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The path to Industry 4.0: The evolution of industry in the national economies of the European Union in 2009-2020

Michał Niewiadomski, Agata Niemczyk, Zofia Gródek-Szostak, Jacek Strojny

A B S T R A C T

Objective: This study aims to present the economies of EU countries in the context of transformations in the industrial sector to increase the share of branches with higher technological intensity (changes in the industrial turnover structure). The analysis was carried out at different time horizons.

Research Design & Methods: Research has a quantitative character. The vector elimination method was used to analyse the industrial turnover structure from 2009 to 2020 in 17 EU countries, based on EUROSTAT data.

Findings: The research identified the following national economies: 1) with intensive and long-term but not permanent changes in the structure during the study period; 2) stagnated in the industrial turnover structure due to high-tech; 3) with unambiguous transformations in their industrial turnover structures due to high-tech, aimed at the development of medium-high-tech industries. The research identified countries in which industry did not undergo significant transformations or these transformations were relatively slow. The adopted research hypothesis was confirmed.

Implications & Recommendations: The observed structural changes in the industries of the studied countries allowed us to identify ongoing transformations and assess their stability. Currently, transformations in the industrial sector are associated with innovation and the implementation of new technologies. The development of modern industries in the EU countries affects the economic position on the international stage. Therefore, it is reasonable to constantly monitor the changes that take place in the industrial structure of individual countries, which can provide important recommendations to their respective governments. The results of the research indicate the development directions for the industrial sector, which can significantly facilitate the introduction of regulations that support the development of modern industries.

Contribution & Value Added: The novelty of the paper is that it illustrates changes in the industry turnover structure due to the advancement of technology. The rule of Industry 4.0 development was confirmed, although with uneven dynamics in respective European economies. It will be interesting to study this phenomenon in the future given the impact of the pandemic and the war in Ukraine on the studied phenomenon. The applied method proved useful for this type of analysis and was deemed useful in other areas of studies of the turnover structure in other markets, such as nutrition, which will be undertaken by the authors in the future.

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INTRODUCTION

The industrial revolution has come a long way. It started with the water and steam drive to mechanize production (First Revolution). Next, there was the electric drive, enabling mass production and the division of labour (Second Revolution), followed by production automation, using electronics and IT (Third Revolution), as well as cyber-physical systems, and the internet of things and services (Fourth Revolution)

(Siuta-Tokarska, 2021). The latter, also called Industry 4.0, connects the cyber and physical worlds, revolutionizes the production and delivery of goods and services by connecting products, processes, and consumers (Lee, 2015; Teixeira & Tavares-Lehmann, 2022). Industry 4.0 leverages many new technologies (Zhang & Chen, 2020; Adamczyk & Gródek-Szostak, 2022), such as the internet of things (IoT), artificial intelligence (AI), cloud computing, autonomous robots, and sensors (Xu, 2020). As they are implemented more extensively, they impact the evolution of the industrial sector. These changes are reflected in the structure of industrial turnover. At the same time, customers are kept informed about the latest production developments (Bai *et al.,* 2020; Ghobakhloo, 2020; Furstenau *et al.,* 2020).

Manufacturing methods and processes have developed over the decades, allowing companies to increase production, efficiency, and productivity (Luthra & Mangla, 2018; Sharma *et al.,* 2021). The comparative advantage of developing countries in terms of low-skilled and low-cost production is threatened by the increasing automation of repetitive, low-skilled tasks. Today's hub infrastructure increases efficiency and cuts some costs. It also reduces capital costs and delays overseas export to lower-wage countries (Burritt & Christ, 2016; Bonilla *et al.,* 2018; Brozzi *et al.,* 2020).

Industry 4.0 is therefore characterized by a combination of smart products, smart factories, smart logistics, and the internet of things to enable real-time information on a number of operations throughout the supply chain (de Sousa Jabbour *et al.,* 2017). Liu *et al.* (2020) predict that the new era of smart production will be driven by the principles of sustainable development. Along with its technologies, Industry 4.0 is a new business mindset that helps organizations transition to sustainable development. Smart systems that take advantage of the possibilities of Industry 4.0 have several consequences in terms of sustainable development, such as an optimized use of resources and technology (Quezada *et al.,* 2017; Felsberger *et al.,* 2020).

The transformations in question are also determined by the state of the economy of a country resulting from its social, economic, or technological capabilities, *i.e.* its potential. Bearing this in mind, an attempt was made to fill the research gap and to recognize the structures of industry in the economies of EU member states that have appeared on the way to the Fourth Industrial Revolution. Hence, we formulated the following research question:

RQ: What is the time span of transformations in the industrial sector, which are to increase the share of high-tech industries?

The structure of industrial turnover was analysed within a twelve-year period.

The research hypothesis is as follows. Among the national economies that undergo industrial transformations that increase the share of high-tech sectors over time, some countries undergo this transformation in a short period. The applied research methodology was desk research. The analysis was based on a public dataset from EUROSTAT in 17 EU counties between 2009 and 2020. The vector elimination method was used in the study.

