, e.g. National Strategy for Regional Development 2030, Warsaw, September 2019, https://www.gov.pl/web/fundusze-regiony/krajowa-strategia-rozwoju-regionalnego, and also (Sobala-Gwosdz 2023).

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W poszukiwaniu konwergencji dochodowej i idealnego podziału – przypadek regionów Unii Europejskiej

W obszarze ekonomii i badań regionalnych badania konwergencji dochodów między krajami i regionami prowadzone są od lat 80. XX wieku. Na początku XXI w. ukazało się wiele artykułów poruszających kwestię konwergencji dochodowej krajów UE, co wiązało się m.in. z przystąpieniem w latach 2004–2007 dwunastu krajów do struktur Unii Europejskiej (UE). Inspiracją do przygotowania niniejszego opracowania była rozbieżność wniosków na temat występowania procesów konwergencji w różnych grupach regionów UE. Celem artykułu jest omówienie istniejącej wiedzy na temat procesów konwergencji gospodarczej regionów UE i poszerzenie jej o wyniki badań obejmujących okres 2000–2021. Uzyskane wyniki potwierdzają konwergencję dochodów w obrębie regionów UE, co przekłada się na zmianę geograficznego rozkładu dochodów w UE i powoli zacierające się granice między regionami krajów objętych procesem rozszerzenia 2004–2007 a krajami położonymi na południu i zachodzie UE. Jednocześnie nie odnotowano konwergencji w obrębie większości największych krajów UE oraz w ramach klubu regionów o rozwiniętym sektorze usług opartych na wiedzy.

Słowa kluczowe: wzrost gospodarczy, beta i sigma konwergencja, autokorelacja przestrzenna, regiony UE

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Calibrating Ukraine's Growth Model: How Can Ukraine Emulate Poland's Growth?

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Abstract

This study provides a comparative analysis of the economic growth paths of Ukraine and Poland from a growth-model perspective and determines how to calibrate Ukraine's growth model to converge with Poland's booming economy. The methodology comprises an approach to operationalizing growth models for GDP growth decomposition into "import-adjusted" demand components, drawing on national input-output data from 2000 to 2019. I found that from 2000 to 2003, both European economies relied on a combination of exports and domestic consumption. Expanded trade integration and an FDI boost after Poland joined the EU in 2004 spurred the Polish growth model's shift to a distinctively export-led, FDI-driven strategy with accelerated GDP growth rates. In Ukraine, in the wake of the great financial crisis, I identified a transition to a consumption-led growth model that, along with a declining investment component of aggregate demand, led to fading growth rates. An analysis of sectoral contributions to GDP growth revealed that avoiding deindustrialization in Poland underpinned the country's export-led strategy, unlike Ukraine, which underwent a key sectoral shift from manufacturing to a commodities-based orientation after 2008. Both these economies demonstrated a high level of integration into global value chains, focusing on labor-intensive manufacturing and services, but Poland has outperformed Ukraine in terms of share of high value-added exports, which increased after EU accession. Following the Polish pattern, I propose that Ukraine's growth model should activate the FDI driver of economic growth, upgrading the export structure and moving up value chains to unlock the country's growth opportunities. The study represents the first comparison of Ukraine's and Poland's economic growth paths that traces the changes in dominant final demand components and macro-sectors in the two countries' economic growth profiles. This paper contributes to the comparative

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political economy literature on the growth models of peripheral economies, providing insights that can inform policies for growth model transformation.

Keywords: growth model, economic growth, manufacturing, FDI, Ukraine, Poland

JEL: N10, O11, O47, O52, P52

Introduction

When Ukraine first raised the issue of independence, its strategic goal on leaving the USSR was to attain the living standards of core European economies. The independence process culminated in 1991 but the ensuing severe decline of Ukraine's economy prevented this. Since the end of the 1990s, catching up with Poland, its nearest western neighbor with its own post-Soviet legacy, is the new aspirational program for Ukraine's economy. Similar economies in terms of starting conditions (large domestic market, access to medium-to-highly skilled labor, proximity to core European capitalism) and living standards took different growth trajectories, leading to decades of divergence.

The Polish economy is now ahead of all its former socialist neighbors, which preferred to transform with less resort to the "shock" doctrine. Since 1992, the Polish economy has grown steadily (except for 2020 as a result of COVID–19), and it had tripled its real GDP by 2021. According to the World Bank, even in the hardest year of 2009, at the peak of the global financial crisis, when the EU conomy fell by 4.3 percent, Poland's GDP grew by 2.8 percent. Since EU accession, Poland has been able to take advantage of European integration and is today among the six largest EU economies by nominal GDP. Acknowledging the Polish economy's progress and capital market infrastructure improvements, FTSE Russell (2018) upgraded the Polish economy's status from advanced emerging to developed in its annual market classification. Poland is the first post-socialist state in Europe to achieve developed market status. By catching up with the advanced Western economies, the booming Polish economy has established itself as a model to emulate for other emerging countries.

Ukraine's economy, by contrast, is a chronic "underachiever". The incomplete transformation into a market economy in the 1990s, with the increasing predominance of vested interests, disruption of economic ties, and hyperinflation, plunged Ukraine's economy into the abyss. In the first half of the 2000s, this trend was interrupted, but not for long. Global economic shocks, Russian military aggression, and the COVID–19 crisis hindered GDP recovery. In 2020, Ukraine's real GDP was only 63 percent of its 1990 value. The economy shifted from a focus on heavy manufacturing to a distinctly raw-material orientation. According to the World Bank, Ukraine was ranked the poorest country in Europe in 2020, with a per capita GDP of $3,540, only one-fifth that of Poland. Russia's escalation of its war on Ukraine only exacerbated this. According to World Bank calculations, at a growth rate of 3 percent, it will take Ukraine fifty years to reach the Polish income level (Smits et al. 2019). The Ukrainian economy faces the major challenge of changing its growth strategy to catch up with the leading European economies, simultaneously overcoming exogenous shocks and endogenous contradictions.

Since the 1990s, a growing body of comparative political economy literature has attempted to explore the particular nature of Ukraine's growth path and highlight its divergence from other countries, including Poland. The traditional juxtaposition of two economies from a supply-side perspective, focusing on institutional differences and contrasting rates of structural transformation and successes in the initial phase of transition (Aslund 2013; Havrylyshyn 2017), neglects the demand-side context. A recent contribution by Baccaro and Pontusson (2016), who proposed the growth model perspective in comparative political economy, put the spotlight on the demand drivers of economic growth in political-economic analysis.

From a growth model perspective, Ukraine's growth path has received little attention in comparison with the other Central and Eastern European (CEE) countries from the post-socialist bloc. A comprehensive report prepared by the World Bank Group (Smits et al. 2019) represents the first analytical attempt to identify key growth drivers of Ukraine's economy from a growth model perspective. It claims that the old growth model based on "legacy industries dependent on cheap energy resources, commodity exports, and trade exclusively with the Commonwealth of Independent States (CIS) countries" cannot provide the accelerated growth needed to reach Poland's current income levels. To unleash its potential and achieve rapid, lasting, and inclusive economic growth, Ukraine requires a lot of structural reforms. Shepotylo et al. (2017) analyzed the Ukrainian economy at firm and sectoral levels in relation to the EU and offered both supply- and demand-side recommendations to boost exports and foster private sector-driven economic growth.