The following section will review the related literature on the subject and develop the hypotheses to be verified in the article. Section 3 will describe the methods and data used, while section 4 will present the results of the analysis. Section 5 will provide conclusions.

LITERATURE REVIEW (AND HYPOTHESES DEVELOPMENT)

The term 'Industry 4.0' appeared in the strategy of the German industry project in 2011. It was approved in 2015 at the World Economic Forum (WEF) in Davos and used in the book by Schwab (2017), the founder and president of WEF. In this aspect, please note how Ślusarczyk (2019) comments on the concept of Industry 4.0, *i.e.* that it was created by the German government as an attempt to mitigate the effects of the global financial crisis (2007-2009). At the request of the German government, in 2014, the 2011 concept became the national strategy for the development of the German economy (Rao & Prasad, 2018).

From the historical point of view, Kondratiev's observations on Industry 4.0 seem to be significant, as he had identified the waves of economic changes in time intervals. In his research, he distinguished three waves of similar duration (Kondratiev, 1935; Tinbergen, 1981). Kondratiev found that long business waves are caused, *e.g.* by the expansion of capital goods. The stimulus to induce change is technical progress that occurs in waves. This concept was developed by Schumpeter (1934), who pointed to three economic waves related to the emergence of breakthrough technical or technological developments. Kondratiev's theory is not accepted by most academic economists. However, it is generally agreed that Kondratiev waves are based on pattern recognition. On the other hand, the authors of this study believe that it was Kondratiev, who was the first to emphasize the importance of technological progress for economic development, which is reflected in the contemporary concepts of Industry 4.0.

The Fourth Industrial Revolution involves the implementation of new technologies in the processes of business digitalization (Ghobakhloo, 2018). According to Čater (2021), Muller *et al*. (2018), and Nosalska *et al.* (2019), the main benefits brought about by the introduction of new technologies are: increased productivity, resource savings, process transparency, higher quality, improved working conditions, and more profitable business models. However, according to Terziyan *et al.* (2018), Industry 4.0 is a new way of operating in business (in terms of production and management). The authors believe that Pereira and Romero (2017) were correct in saying that the implementation of Industry 4.0 is beneficial to many areas. For example, it improves production, provides new business and economic opportunities, and affects the transformation of the current environment.

Many authors of works on Industry 4.0 indicate that the main pillars of its development are the development of the internet, ICT technologies, the internet of things and big data (Woźniak *et al.,* 2018; Boyes *et al.*, 2018, Zhong *et al.*, 2017). Technological progress causes dynamic changes in the industry, but as Woźniak *et al.* (2018) emphasize, it is a complicated process that requires knowledge and determination. New technologies are currently a factor enabling changes in standard methods of production. Currently, in the relationship between industry and market, four basic production paradigms can be distinguished in the periods of industrial production. These include craft production, mass production, mass customization, and personalized production (Furmanek, 2018). These last two paradigms can be implemented only thanks to the development of modern technologies and knowledge of consumer preferences. This requires conducting detailed qualitative research and big data statistical analyses. As emphasized by Furmanek (2018) and Ciechomski (2015), product customization is applied in the automotive, jewellery, clothing, and footwear industries. Flexible, programmable production lines are of key importance to the process as they enable the expansion of the product range at a cost comparable to mass production.

Another important factor in the Industrial Revolution 4.0 is its impact on labour. Bendkowski (2017) and Ittermann *et al.* (2015) argue that it is impossible to assess it unequivocally. On the other hand, other authors point to the process of replacing human labour with high-tech machines (Schlund *et al.*, 2014). When analysing the impact of Industry 4.0 on labour, two main concepts can be identified. One has negative connotations, *i.e.* that employees' know-how will be replaced by software. The other is positive, namely that Industry 4.0 will increase employment in response to reindustrialization processes (Bentkowski, 2017). Today, industry includes not only basic machines and production devices, but also IT and customer service systems. Industry 4.0 is based on technologies that integrate the exchange of information between devices, systems, and people. Its idea is to provide access to information anytime, anywhere. According to Wittbrodt and Łapuńka (2017), these aspects should be strongly integrated and connected. Production companies will therefore integrate systems at various levels (Qina *et al.*, 2016).

Industry 4.0 is associated with the implementation of radical innovations that increase efficiency. Novelty and originality create new markets or change the rules of their functioning (one perfect example is marketplaces). Another characteristic feature of Industry 4.0 is the lack of specific manufacturing structures. However, control over industrial processes can be executed by advanced IT systems implemented at various hierarchical levels. In this case, they constitute the framework for the functioning of industrial enterprises.

Despite the growing importance of services, industry is still an important element of countries in the economies of the European Union. Historically, until the 1990s, this sector was undergoing slow and abrupt transformations. The most intense changes in the industry were observed at the turn of the twenty-first century. The reasons for the transformations of the industrial sector are related to innovation and technology development. As a result of the development of economies, production processes were automated, with particular emphasis on data exchange. Industry is not a single technology, but a cluster of interconnected technologies. These days, companies are slowly learning how to use technologies that are interconnected using communication protocols and increase the productivity of the industry, especially high-tech. As they are implemented more extensively, they impact the evolution of the industrial sector. These changes are reflected in the structure of industrial turnover. By nature, the changes in question do not appear at the same time in all economies of EU countries, which allows for the verification of the adopted research hypothesis:

H: Among national economies undergoing industrial transformations that increase the share of high-tech sectors over time, some countries undergo this transformation in a short period.

RESEARCH METHODOLOGY

Theoretical Issues Related to the Vector Elimination Method

For the purposes of this study, the vector elimination method was used to analyse the structure of industrial turnover in 2009-2020, because it allows for isolating groups of objects with a similar structure from a cluster (Wasilewska, 2009). The vector elimination method allows for assessing the regularity of economic development. It is easy to use and at the same time, it allows for statistical and substantive analysis of the phenomenon.

The vector elimination method was developed by Chomątowski and Sokołowski (1978). It allows for dividing a set of objects into groups per similarity of their structure. Homogeneous groups are separated following a comparison of objects using the 'peer-to-peer' method (Strojny, 2013). The structures of the studied objects in this study were compared by dissimilarity (Kukuła, 1996).

$$v_{jp} = \frac{\sum_{i=1}^{k} |\alpha_{ij} - \alpha_{ip}|}{2}, \quad (j, p = 1, 2, \dots, r) \tag{1}$$

In which:

α_{ij} - share of the *i*-th structure component of the *j*-th object;

α_{ip} - share of the *i*-th structure component of the *p*-th object.

The coefficient v_{jp} ranges from 0 to 1. If its value is 0, the structures of objects p and j are identical. The coefficient v_{jp} takes the value 1 when the structures of the compared objects do not show any similarity. The higher the value of the factor v_{jp}, the more the structures of the examined objects differ from each other (Luty 2012).

Using the coefficient v_{jp}, a structural differentiation matrix was created. The elements on the matrix diagonal take the value 0, which means that the object was compared with itself (Kukuła 1996):

$$v = [v_{jp}] = \begin{bmatrix} 0 & v_{12} & v_{13} & \dots & v_{1r} \\ v_{21} & 0 & v_{23} & \dots & v_{2r} \\ \dots & \dots & \dots & \dots & \dots \\ v_{r1} & v_{r2} & v_{r3} & \dots & 0 \end{bmatrix}, \qquad (\mathrm{j}, \mathrm{p} = 1, 2, \dots, \mathrm{r}), \qquad v_{jp} = v_{pj} \tag{2}$$

In the next stage of the research, the threshold value of structure differentiation ε was established. It was determined based on the arithmetic mean of the non-diagonal elements of the matrix. Specifying the value of the parameter ε allowed us to create the matrix w_{jp} with v_{jp}. This transformation was based on the following assumption:

$$w_{jp} = \begin{cases} 0, if\ v_{jp} < \varepsilon \\ 1, if\ v_{jp} \geq \varepsilon \end{cases} \tag{3}$$

The division of objects into groups was performed using the following algorithm (Kukuła, 1996):

1. Each row of the matrix w_{jp} was summed up and the vector w_{j0} was created according to the formula:

$$w_{j0} = \sum_{p=1}^{r} w_{jp}, \quad (j = 1, 2, \dots, r) \tag{4}$$

2. he maximum value of the vector w_{j0} was identified and the object was eliminated by deleting the corresponding row and column.
3. Each row of the reduced matrix w_{jp} was then summed up again and a new vector w_{j0} was thus obtained. Then the maximum value of the vector w_{j0} was determined and another object was removed from the reduced matrix w_{jp}.
4. The operation was repeated from point 3 until all components of the vector w_{j0} took the value 0.
5. Objects corresponding to the rows in the matrix w_{j0} constituted the first group with a similar structure.

This algorithm was applied to the set of eliminated elements. Repeating the procedure formed a second group. The presented course of action was repeated until all objects were grouped.

The use of the vector elimination method allowed for the formation of clusters. The initial groups formed typical structures that showed features of many objects. The last groups, on the other hand, consisted of a few objects with atypical structures.

The Database

The subject of the study was the structure of industrial turnover as per technological advancement in selected EU countries (Austria, Belgium, Denmark, Finland, France, Italy, Netherlands, Poland, Portugal, Romania, Spain, Czech Republic, Germany, Hungary, Slovakia, Estonia, Greece) in the years 2009-2020.

The above classification of industry turnover was carried out according to Eurostat guidelines (Eurostat Statistics Explained, 2022). The European Statistical Office presents the statistics regarding the manufacturing industry by technology intensity. Based on the statistical classification of economic activities in the European Community (NACE), Eurostat compiles data aggregates related to high-tech, medium-high-tech, medium-low-tech, and low-tech (Eurostat, 2015).

At the time of the research, some of the records in the Eurostat database concerning industry turnover in several categories for European Union countries, such as Bulgaria, Croatia, Cyprus, Ireland, Lithuania, Latvia, Luxembourg, Malta, Slovenia, and Sweden, had significant gaps. Therefore, these countries were not included in the analysis.