The Polish growth model has received far more attention from researchers. In studies of growth models on CEE's periphery by Hagemejer and Mućk (2019), Ban and Adascalitei (2020), and Vukov (2023), the Polish economy is classified as an export-led, FDI-driven model. Hein, Meloni, and Tridico (2021) and Akcay and Jungmann (2022) claim that, in line with European export orientations, after the global financial crisis, Poland transitioned from a domestic demand-led regime towards a weak export-led regime. In identifying crucial factors that impacted the transformation of Poland's growth regime, researchers commonly refer to the global economic crisis, with less focus on Poland's accession to the EU.

Because of the lack of previous research on the topic, this paper attempts to answer the following questions: Are the two countries similar or different in terms of their growth models and sectoral contributions to GDP growth? Did their growth models change from 2000 to 2019? And if so, what critical factors impacted these transformations? What is the principal driver of Poland's successful growth model, and how can it be reproduced in Ukraine? The paper's main objective is thus to compare Ukraine's and Poland's economic growth paths from a growth model perspective and determine the direction of Ukraine's growth model to enable it to converge with the booming Polish economy.

To achieve this, I used Baccaro and Hadziabdic's (2023) methodology for operationalizing growth models based on calculating the import-adjusted contributions to GDP growth of consumption, government expenditure, investment, and exports. The results of analyzing sectoral contributions to GDP growth provided insights into the sectoral shifts that underpin changes in the growth model.

Statistical data from national input-output tables covering the period between 2000 and 2019, divided into four sub-periods, allows us to trace the changes in dominant final demand components and macro-sectors in the two countries' economic growth profiles.

The paper is organized as follows. Section 2 outlines the theoretical framework of changes in the countries' growth trajectories from a growth model perspective. Section 3 interprets the results of the growth model analysis for the two economies. Section 4 explains the role of FDI and participation in global value chains in Poland's successful economic development. Section 5 concludes.

Theoretical analysis of growth model changes

To investigate the particular nature of the two countries' growth paths, many scholars use the influential "varieties of capitalism" framework (Hall and Soskice 2001). This strongly emphasizes the institutional differences between economies and their continuity over time. The "varieties of capitalism" approach provides tools for comparing national political economies in terms of supply-side macroeconomics. Exploring trajectories in the economic development of post-socialist European states, Bilenko (2014) focuses on rapid economic liberalization, accompanied by the creation of effective new market institutions in eastern European countries, in contrast to piecemeal reforms aimed at transition to a market economy in post-Soviet states. In an important book, *The Political Economy of Independent Ukraine*, Havrylyshyn (2017) examines the Ukrainian transition story by comparing it with Poland's, concluding that Ukraine bore huge economic costs and social pains due to reforms that were "too late, too little, and too slow." Ari and Pula (2021) point to Ukraine's legal system as the area in which institutional quality is the lowest compared with Poland. The lack of strong and independent institutions and regulated markets in Ukraine, often monopolized by the state or oligarchs, undermines incentives to accumulate capital and attract foreign investment. Hartwell (2016) traces Poland's success in developing both economic and political institutions in contrast to Ukraine's experience. Gylfason, Hochreiter, and Kowalski (2022), seeking to understand how and why Poland has charged so far ahead of Ukraine, focus in particular on its effective use of capital and other factors. Brintseva (2023) stresses the role of human capital investment when identifying priority directions for implementing the Polish experience in Ukraine. Pavlova et al. (2021) highlight the importance of European integration in shaping the strategic priorities for Ukraine's socio-economic development.

In contrast with the supply-side dominated macroeconomic backbone of the "varieties of capitalism" literature, a different research strand explains the divergence in national growth paths from the demand side. Baccaro and Pontusson (2016) proposed the growth model perspective, spotlighting the demand drivers of economic growth in their political-economic analysis. Within post-Keynesian theory, drawing on Kaleckian macroeconomics of demand regimes, the growth model perspective identifies diverse growth models, focusing on the role of aggregate demand in GDP growth and the dynamic relations between them. They found that due to the erosion of institutionalized wage bargaining that results from a declining wage share and depressed aggregate demand, the Fordist model of wage-led growth was exhausted. Countries responded differently to the challenge and replaced diminishing wage-led growth with a variety of post-Fordist growth models, differentiated by growth drivers. The foundational contribution of the growth model perspective in comparative political economy explains why some countries rely strongly on export-led growth while others are driven by consumption. Between the ideal types of export-led and consumption-led growth models, we find both balanced and unsuccessful models (Baccaro and Pontusson 2016).

I suggest that the growth model perspective is a promising analytical approach, shedding light on the dynamics of dominant growth drivers underpinning changes in a country's growth regime.

According to classic international regime theory, regimes cannot be static (Young 1983). Because "growth models are more numerous and more unstable than Hall and Soskice's varieties of capitalism" (Baccaro and Pontusson 2016), the theoretical approach to growth models may be able to explain instability and change within different national models. It provides a framework in which to explore the factors shaping growth regimes in different countries, comparability of growth paths, and changes in national growth models over time.

Bondy and Maggor (2023) claim that current empirical research focuses primarily on identifying existing national growth models and explaining their endurance. Shifts between growth models thus remain undertheorized.

Pressures on regime dynamics arise from endogenous or exogenous forces. According to Ban and Adascalitei (2020), a growth model changes "when its growth driver becomes so internally entrained and externally shocked that it can no longer finetune its endogenous socio-economic contradictions." Shifting from the usual emphasis on income distribution between wages and profits (Baccaro and Pontusson 2018), Behringer and van Treeck (2019) and Braun and Deeg (2020) modify the political economy of national growth models by focusing on income distribution between institutional sectors, generating financial imbalances. Spielberg and Voss (2022) consider debt dynamics to be the driver of growth model instability, promoting change in times of crisis. Another strand of research (Acemoglu and Robinson 2013; Regan and Brazys 2018; Bondy and Maggor 2023) deals with political mechanisms that weaken the political balance underpinning the structural transformation of national growth models.

The view put forward in this article is that both economic and political mechanisms underlie change in countries' growth models. National growth models have their own internal potential and "safety margin" based on the combined effects of economic growth drivers. In order to maintain a stable trajectory of economic dynamics, growth drivers must not be permitted to weaken. When their potential is exhausted, the role of current growth determinants should be reconsidered. Early readjustment or calibration of the growth model means reprioritizing by instigating new growth drivers to replace less effective ones to reboot growth dynamics.

Growth model analysis: Ukraine vs. Poland

I apply Baccaro and Hadziabdic's (2023) methodology for operationalizing growth models. This methodology is based on the growth decomposition of "import-adjusted" demand components, which include spending on domestically produced goods and services minus spending on imports induced indirectly by domestically produced goods and services. I use data from input-output tables to calculate the import-adjusted contributions of consumption, government expenditures, investment, and exports to GDP growth to identify the key growth drivers that determine the type of growth model. To classify growth models according to the largest growth contribution of demand components, I use the criteria that Baccaro and Hadziabdic (2023) use to distinguish between export-led or consumption-led growth models and models driven by a combination of demand components (balanced or demand-led). The economy is considered to be driven by the demand component if its relative contribution to GDP growth exceeds 40 percent.

To calculate the import-adjusted contributions of final demand components (K) to GDP growth, I apply the following formula:

$$\text{Growth contribution of } K_{imp-adj.} = \frac{\Delta K_{imp-adj.}}{GDP_0}. \quad (1)$$

Ban and Adascalitei (2020), Picot (2021), and Baccaro and Hadziabdic (2023), among others, distinguish between the pre- and the post-financial crisis periods to capture the change in countries' growth models under the strong impact of this exogenous factor. Taking into account that different endogenous and exogenous factors affect countries' growth drivers in different periods to explain the shift in growth models, I divide up the observation period into shorter periods when calculating the growth contribution of demand components. This approach allows us to identify the crucial points that condition growth model change in a specific country.

To measure the growth contributions of import-adjusted final demand components in Poland, I use data from the latest release of the OECD Input-Output Tables database for the period under analysis, i.e., from 2000 to 2018. Ukraine's State Statistics Service provides Input-Output Tables from 2000 to 2019. Data on the contribution of import-adjusted components to final demand growth in Ukraine are available only from 2010, which is explained by the lack of import matrix data in input-output tables before then. In order to measure the relative growth contributions of final demand components from 2000 to 2007, I use non-import-adjusted values for consumption, government expenditures, investment, and exports. The discrepancy in the applied methodology complicates the comparison of growth contributions of demand components and macro-sectors both before and after the financial crisis in Ukraine, but it underlies the identification of dominant demand drivers and, accordingly, the growth model in both periods.

Table 1. Average growth and average relative growth contributions of import-adjusted aggregate demand components

Country	Period	GDP growth	Consumption	Government	Investment	Exports	Growth model
Ukraine	2000–2003	7.39%	20.53%*	7.69%*	36.24%*	35.54%*	Balanced
	2004–2007	7.66%	127.08%*	5.17%*	51.97%*	– 84.23%*	Domestic demand-led
	2010–2013	3.33%	43.60%	6.34%	39.67%	10.39%	Consumption-led
	2016–2019	3.01%	84.06%	28.64%	0.20%	– 12.90%	Very consumption-led
	2000–2007	**7.53%**	**74.78%***	**6.41%***	**44.25%***	**– 25.44%***	Very consumption-led
	2010–2019	**3.17%**	**62.79%**	**16.92%**	**20.94%**	**– 0.66%**	Very consumption-led

Country	Period	GDP growth	Consumption	Government	Investment	Exports	Growth model
Poland	2000–2003	2.69%	43.01%	23.78%	–38.67%	71.88%	Export & consumption
	2004–2007	5.46%	14.99%	10.78%	32.55%	41.68%	Export-led FDI-driven
	2010–2013	2.91%	14.75%	12.87%	5.77%	66.61%	Very export-led
	2014–2018	4.12%	13.27%	13.30%	12.62%	60.81%	Very export-led
	2000–2007	**4.08%**	**24.24%**	**15.07%**	**9.05%**	**51.65%**	Very export-led
	2010–2018	**3.50%**	**13.81%**	**13.15%**	**10.15%**	**62.90%**	Very export-led

Note: * non-import-adjusted values.
Source: own elaboration based on data retrieved from OECD 2021; State Statistics Service of Ukraine 2023.

Table 1 presents the calculated growth contributions of import-adjusted aggregate demand components from 2000 to 2018 for Poland, and to 2019 for Ukraine. The period is divided into four subperiods with average growth contributions to eliminate annual fluctuations. Table 1 also presents aggregated averages from 2000 to 2007 (before the financial crisis) and from 2010 (the first year of growth after the financial crisis) to the last available year.

In the first time interval, from 2000 to 2003, Ukraine had a balanced growth model with a dominant investment component (36.24 percent) and a high export share (35.5 percent) in GDP growth. From 2004, the export growth contribution turned negative simultaneously with a boom in the consumption component of aggregate demand in total output growth. Since 2004–2007, Ukraine's orientation towards consumption-led growth has consolidated and intensified. The investment driver provided the largest contribution to Ukraine's GDP growth during the period from 2000 to 2003. This component of final demand was important for growth in all periods except 2016–2019, which is explained mainly by decreasing FDI inflows as a result of increasing military conflict in Ukraine.

Ukraine's average GDP growth rate halved in the post-financial crisis period (from 7.66 percent in 2004–2007 to 3.33 percent in 2010–2013). Decelerating economic growth can be attributed to the declining role of the investment demand component and a final shift to the consumption-led growth model.

Analysis of average demand component contributions to growth over a longer period indicates a very consumption-led growth model both before and after the financial crisis but does not make it possible to capture the shift in growth drivers. Dividing the period into four four-year subperiods accentuates the temporal shift from reliance on balanced growth driven by investment and exports to the increasing importance of the household consumption component, accompanied by simultaneously falling relative growth contributions from investment and exports. The transition from a balanced (2000–2003) to a domestic-led growth model (2004–2007), subsequently replaced by consumption (2010–2013) and a very consumption-led model (2016–2019), took about two decades, with two exogenous crises in between. The 2008 global financial crisis and the start of Russia's war aggression in Ukraine in 2014 are crucial points in Ukraine's shifting growth model.

Table 1 depicts an important transition between different growth models in Poland forced by the redistribution of growth driver contributions. From 2000 to 2003, Poland's export- and consumption-led economy reoriented its growth profile to become export-led and FDI-driven in the following sub-period (2004–2007). In 2004, the country finalized EU accession and started to enjoy the benefits of membership. It enjoyed sound economic growth caused by early liberalization of trade that boosted exports and a spectacular increase in FDI inflows from the EU15 as major investors (Balcerowicz 2007). The record amount of foreign capital inflow turned the GDP growth contribution of the investment demand component positive and underpinned the shift to an FDI-driven export-oriented growth model. After the financial crisis started, the declining role of the investment component in generating GDP growth also contributed to falling economic growth rates. Boosting exports' relative growth contribution, the country moved further towards a very export-led growth model in the wake of the financial crisis. As a result, the importance of the domestic consumption component of final demand decreased significantly. As in the case of Ukraine, one can observe the change in the Polish growth model only by breaking up the pre- and post-financial crisis periods into sub-periods.

Sectoral shifts in the two economies underlay the modification of their growth models and predetermined growth dynamics.

First, I focus on the importance of manufacturing in generating value added in the two countries to characterize the changes in sectoral distribution in GDP.

Figure 1. Average sectoral share of manufacturing in value added

Source: OECD 2021; State Statistics Service of Ukraine 2023.