The completeness of the data used to conduct the study was important. Therefore, for the selected countries, aggregates of the industrial turnover structure, which had significant data gaps, were eliminated. These include the manufacturing of tobacco products, clothing, and leather products, the production of coke, crude oil products, chemicals and chemical products, repair and installation of machinery and equipment, as well as the production of basic pharmaceutical products and preparations.

Based on a list of available aggregates related to high-tech, medium-high-tech, medium-low tech, and low-tech (NACE Rev. 2 2-digit level, Eurostat Statistics Explained, 2022) the structure of industrial turnover was created as per the level of technological advancement. The main components of the structure were included the following aggregates:

Major component 1: high-tech industry turnover.

Aggregate: production of computers, electronic and optical products.

Major component 2: medium-high-tech industry turnover.

Aggregates: manufacture of electrical equipment; manufacture of machinery and equipment n.e.c.; manufacture of motor vehicles, trailers and semi-trailers; manufacture of other transport equipment.

Major component 3: medium-low-tech industry turnover.

Aggregates: manufacture of rubber and plastic products; manufacture of other non-metallic mineral products; manufacture of basic metals; manufacture of fabricated metal products, except machinery and equipment;

Major component 4: low-tech industry turnover.

Aggregates: production of food; production of beverages; manufacture of textiles; manufacture of wood and cork products, except furniture, manufacture of articles of straw and plaiting materials; manufacture of paper and paper products; printing and duplication of recorded information carriers; production of furniture; remaining production.

RESULTS AND DISCUSSION

The study of the turnover structure allowed us to select sectors that played an important role in the industry in the economies of individual countries. The analysis also allowed for observing the directions of the transformation of economies in terms of industry.

Groups of objects that showed structural similarity were separated using the vector elimination method. The process of grouping the structures was influenced by the alpha coefficient, established based on the arithmetic mean of the non-diagonal elements of the matrix that represents the structural differentiation of the examined objects. The cut of distance for similar groups was $\alpha = 0.191$. The pairs of objects with a lower degree of differentiation than α were classified in the same group.

The turnover records of high-tech, medium-high-tech, medium-low-tech, and low-tech industries were converted into percentages. In total, 17 countries were classified in 12 periods and 8 subgroups with a significant degree of differentiation were selected. The numbers of the largest clusters were as follows: 106 – the first group (approximately 52% of the population), 48 – the second group (approximately 23% of the population), 19 – the third group (approximately 9% of the population), 15 – the fourth group (approximately 7% of the population) (Table 1). The remaining observations from groups 5 to 7 accounted for approximately 8% of the group.

Table 1. Percentage shares of observations in groups selected by the vector elimination method for the industry turnover structure

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
51.96%	23.53%	9.31%	7.35%	3.43%	2.94%	0.49%	1.47%

Source: own elaboration.

Table 2. Structure of industrial turnover in selected EU countries: Characteristics of groups selected by the vector elimination method

Groups / Numbers of respondents		High-tech industry		Medium-high-tech industry		Medium-low-tech industry		Low-tech industry	
Group	N	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V
1	106	4.49%	67.84	29.13%	16.58	26.34%	16.65	40.04%	12.66
2	48	8.48%	45.84	47.65%	9.58	23.62%	10.94	20.24%	20.13
3	19	4.41%	102.87	11.11%	32.23	30.05%	21.28	54.43%	7.16
4	15	18.50%	23.84	19.90%	24.61	19.84%	6.26	41.76%	14.87
5	7	5.96%	90.67	41.14%	2.85	19.93%	9.71	32.97%	14.61
6	6	26.51%	13.04	30.09%	28.31	17.63%	4.22	25.77%	19.84
7	1	16.09%	-	13.32%	-	19.38%	-	51.22%	-
8	3	2.74%	19.99	25.13%	34.12	30.32%	7.47	41.81%	18.78

Note: N – group size, $\bar{x}$ – arithmetic mean, V – coefficient of variation.
Source: own elaboration.

The first group of 106 observations was characterized by a share of approximately 40% of the low-tech industry component. At the same time, the turnover in the medium-low-tech industry was approximately 26%, and the medium-high-tech industry component accounted for approximately 29% of the structure. This group also had an approximately 4.5% share of the high-tech industry. The countries characterized by structural stability in the first group were Austria, Denmark, Poland, and Spain.

The second group consisted of 48 objects. In comparison to the first group, it was characterized by a lower share of turnover in the low-tech industry (by approximately 20 pp), medium-low-tech industry (by approximately 3%) and a higher average share of turnover (by approximately 18.5 pp) in medium-high and high-tech industries (by approximately 4 pp). The average components of the structure of turnover in the industry in the second group were as follows: high-tech industry – approximately 8.5%, medium-high-tech industry – approximately 48%, medium-low-tech industry – approximately 24, and low-tech industry – approximately 20%. The countries that belonged to the second cluster and showed no variability during the study period were the Czech Republic, Germany, and Slovakia.

The third cluster comprised 19 observations. It was characterized by the highest average share of the low-tech industry component in the structure among all clusters (approximately 54%). At the same time, this group had approximately 30% share of the medium-low-tech industry. In this cluster, the medium-high-tech industry component accounted for approximately 11%, and the average value of the high-tech industry was the lowest among the first four groups and amounted to approximately 4%. The structurally stable country in the third group was Greece.