Figure 1 indicates important country differences. Poland managed to avoid deindustrialization and experienced slight growth in manufacturing's share in value added. After a marginal decline during 2000–2003, the indicator showed growth in 2004, the year of EU accession. Another growth spurt happened in 2016 when the manufacturing share of value added reached 20.34 percent. The results for Ukraine are more striking. From 2000 to 2008, the country maintained a strong manufacturing performance, providing 26–27 percent of value added. After the global financial crisis, this indicator fell significantly, as the manufacturing share in value added underwent a severe downturn, contracting by around half from 2008 to 2019.

Table 2. Average sectoral shares of GDP growth by value added and final demand perspectives (%)

Period	GDP growth	Manufacturing	Low-end services	High-end services	Public administration	Education and health	Construction	Commodities and energy
Ukraine								
2000–2003	Value added	29.53%	36.18%	13.09%	2.11%	4.93%	10.94%	3.22%
2004–2007	Value added	26.53%	34.27%	20.39%	1.27%	0.47%	12.43%	4.64%
2010–2013	Value added	– 20.99%	31.69%	23.27%	2.37%	6.56%	19.58%	37.54%
	Final demand	– 19.84%	28.92%	10.52%	7.68%	8.05%	15.24%	49.44%
2016–2019	Value added	2.02%	27.19%	22.10%	23.93%	6.93%	14.52%	3.31%
	Final demand	– 19.31%	16.99%	18.52%	15.91%	9.11%	28.07%	30.70%
2000–2007	**Value added**	**28.12%**	**35.28%**	**16.53%**	**1.71%**	**2.83%**	**11.64%**	**3.89%**
2010–2019	**Value added**	**– 10.07%**	**29.55%**	**22.71%**	**12.60%**	**6.74%**	**17.17%**	**21.28%**
	Final demand	**– 19.59%**	**23.26%**	**14.31%**	**11.58%**	**8.56%**	**21.32%**	**40.55%**

Period	GDP growth	Manufac-turing	Low-end services	High-end services	Public adminis-tration	Education and health	Con-struction	Com-modities and energy
Poland								
2000–2003	Value added	2.90%	19.93%	38.60%	0.92%	38.76%	– 10.29%	9.17%
	Final demand	14.05%	21.13%	12.55%	3.24%	41.68%	11.74%	20.60%
2004–2007	Value added	23.67%	26.64%	17.17%	2.46%	5.22%	14.17%	10.67%
	Final demand	27.97%	12.87%	18.17%	5.67%	6.66%	26.71%	2.39%
2010–2013	Value added	10.93%	41.93%	9.77%	3.31%	9.29%	2.93%	21.83%
	Final demand	57.45%	26.97%	4.67%	4.64%	11.09%	5.04%	9.02%
2014–2018	Value added	26.76%	30.54%	19.66%	3.70%	7.51%	12.61%	– 0.79%
	Final demand	27.64%	35.95%	10.56%	4.34%	10.74%	11.29%	0.42%
2000–2007	**Value added**	**16.98%**	**24.48%**	**24.07%**	**1.97%**	**16.02%**	**6.29%**	**10.19%**
	Final demand	**23.36%**	**15.60%**	**16.31%**	**4.87%**	**18.26%**	**21.75%**	**8.42%**
2010–2018	**Value added**	**21.05%**	**34.65%**	**16.09%**	**3.56%**	**8.16%**	**9.11%**	**7.38%**
	Final demand	**38.45%**	**32.70%**	**8.42%**	**4.45%**	**10.87%**	**9.02%**	**3.54%**

Source: own elaboration based on data retrieved from OECD 2021; State Statistics Service of Ukraine 2023.

The dynamics of the manufacturing share in GDP growth are in line with its previously highlighted GDP share. Table 2 presents average sectoral shares in output growth for four subperiods from 2000 to 2019 for Ukraine and from 2000 to 2018 for Poland. Based on the original input-output tables out of 45 economic sectors, I created seven macro-sectors (manufacturing, low-end services, high-end services, public administration, education and health, construction, and commodities and energy) for this research. The prevailing skill level in each sector serves as the criterion to group macro-sectors. I use two different approaches to calculate the importance of macro-sectors in generating GDP growth, both traditional value added and the final demand approach proposed by Baccaro and Hadziabdic (2023).

To calculate the import-adjusted growth contributions of aggregated macro-sectors (S), I use the formula:

$$\text{Growth contribution of } S_{imp-adj.} = \frac{\Delta S_{imp-adj.}}{GDP_0}. \quad (2)$$

The final demand perspective for calculating a sector's contributions to growth is preferred to the value added perspective in an effort to reassess the role of sectors in which goods and services satisfy final demand, in particular manufacturing and construction. By contrast, the value added perspective leads to a clear underestimation of these sectors' importance. Sectoral contributions to final demand growth in Ukraine are presented only from 2010. This is because of the availability of data in input-output tables from Ukraine's State Statistics Service.

The results are striking. From 2010, Ukraine experienced a downward shift in the share of manufacturing in GDP growth calculated from both the final demand and the value added perspectives. First, manufacturing was affected negatively by the financial crisis of 2008–2009 followed by the war in eastern Ukraine that started in 2014, as a result of which it lost part of its industrial base. At the same time, the commodities and energy sector's contribution to final demand growth rose sharply from 2010, rising to 50 percent. Second, the low-end services sector experienced a gradual decline from a final demand perspective. The contribution of the construction, public administration, education and health, and high-end services sectors to both final demand and value added grew significantly, which confirms the consumption-led growth model of Ukraine's economy. Between 2010 and 2019, the value-added perspective shows the contributions of low-end services (29.55 percent), followed by high-end services (22.71 percent), and commodities and energy (21.28 percent).

In Ukraine, the global financial crisis served as the starting point for crucial sectoral shifts. It entailed a transition from a manufacturing and low-end services-oriented economy to a commodity-based one.

The results of calculating sectoral contributions to GDP growth in Poland using both approaches show the strong dominance of manufacturing and low-end services, which increased their shares from 2000 to 2018. This is not surprising for an export-led economy. The exponential growth of the manufacturing sector started in 2004. The similar pattern of construction's contribution to economic growth in 2004–2007, calculated from both perspectives, points to the role of Poland's EU accession, with its subsequent increase in FDI inflows as the main catalyst of sectoral shifts. From 2010, one can observe a decline in construction's share in GDP growth. Education and health, which provided 41.68 percent of final demand growth in 2000–2003, fell to 6.66 percent after 2004. From 2014 to 2018, the commodities and energy sector's contribution to GDP growth declined sharply to 0.42 percent (compared with 20.6 percent in 2000–2003). Both from a final demand and a value added perspective, the share of high-end services fluctuated, with a declining trend during the period under observation. According to the value added approach, between 2010 and 2018, the top three sectors with the largest average shares in value added growth were low-end services (34.65 percent), followed by manufacturing (21.05 percent) and high-end services (16.09 percent).

Joining the European Union in 2004 incentivized the most significant sectoral shifts in Poland because of the growing importance of manufacturing, the declining education and health sector, and a short-term increase in construction's share in GDP growth.

The results indicate the stark contrast between the sectors' contributions to economic growth in the two countries. Since joining the EU, Polish manufacturing has contributed most to final demand, peaking at 57.45 percent in 2010–2013. These results are what one would expect, given the country's export-led growth model.

In Ukraine, the commodities and energy sector has enjoyed the highest average share in final demand growth since the global financial crisis, rising to 49.44 percent in 2010–2013. At the same time, the manufacturing contribution to GDP growth has declined. The growing importance of construction and low-end services has partly substituted for manufacturing in contribution to final demand. The current sectoral distribution underpins Ukraine's consumption-driven growth model with high commodity export potential.

An impulsive move in the direction of deindustrialization fostered the change in dominant growth drivers in Ukraine's economy, accompanying the transition from a balanced to a very consumption-led growth model. For a lower-middle-income country like Ukraine, premature deindustrialization can reduce growth (Rodrik 2016). Rodrik also found that a shrinking manufacturing sector can lead to increasing informality, shifting workers into low-productivity services. This threatens economy-wide productivity and fosters wage moderation. With the exception of a few resource-rich economies, successful growth, together with rapid convergence on the part of developing economies, has historically required industrialization.

FDI and integration into global value chains

Foreign direct investment (FDI) has become an important source of economic growth, development, and modernization for developing, emerging, and transition economies (OECD 2002). Both Poland (before 2017) and Ukraine can be categorized in this way.

FDI helps to fill the gap between savings and the required level of investment (Sabir and Khan 2018), attract new knowledge and provide technological transfer from developed to developing countries (Chenaf-Nicet and Rougier 2016), improve human capital skills and knowledge, reduce unemployment, boost productivity, enhance business competitiveness, and contribute to international trade integration. All these benefits increase a country's industrial and export potential, contributing to higher economic growth and social standards.

In the late 1990s, falling behind in terms of global competitiveness, post-socialist CEE countries "responded to external dynamics by competing with each other [by] institutionalizing an economic growth model that relied heavily on FDI" (Ban and Adascalitei 2020). As a result, the FDI-led growth regime replaced the wage-driven growth model with credit-based consumption (Grittersová 2017).

A number of research studies attribute successful Polish growth to its geographical proximity to Western European countries and the resulting FDI flow (Balcerowicz 2007; Breznitz and Ornston 2017; Ghodsee and Orenstein 2021). Recognizing the leading role of the Polish economy in CEE growth, Piatkowski (2014) proposed a new growth model to enable "New Europe" to converge with Western Europe, which he called the "Warsaw Consensus." This new growth model is based on ten pillars, including high domestic savings and investment, diversified exports, full integration in the EU market, and further EU enlargement.

In 2004, eight CEE countries, including Poland, joined the European Union. Poland took full advantage of its membership, receiving substantial subsidies, significant funds for large-scale infrastructure projects, and attracting more foreign investment.

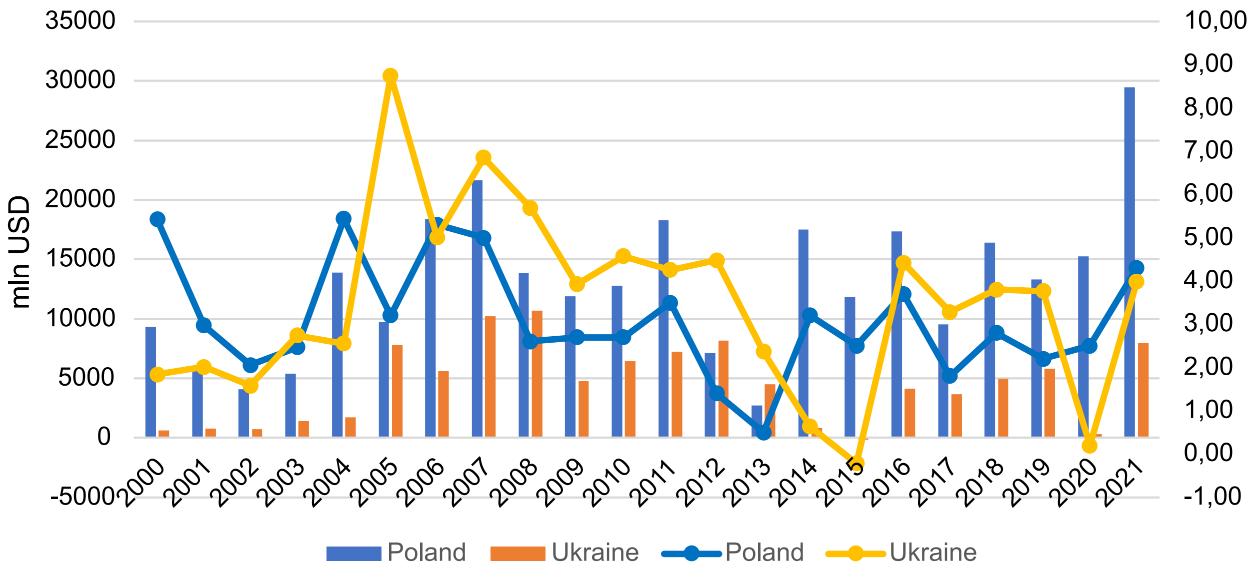

Figure 2. Foreign direct investment (net inflows)

Source: OECD 2023a; World Bank n.d.

Figure 2 shows that in the year of EU accession (2004), Poland experienced a two-and-a-half-fold increase in FDI compared with the previous year. In relative terms, the volume of FDI reached a peak of 5.4 percent of GDP. From 2004 to 2007, FDI inflows flourished in both absolute and relative terms, making the largest contribution of the investment component to GDP growth. In the following years, FDI inflows fluctuated but did not exceed this value. According to UNCTAD (2021), in 2020, Poland achieved US$24.3 billion of greenfield inflows, putting the country in fifth place in global rankings after EU leader Germany.

According to the OECD's international direct investment database, in 2021, Polish inward FDI flows were predominantly in manufacturing (36.2 percent), professional, scientific and technical activities (20.2 percent), wholesale and retail (16.2 percent), and real estate

(9.9 percent). In the manufacturing sector, the most attractive destinations for foreign capital were metal and machinery products (10.0 percent), vehicle manufacturing (6.9 percent), and chemical production (5.7 percent).

Like Poland, Ukraine experienced its highest FDI inflows from 2005 to 2008, during the global economic boom. During this period, significant investments flowed into the banking sector. After the 2009 recession, FDI recovered, but the beginning of the war in 2014 dealt a significant blow to investor confidence.

The National Bank of Ukraine (2023) reports that inward FDI was concentrated in manufacturing (55.2 percent), agriculture (15.4 percent), wholesale and retail (9.0 percent), and financial and insurance activities (8.8 percent). Comparing the FDI sectoral profiles in Ukraine and Poland, Ukraine's higher share of FDI inflows in manufacturing attracts attention. A more detailed view of FDI distribution by economic activity indicates Ukraine's low value added orientation, which attracts investment mainly in mining (23.6 percent) and metal production (13.8 percent).

Ukraine has been slow in attracting FDI. On average, the volume of FDI inflows in Ukraine is only 20 to 25 percent that of Poland.