The fourth group comprised 15 observations. It was distinguished by the highest share of the high-tech industry component, amounting to approximately 18.5%, among the first four numerous clusters. The medium-high-tech industry accounted for approximately 20% of this group. At the same time, the average value of the medium-low-tech industry component was approximately 30% and the average value of the low-tech industry was approximately 42%. The fourth cluster did not include countries that demonstrated structural stability.

The groups from 5 to 8 were characterized by a low number of observations and did not include countries showing a stable industry turnover. In groups 4, 6, and 7, the observed average level of the share of the high-tech industry was higher than 15%. The highest average value of the medium-high-tech industry component, amounting to over 40%, was observed in groups 2 and 5. The turnover in the medium-low-tech industry was approximately 30% in groups 3 and 8. The first cluster, on the other hand, contained the most observations (over 50%) and the components of the structure of industrial turnover were not characterized by any special features.

The structures of the studied countries evolved over time, which resulted in changes in the classification of the taxonomic groups. Based on the above, area clusters were distinguished (Figure 1):

- countries that are structurally stable over time: Austria, Denmark, Poland, Spain, Czech Republic, Germany, Slovakia, and Greece;
- countries with a changing structure of industrial turnover over time: France, Romania, and Hungary.

Based on the research results, a diagram was created to graphically present the movement of countries to particular groups in time (Table 3). Groups 4, 6, and 7 are marked green. In these clusters, the share of the high-tech industry was higher than 15%. The orange colour was assigned to groups 2 and 5, which included medium-high-tech industry values that were higher by approximately 40%. Clusters 3 and 8 are marked with a violet colour. The turnover in the medium-low-tech industry was approximately 30% in these clusters. The observations belonging to group 1 are in white.

Among the countries in which the structure of industrial turnover changed, note Belgium in 2017 and 2020, Italy in 2018, and Portugal in 2009. During these periods, the share of the medium-low-tech industry component in the structure increased in the analysed countries. At the same time, the shifting of Belgium, Italy, and Portugal to the segment marked with a dark grid meant that medium-high-tech and high-tech industries were falling in these countries.

The economies of France and Romania transformed during the period considered changing their industrial turnover structure. They increased the share of the medium-high-tech industry component.

From 2009 to 2014 and in 2020, Finland belonged to the group in which the share of the high-tech industry was greater than 15% (marked by light horizontal lines). The same situation affected the Dutch economy in 2009 and the years 2014-2017. The studied countries moved to Group 1 (Finland from 2015 to 2019, and the Netherlands from 2010 to 2013 and 2018-2020). In this group, the average value of the high-tech industry component was approximately 4.5%.

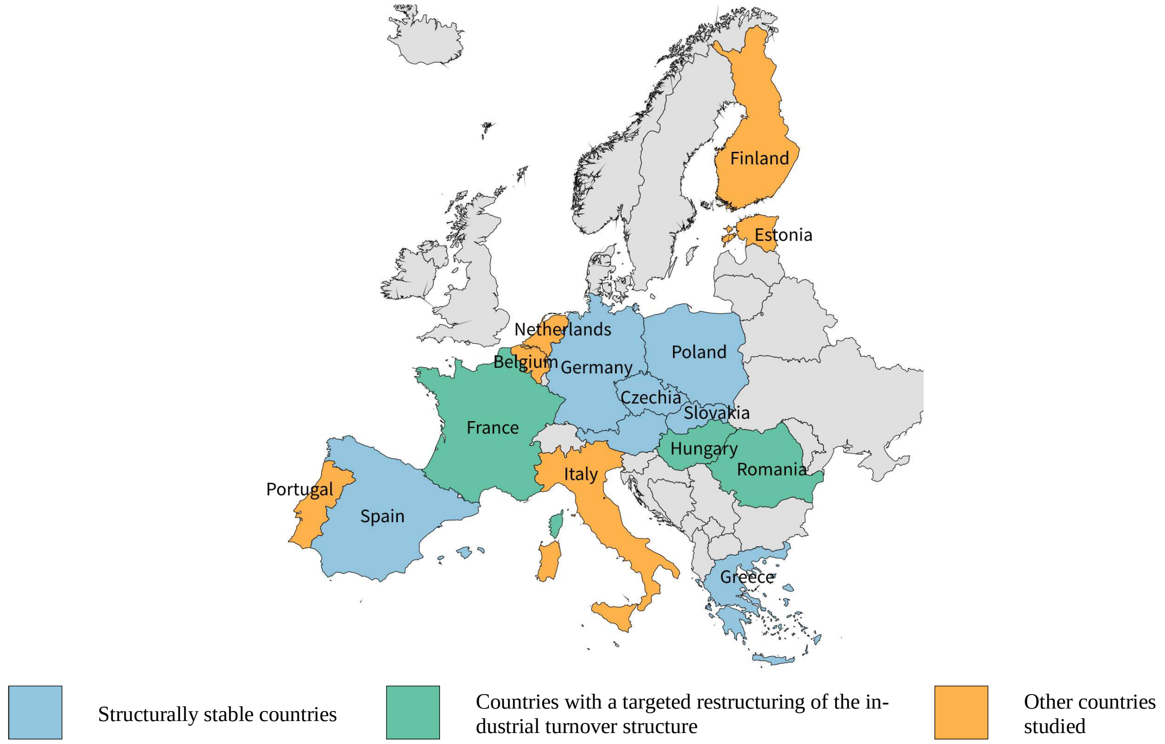

Figure 1. Variability of the structure of industrial turnover over time for selected EU countries
Source: own study in 2023 based ©EuroGeographics for the administrative boundaries.