A significant part of foreign investments in Ukraine is, in fact, "domestic" investments structured through foreign jurisdictions (based on the registration of holding companies). According to NBU estimates (National Bank of Ukraine 2023), during the period 2010–2022, "round-tripping transactions" used to redistribute FDI flows from the ultimate investing countries represented, on average, 28 percent of Ukraine's foreign direct investment inflow compared with only 5 percent in Poland. In 2021, round-tripping reached 68.5 percent of total FDI inflows. The largest volumes of round-tripping transactions were routed through Cyprus, the Netherlands, Switzerland and Austria, which are the top direct investing countries in Ukraine.

Investors use round-tripping through offshore centers to benefit from preferential tax treatment. Aykut, Sanghi, and Kosmidou (2017) stress that investments on this basis may result in tax revenue and welfare losses or illegal activities, such as corruption or money laundering. Such investments do not enhance the country's inclusion in value added networks or technology transfer. This maintains the current raw material-oriented export structure. In an institutionally distorted economy such as Ukraine's, round-tripping cements concentrated asset ownership. This sheds light on the volume of real FDI inflows, which are much lower after leaving out indirect transactions.

Poland's success in attracting FDI results from a number of factors, including a growing economy, a large domestic market, EU membership, a stable banking sector, and skilled labor at a competitive price. According to Eurostat, average hourly labor costs in Poland were estimated at €12.5 in 2022 compared with an average of €34.3 in the Eurozone as a whole.

An FDI focus promotes the embedding of national firms in global production networks, which serves to enhance economic development. The position of these firms in global value chains affects GDP growth. The theory of global value chains, combined with the concept of a "franchise economy," as set out by Schwartz (2021), determines the dominant organizational level occupied by domestic firms in global production networks and explains investment trends. Characterizing a shift from Fordism to a "Knowledge Economy," Schwartz highlighted the transformation of the old Fordist dual organizational structure into a tripartite structure, depressing investment and mass consumption. A three-tier "franchise industrial structure" comprises high-profit volume monopolies based on intellectual property rights (top layer), physical capital-intensive firms (second layer) and low-profit labor-intensive manufacturing and service production (third layer).

To characterize the two countries' position in the tripartite organizational structure, I analyze their level of integration into global value chains and their export structure in terms of product categories.

The foreign value added content of gross exports indicates the level of an economy's integration in global value chains. To characterize these measurements, I used the 2023 edition of the *Trade in Value Added* (TiVA) database from OECD Statistics and the World Trade Organization (WTO), which provide data on 76 economies (including Ukraine) over the period 1995–2020. The TiVA estimates are derived from OECD Inter-Country Input-Output tables. For this research, I used data for the two countries and aggregated statistics for the EU that cover the years 2000–2020.

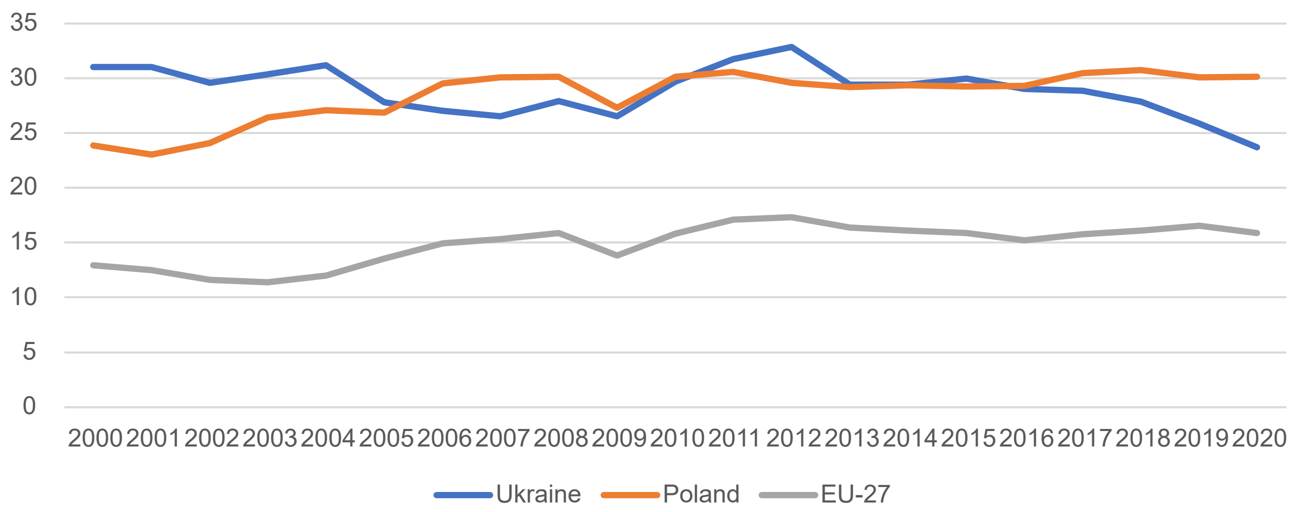

Figure 3. Foreign value added share of the countries' gross exports (backward participation in global value chains)

Source: OECD 2023b.

Figure 3 shows that Ukraine had a higher share of foreign value added in gross exports than Poland during the two subperiods (2000–2005 and 2011–2015). The EU's estimations are, on average, half the country-level values. Considering the dynamics of the share of imported semi-finished products, components, and materials in exports, one can observe Polish growth from 24 percent in 2000 to 30 percent in 2020, while Ukraine's rate trended downward from 31 to 24 percent over two decades. The growth of EU integration has contributed to increasing Poland's backward participation in global value chains.

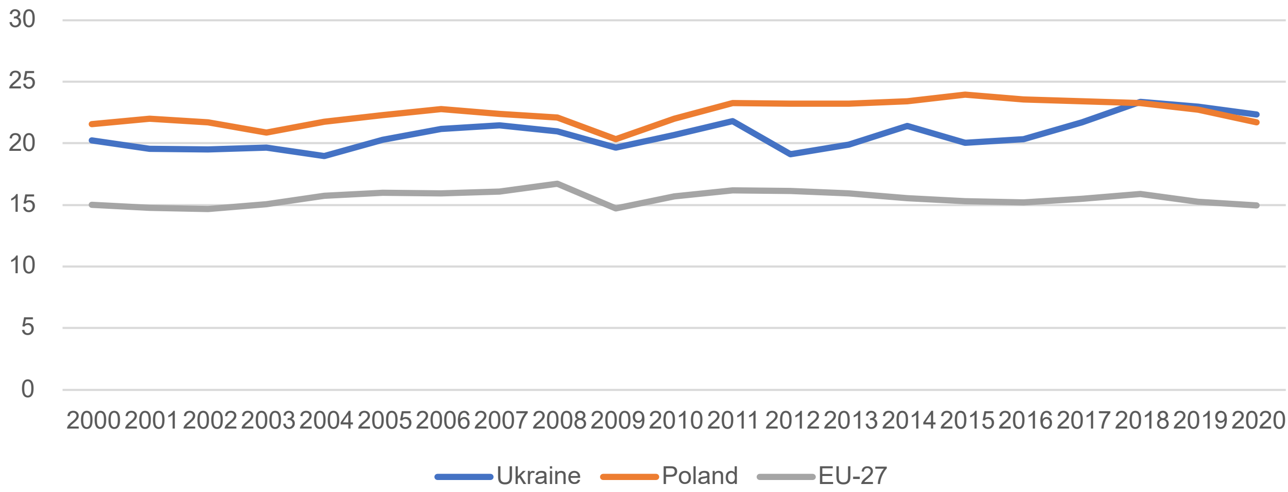

Figure 4. Domestic value added in foreign exports as a share of gross exports (forward participation in global value chains)

Source: OECD 2023b.