Table 3. Affiliation of countries to groups obtained by the vector elimination method for the structure of industrial turnover as per technological advancement

Country / year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria												
Belgium												
Denmark												
Finland												
France												
Italy												
Netherlands												
Poland												
Portugal												
Romania												
Spain												
Czech Republic												
Germany												
Hungary												
Slovakia												
Estonia												
Greece												

Source: own studies in 2023.

In the Hungarian economy, the structure of industrial turnover changed due to the country's technological advancement. The country moved from the cluster marked by light horizontal lines to the cluster marked in grey. This means that in the analysed structure, there was an increase in the medium-high-tech industry component. At the same time, the share of the high-tech industry decreased. The transformation of the analysed structure in the Hungarian economy was long-term. The observed changes persisted throughout the nine study periods.

On the other hand, for six survey periods (years: 2009-2010 and 2017-020) Estonia belonged to the group marked with a dark grid, in which the share of low-tech and medium-low-tech industry in the structure dominated. In the period from 2011 to 2014, the country shifted to a cluster with a higher share of high-tech industry (averaging over 15%).

The structure of industrial turnover per technological advancement in the economies of the Czech Republic, Slovakia, and Germany was characterized by a high share of the medium-high-tech industry component (over 40% on average) throughout the entire study period. On the other hand, the structure of industrial turnover in Greece was dominated by the medium-low-tech industry component.

The first group included countries such as Austria, Denmark, Poland, and Spain throughout the study period. There were no significant changes in the structure of industrial turnover in these countries. The structures of these countries were characterized by a low value of the high-tech industry component, which was approximately 4.5% on average. In the structure of industrial turnover per technological advancement in the economies of Austria, Denmark, Poland and Spain, the low-tech industry dominated (approximately 40%).

As part of the Industry 4.0 paradigm, production and manufacturing systems are becoming more adaptive and flexible. The point is to meet the growing requirements for the customization of the final product (Profanter *et al.,* 2017). Therefore, according to Nicolae *et al.* (2019), industry will have to adapt to integrating new devices into existing systems without manual intervention. The interest in the concepts related to Industry 4.0 is growing and the implementation of new technologies and their integration with legacy solutions can provide tangible benefits for the economy, society, and the environment. Industry 4.0 also means the digitalization of production through networks of people and machines interacting with each other. Therefore, the main goal of the concept is to improve the competitive position of enterprises by increasing production and minimizing risk. However, as Foresca (2018) indicates, for most companies, the Industry 4.0 concept is still at an early stage. Digital transformation requires overcoming several barriers to its successful implementation. Therefore, there are still many organizations that have not yet applied the Industry 4.0 concept (Foresca, 2018). This is confirmed by the results of the research presented in this paper. To explain the changes in the turnover structure in industry in Romania, France, and Hungary, a study of aggregates of component 2 was carried out (Table 4).

Table 4. The average value of aggregates of the turnover component in the medium-tech industry in the years 2009-2020

Aggregates of component 2 / Countries	France	Romania	Hungary
Manufacture of electrical equipment	11.75%	13.39%	15.69%
Manufacture of machinery and equipment n.e.c.	18.85%	22.35%	14.07%
Manufacture of motor vehicles, trailers and semi-trailers	42.60%	62.37%	63.58%
Manufacture of other transport equipment	26.80%	1.89%	6.66%

Source: own elaboration.

Analysis of data from 2009-2020 showed that the most important aggregate for the component was the production of motor vehicles, trailers, and semi-trailers. On average, it accounted for nearly 43% of the structure of turnover in the medium-tech industry in France. At the same time, this value was approximately 62% for Romania and approximately 64% for Hungary. The average value of the aggregate ‘production of other transport equipment’ was lower by 2% in Hungary and Romania. In contrast, in France, it was approximately 27%. Aggregates ‘production of electrical equipment’ and ‘production of machinery and equipment not classified elsewhere’ accounted for less than 23% in the component structure no. 2 for all three studied countries.

The average value of the aggregate ‘production of motor vehicles, trailers and semi-trailers’ was higher in 2016-2020 by approximately 31% than in 2009-2015 in France. Moreover, high values in this respect were recorded in Romania and Hungary. In 2016-2020, the average value of the analysed aggregate was 55% higher in Romania and 95% higher in Hungary compared to 2009-2015.

The values of the other aggregates within the component structure no. 2 also showed an upward trend. However, the share of the ‘production of motor vehicles, trailers, and semi-trailers’ aggregate in the component structure was the highest. This confirms its high importance for the transformation of the economies of the studied countries in 2016-2020.