Figure 4 shows that Poland slightly outperforms Ukraine in terms of forward participation in global value chains during the whole period observed. Its share of domestic value added in foreign exports as a share of gross exports fluctuates between 20 and 24 percent, which is above the EU average.

A closer look at global value chains from the two countries' perspectives indicates their high level of integration in global trade. Market opening, together with EU accession, contributed to the growth of Poland's backward participation in global value chains, while Ukraine's foreign value added content of gross exports shrank at the end of the period under observation. This resulted in changes in the export product structure.

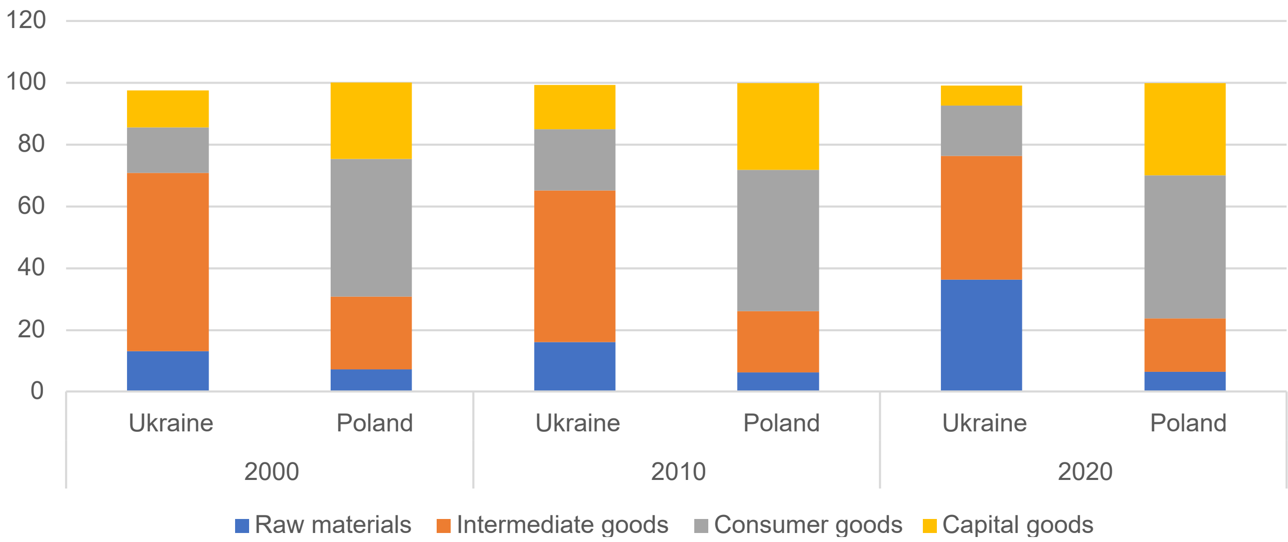

Figure 5. Export product share in Ukraine and Poland

Source: UN Commodity Trade Statistics Database n.d.

The distribution of exports between product categories presented in Figure 5 shows the increasing trend of commodity specialization in Ukraine. The percentage of raw materials in total exports grew from 13.1 percent in 2000 to 36.3 percent in 2020. Exports of intermediate goods declined in relative terms from a maximum of 57.8 percent to 40 percent in two decades. These two product categories accounted or 76 percent of total exports in 2020, determining Ukraine's focus on upstream participation in manufacturing activities in global value chains. The relative share of capital goods exports shrank from 12 percent in 2000 to 6.5 percent in 2020. According to Ukraine's State Statistics Service, agriculture, forestry and fisheries, extractive industry, metallurgy, food production and other low value added industries accounted for the largest share of exports in Ukraine in the past decade.

Poland's export product structure is completely different. Figure 5 shows the substantial growth in capital goods in relative terms from 24.6 percent in 2000 to 30 percent in 2020 and a moderate increase in the share of consumer goods from 44.6 percent in 2000 to 46 percent in 2020. Exports of intermediate goods dropped by 6 percent in relative terms over the past two decades to reach 17.3 percent in 2020, which is 2.5 times less than Ukraine's value.

Figure 1 and Table 2 present evidence that in Poland, manufacturing's share of GDP growth is higher than its sectoral share of GDP. This confirms the increasing complexity of manufacturing in general and its exports in particular. According to the UN Commodity Trade Statistics Database (n.d.), in Poland, the share of high-technology exports increased from 4 percent in 2007 to 9 percent of manufactured exports by 2021, although it still lags behind the EU average of 15 percent. In Ukraine, this indicator was

5 percent in 2021. In Ukraine, the share of the commodities and energy sector in GDP and GDP growth has been increasing, constituting the bulk of exports.

The results confirm that Ukraine is highly integrated in global value chains as a supplier of intermediate goods. For most industrial and high-tech goods, Ukraine occupies the left (or lower) part of value chains, ranging from being a supplier of raw materials to a producer of semi-finished products and components. Accelerating GDP growth requires increasing exports of goods and services, which provide higher value added growth (Venger, Romanovska and Chyzhevska 2022). Given that manufacturing, like any other sector of the economy, is capable of building complex and deep value chains, broad deindustrialization hampers a country's efforts to climb up value chains.

In accordance with the country's three-tier economy, Ukrainian companies predominantly occupy the niche of labor-intensive manufacturing and services within the industrial structure, de facto controlled by top-level foreign firms (Schwartz 2021). The third layer has a weak investment propensity caused by the hyper-exploitation of labor, which results in low productivity. Focusing on low-profit, labor-intensive manufacturing and services in global value chains preserves the country's FDI-deficit status and hinders growth opportunities.

As in Ukraine, most Polish companies belong to the third layer. Gołębiowska (2017) asserts that Poland participates in global value chains through the import of foreign technologies and raw materials, using them in labor-intensive sectors that generate the lowest value added. The transition to the physical capital-intensive organizational level in the commodity chain is hindered by an investment barrier to entry. Although Poland outperforms Ukraine in terms of share of high value-added exports, it still lags far behind Germany, which has a distinct second-layer economy with dominant physical capital-intensive firms.

Despite the success of the Polish growth model and the country's escape from the "middle-income trap," after moving from middle to high-income status, Poland still faces the risk of stagnant economic growth. The deceleration of total factor productivity growth and a weak innovation system are expected to make it difficult for Poland to maintain its growth pace (Breznitz and Ornston 2017).

Upgrading the export structure and moving up value chains are challenging for both the Ukrainian and the Polish economies but promising in terms of national development. Boosting research and development to come up with capital-intensive products requires significant growth in funding and enhancement of the policy framework for research and technological development.

At the same time, in intra-regional competition Poland has taken advantage of regional value chains and provides the largest basis for German manufacturing, which is

Europe's major direct investor. According to Eurostat data, Germany has become Poland's biggest trading partner, accounting for 27.8 percent of Poland's export value and 20.2 percent of total imports in 2022. Services trade with Germany shows a similar picture. The Polish economy has benefited from integration into global value chains with increasing value added of its exports, shifting to a distinctive export growth model that has conferred the status of the EU's growth champion.

Against the background of international companies moving industrial sites from China and Russia to other regions after the war is over, Ukraine will gain additional opportunities to receive relocated facilities and create new ones. Proximity to European markets, developed transport and energy infrastructure, relatively cheap qualified workers, and a highly developed information and communication technology sector are among the factors enabling Ukrainian industrial companies to enter European value chains.

Conclusion

The paper represents the first attempt to provide a comparison of Ukraine's and Poland's economic growth paths, tracing the changes in dominant final demand components and macro-sectors in the two countries' economic growth profiles.

Taking its inspiration from the burgeoning growth-model literature, the paper looks at the benefits of switching growth drivers to restart Ukraine's economy by emulating Polish growth.

The presented results of country-level analysis of the relative contributions of various aggregate demand components to GDP growth led to the following conclusions.

First, having started the transition from similar growth models at the beginning of the 2000s, Ukraine's and Poland's growth paths diverged. Differing in the speed and depth of their structural transformations from 2000 to 2003, the two European post-socialist economies relied on both exports and domestic consumption drivers. Subsequent years saw a cleavage between the distinct export orientation of Polish growth and the consumption-led model of Ukraine's economic growth.

Second, rather than the global financial crisis, Poland's EU accession in 2004 impacted the shift of the Polish growth model from both consumption and exports to a distinctive export-led FDI-driven model. As a new EU member, Poland experienced a considerable increase in FDI, which was concentrated predominantly in manufacturing. Combined with expanded trade integration in the EU, the growth of FDI stock fostered the country's export orientation. The global financial crisis promoted further redistribution of growth drivers towards the enhancement of exports, accompanied by a declining relative contribution of investment and consumption components to final demand that confirmed the country's shift to a very export-led growth model in the post-financial crisis period. The crucial changes in the country's growth model were observed by dividing the pre- and post-financial crisis periods in Poland into sub-periods within the framework of GDP growth decomposition to demand components.

Third, the declining role of the investment driver in economic growth and a shift from a balanced to a consumption-led growth model in Ukraine resulted in decelerating GDP growth. From 2000 to 2003, investment was the major determinant of the country's economic growth. From 2004 to 2007, it was succeeded by consumption, followed by the investment component of aggregate demand. After the global financial crisis, the underuse of the investment driver of GDP growth, along with a rising consumption-led orientation, led to fading growth rates in Ukraine. Unlike Poland, with its booming manufacturing share in GDP growth, after the world financial crisis and war in the industrialized eastern part of the country, Ukraine went through tough deindustrialization, cementing its focus on the commodities and energy sector. Unsurprisingly, therefore, this sectoral shift underpinned the economy's transition to a consumption-led growth model.

Fourth, Poland outperforms Ukraine in terms of the share of high value added exports. Focusing on low value-added exports means that Ukraine is left behind as regards the distribution of the fruits of capitalism and maintains the country's FDI deficit status. This hits its growth opportunities.

These findings are a contribution to the comparative political economy literature on the growth models of peripheral economies, providing insights that can inform policies for growth model transformation. Drawing on the Polish growth model's success, I proposed activating the FDI driver of Ukraine's economic growth in the direction of upgrading its export structure and moving up value chains to unlock the country's growth opportunities. Ukraine is on track towards EU accession, which could push the changing Ukrainian growth model towards boosting the investment component of final demand.

The study has some limitations. Due to data availability, I calculated the contribution of import-adjusted demand components and aggregated macro-sectors to final demand growth in Ukraine only from 2010. I did not employ a quantitative framework to estimate the relative importance of the different factors that determine FDI inflows. Furthermore, the impact of institutional quality in general and of the different components of FDI inflows on growth-model change could be investigated in subsequent studies.

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Kalibracja modelu wzrostu Ukrainy. Jak Ukraina może powtórzyć sukces rozwojowy Polski?

Niniejsze opracowanie prezentuje analizę porównawczą ścieżek wzrostu gospodarczego Ukrainy i Polski z perspektywy modelu wzrostu i określa, w jaki sposób należy skalibrować model wzrostu Ukrainy, aby był zbieżny z dynamicznym rozwojem gospodarki polskiej. Metodologia obejmuje podejście do operacjonalizacji modeli wzrostu w celu dekompozycji wzrostu PKB na komponenty popytu „skorygowane o import", na podstawie krajowych danych dotyczących nakładów i wyników z lat 2000–2019. Zauważono, że w latach 2000–2003 obie gospodarki europejskie rozwijały się w oparciu o eksport i konsumpcję krajową. Rozszerzona integracja handlowa i wzrost BIZ po przystąpieniu Polski do UE w 2004 r. przyspieszyły przejście polskiego modelu wzrostu w kierunku strategii opartej na eksporcie oraz BIZ z przyspieszonym tempem wzrostu PKB. Na Ukrainie, w następstwie wielkiego kryzysu finansowego, zaobserwowano przejście w kierunku modelu wzrostu opartego na konsumpcji, który wraz ze spadającym komponentem inwestycyjnym zagregowanego popytu doprowadził do zaniku stóp wzrostu. Analiza wkładu poszczególnych sektorów gospodarki we wzrost PKB wykazała, że zapobieganie deindustrializacji w Polsce stanowiło podstawę strategii eksportowej tego kraju, w przeciwieństwie do Ukrainy, która przeszła po 2008 roku kluczową zmianę sektorową z produkcji na orientację opartą na sprzedaży towarów. Obie te gospodarki wykazały wysoki poziom integracji z globalnymi łańcuchami wartości, koncentrując się na pracochłonnej produkcji i usługach, ale Polska wyprzedziła Ukrainę pod względem udziału eksportu o wysokiej wartości dodanej, który wzrósł po przystąpieniu do UE. Podążając za polskim wzorcem, zaproponowano, aby model wzrostu Ukrainy pobudził siłę napędową wzrostu gospodarczego poprzez polepszenie struktury eksportu i zwiększenie łańcuchów wartości, aby odblokować możliwości wzrostu tego kraju. Opracowanie to jest pierwszym porównaniem ścieżek wzrostu gospodarczego Ukrainy i Polski, które śledzi zmiany dominujących komponentów popytu końcowego i makrosektorów w profilach wzrostu gospodarczego obu krajów. Niniejszy artykuł stanowi wkład do literatury porównawczej z zakresu ekonomii politycznej na temat modeli wzrostu gospodarek peryferyjnych, dostarczając spostrzeżeń, które mogą stanowić podstawę polityki transformacji modeli wzrostu.

Słowa kluczowe: model wzrostu, wzrost gospodarczy, produkcja, BIZ, Ukraina, Polska