The explanation of this situation should be sought in the values of economic indicators. The countries of Central and Eastern Europe (Romania and Hungary) are attractive in terms of investment. This is due, among others, to labour costs that remain low (Table 5). Unfortunately, due to the constantly unstable socio-political situation and the changing business environment, locating industrial companies with advanced technology in these countries is a risky decision.

Table 5. Hourly wage rate in industry in selected EU countries in the years 2004 to 2020 in EUR

Country / Year	2004	2008	2012	2016	2017	2018	2019	2020
Romania	1.2	2.5	2.8	3.8	4.4	5.7	6.2	6.6
Poland	3.2	5.6	5.6	6.3	6.9	7.4	7.9	8.1
Hungary	3.9	5.3	5.7	6.3	7.2	7.8	8.5	8.5
Estonia	2.9	5.3	6.0	7.6	8.1	8.6	9.2	9.5
Portugal	6.8	7.8	8.7	8.6	8.8	9.1	9.2	10.0
Slovakia	3.1	5.2	6.6	7.6	8.1	8.8	9.4	10.1
Czechia	3.9	6.4	7.0	7.4	8.2	9.2	9.9	10.2
Greece	10.1	12.1	11.7	11.7	11.7	11.9	12.3	12.6
Spain	12.8	14.9	16.4	16.8	16.9	17.0	17.2	17.6
Italy	15.1	16.8	19.2	19.4	19.5	19.7	20.2	20.9
France	19.5	22.0	23.6	24.7	25.2	25.6	26.1	26.9
Austria	20.4	21.4	23.8	26.3	26.6	27.5	28.3	29.0
Finland	20.9	23.1	27.5	29.0	29.7	30.3	30.7	30.9
Netherlands	21.3	23.2	25.2	27.9	28.7	29.2	29.7	31.6
Belgium	21.7	24.0	28.8	29.9	30.4	31.1	32.0	32.5
Germany	23.5	25.3	27.3	29.9	30.8	31.5	32.2	32.6
Denmark	26.3	30.3	35.1	37.8	38.7	39.7	40.7	41.2

Source: own elaboration based on Eurostat in 2023.

Please note also that the countries of Central and Eastern Europe have significant infrastructural deficiencies and continue to struggle with problems generated by the command-distribution system. Nevertheless, the example of Romania and Hungary shows that the transformation towards Industry 4.0 is possible.

In France, labour costs are average compared to the richest countries in Western Europe. Combined with high political stability and well-developed infrastructure, this makes France a very attractive investment destination. Therefore, it is not surprising that locating a high-tech business in France can be encouraging. Hence, the dynamics of changes in France in the medium-tech industry is noticeable.

Another noteworthy element is France's research and development (R&D) per capita expenditure ratio (Table 6). Its value for the aggregate 'production of motor vehicles, trailers and semi-trailers' was higher in 2020 by approximately 362% compared to the base year (2009) in Romania. In Hungary, however, this indicator was higher by approximately 431% than the value in the base year (2009).

Table 6. Research and development (R&D) expenditure per capita in selected EU countries in 2004-2020 (2009 = 100)

Country / Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Spain	109	103	97	93	108	105	127	145	149	155	168
Portugal	64	56	46	39	47	53	64	61	56	69	69
Romania	81	124	105	100	162	229	267	314	371	395	462
Finland	84	88	91	107	109	170	172	181	226	237	237
Slovakia	169	125	206	436	381	272	497	736	603	522	294
Hungary	107	115	134	170	177	195	225	279	372	357	531
Czechia	101	119	135	184	174	191	212	288	360	378	289
Italy	108	130	138	145	171	166	176	148	161	168	183

Source: own elaboration based on Eurostat in 2023.

Unfortunately, not all surveyed countries provide such detailed R&D indexes. Therefore, Romania, Hungary, and France cannot be compared to other EU countries. However, the results allow for an unequivocal conclusion that there is an upward trend in research and development expenditures in these countries in terms of the production of motor vehicles, trailers, and semi-trailers. This could impact the transformation of the Hungarian and Romanian economies towards the medium-tech industry in the short term.

CONCLUSIONS

The changes taking place in the structure of industrial turnover per technological advancement confirm that in the economies of some of the surveyed countries, such as France, Italy, Romania, Hungary, Estonia, the Netherlands, Portugal, Belgium, and Finland, the analysed structure was transformed. Based on the analyses, it was found that these countries constituted the majority (approximately 53%) of the surveyed population. However, the changes that were clearly aimed at increasing the share of the medium-high-tech industry component in the structure concerned only three countries, *i.e.* France, Romania, and Hungary (approximately 18% of the studied population). Moreover, no permanent migrations of the studied countries to groups with a higher value of the high-tech industry component were observed. Single-country migrations between groups, as in the case of Belgium, Italy, and Portugal, testify to chaotic and individual changes in the industrial turnover structure. It was also found that the economies of Finland, Estonia, and the Netherlands experienced intense and long-term, yet unstable changes in the structure in the analysed period.

Among all the surveyed countries, approximately 41% of countries (Slovakia, Germany, the Czech Republic, Spain, Poland, Denmark, and Austria) demonstrated stagnation in terms of changes in the structure of industrial turnover per technological advancement. This means that some countries did not develop at all or did so at a slow pace.

The first group accounted for approximately 52% of the total pool of studied countries. It presented the typical features of the structure of industrial turnover per technological advancement. However, it cannot be described as high-tech, because the role of the low-tech industry component was dominant in the structure.

The analysis results confirmed the adopted research hypothesis, *i.e.* among the national economies of the European Union that undergo industrial transformations and increase the share of high-tech sectors over time, some countries undergo this transformation in a short period. The transformations of the structure of industrial turnover per technological advancement, which were aimed at increasing the share of the medium-high tech industry component in the structure, took place unequivocally only in the three analysed countries.

Petrillo *et al.* (2018) emphasize that several advanced economies such as Canada, the USA, Belgium, France, Great Britain, Sweden, Germany, Denmark, the Netherlands, India, Australia, South Korea, China, and Japan are implementing the Industry 4.0 concept. This is partially reflected in the presented research results. In the economies of Belgium, France, and the Netherlands, the structure of industrial turnover technological advancement was transformed in 2009-2020. In Germany, by contrast, the medium-high technology industry dominated throughout the entire study period.

The research demonstrated the usefulness of the applied vector elimination method. Noteworthy, the research has certain unavoidable limitations. Some of the records in the Eurostat database regarding industry turnover in several categories for European Union countries, such as Bulgaria, Croatia, Cyprus, Ireland, Lithuania, Latvia, Luxembourg, Malta, Slovenia, and Sweden had significant shortcomings at the time of the research. Therefore, these countries were not included in the analysis. The authors recommend further monitoring of the analyses in subsequent years with a broader range of objects, all the more that these are years with unpredictable circumstances, such as the war in Ukraine, as well as the energy and economic crisis.

In this context, it can be assumed that the set of countries, in which the changes in the structure of industrial turnover per technological advancement aimed at increasing the share of the medium-high-tech industry component will increase. This is a new hypothesis to be verified in future research.

On the other hand, taking into account the difficult times for the functioning of modern European economies, it could be interesting to expand the research problem. This is to recognize, on the one hand, the progress of the Fourth Industrial Revolution, and, on the other hand, the fact that *the impact, triggered by war, will strongly affect* the economic activity of the surveyed countries.

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Authors

The contribution share of authors is equal and amounted to 25% for each of them. AN, MN – conceptualisation, ZG-Sz, JS - literature writing, MN, AN – methodology, MN, AN-calculations, ZG-Sz, JS - discussion

Michał Niewiadomski

His main interests include the analytical aspect is the study of economic and social structures of peripheral regions. He is also passionate about other fields of economic science, as well as computer programming and web application development.

Correspondence to: Michał Niewiadomski, Ph.D., University of Agriculture in Krakow, al. Adama Mickiewicza 21, 31-120 Krakow, e-mail: michal.niewiadomski@ppuz.edu.pl

ORCID http://orcid.org/0000-0002-3129-3331

Agata Niemczyk

Associate Professor (Prof. UEK) of the Cracow University of Economics (Poland). A member of a body of experts researching Cracow's meetings industry; a member of the Krakow Tourism Expert Team researching the impact of the tourism and the meetings industry on the economy of Krakow; a member of expert researching Cracow's tourist industry during COVID-19. A member of Regional Studies Association (RSA).

Correspondence to: Prof UEK, dr hab. Agata Niemczyk, Krakow University of Economics, ul. Rakowicka 27, 31-510 Kraków, Poland, e-mail: niemczya@uek.krakow.pl

ORCID http://orcid.org/0000-0002-5594-6296

Zofia Gródek-Szostak
She is the author and co-author of more than 200 publications in the field of innovation management, management of the technology transfer process, commercialisation of innovations, cooperation of the SME sector with business environment institutions, technological cooperation of enterprises, state aid, development of innovative rural entrepreneurship, sustainable development. Member of the Regional Studies Association (RSA) and the Polish Economic Society (PTE).
Correspondence to: Zofia Gródek-Szostak, Ph.D., Krakow University of Economics, Institute of Management, Department of Economics and Organization of Enterprises, Institute of Computer Science, Accounting and Controlling, College of Management and Quality Sciences, Krakow University of Economics, ul. Rakowicka 27, 31-510 Kraków, Poland, e-mail: grodekz@uek.krakow.pl
ORCID http://orcid.org/0000-0001-6283-6952

Jacek Strojny
His scientific interests focus on the application of quantitative methods in economic sciences. These interests can be divided into two streams, i.e. econometric modelling of economic processes and applications of statistical methods for qualitative data describing economic phenomena.
Correspondence to: Dr hab. Jacek Strojny, Associate Professor, University of Agriculture in Krakow, al. Adama Mickiewicza 21, 31-120 Krakow, e-mail: jacek.strojny@urk.edu.pl
ORCID http://orcid.org/0000-0002-0577-377X

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