

PROCESSES OF SPATIAL CONCENTRATION AND SPECIALISATION OF INDUSTRY BY THE INTENSITY OF R&D WORK IN THE LOWER SILESIAN VOIVODESHIP (POLAND)

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ABSTRACT: The aim of this article is to assess the spatial diversity and to identify the spatial distribution of industry, as well as the directions and scales of its transformations based on the processes of spatial concentration and specialisation of the industrial activity from the perspective of the intensity of research and development (R&D) work in the areas of the Lower Silesian Voivodeship. The analysis of the location of industrial activity was conducted based on the entities registered in section C (manufacturing) of the Polish Classification of Activity (PKD). Spatial structures of the industry innovation are presented by applying the classification of manufacturing concerning the intensity of R&D for high-technology, medium high-technology, medium low-technology and low-technology industries. The research was conducted for municipalities divided into cities and rural areas. The results indicate significant changes that took place in the years 2009–2020 in the spatial structure of the whole region, as well as in the urban spatial distribution due to the occurring processes of concentration and specialisation of industrial activity. These changes were simultaneously accompanied by the decreasing level of the concentration of industrial production. Additionally, the Lower Silesian Voivodeship is also characterised by significant spatial diversity of the concentration and specialisation processes of industrial activity. The identified regularities demonstrate the growing role of the suburban zones of large cities, which is particularly visible in the example of Wrocław, an area of intensive diffusion of industrial activity from the central hub. These processes also diffuse into smaller urban centres in the voivodeship.

KEYWORDS: research and development, concentration processes, industry, region, transformations of spatial structure, deglomeration

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Introduction

The modern development of an economy is based on its intensive use, which results in an increasingly rapid generation of technological and organisational progress. The most important

factors determining the speed of progress and the high level of economic development include innovation, transfer and use of knowledge. An increase in innovation and the introduction of new or significantly improved products or advanced technological processes contribute to the

fuller use of the resources owned, as well as to an increase in the effectiveness of the economy (Ferreira et al. 2013; Brezdeń 2015).

Innovation processes in the economy are usually accompanied by the processes of its concentration and specialisation. Economic models derived from the theory of economic growth, trade and economic geography indicate diverse factors that determine the phenomena of economic concentration and specialisation (Krugman 1991; Porter 1996; Fujita, Thisse 2004). On the one hand, there is an expectation that the sector specialisation of particular economies and regions will grow due to the existing comparative advantage and resources owned (Budner 2006). On the other hand, there are theories of growth that indicate a decrease in specialisation resulting from the levelling of labour and capital productivity (Batóg 2008; Goschin et al. 2009).

Industrial activity is and has always been one of the pillars of the economy. However, in order to satisfy the modern demand generated by socio-economic development, the industry must also be subject to constant transformations, stemming from scientific and technological progress, innovation development and the processes of economic concentration and specialisation.

These processes result in a gradual structural and spatial transformation of industrial activity. In the economies of developed countries, these processes are expressed mostly in the following forms: (i) the natural imposition of a limitation in terms of production and employment on those branches of industry burdened with outdated technology; and (ii) a decreasing demand for products manufactured by such branches, concomitant with a simultaneous acceleration of growth in branches using modern technologies and a growing demand for their products. This tendency is present in all developed industrial countries; yet, the scale and the pace of these transformations vary significantly (Winiarski 2002; Coenen et al. 2014; Brezdeń, Szmytkie 2019; Kourtit, Gordon 2019). In turn, owing to spatial transformations, industrial manufacturing diffuses ('infiltrates') downwards the hierarchical system of cities, both large and small. The process of industry dispersion is currently caused by the increasing labour costs as well as the emergence of development thresholds in large urban agglomerations (Moriarty 1991). This process is

also frequently connected to the product life cycle (Vernon 1960).

The process of concentration and specialisation significantly influences the modern structural and spatial transformations of industry. The process of specialisation in industrial production is greatly dependent on the degree of concentration and the scale of production. Before the production of particular products becomes separated, the production must achieve a certain considerable size. Then, the specialisation of production leads to its further concentration. These processes are closely linked to each other (Batóg 2008). The concentration and specialisation of industrial production should benefit the national economy through higher production, higher labour productivity, improved production quality, lower manufacturing costs and higher profitability.

In the last years, the increasing costs generated by the overload of large urban centres, deterioration of amenities, and higher wage levels have led to the migration from metropolitan centres to areas located in their outskirts. This process afflicts not only individuals but also enterprises, mostly those related to production and services (Bodenman 2000). However, the causes for moving production are more complex. The main motives underlying the relocation of production are clearly the lowering of production costs and the increasing of operational flexibility. The fundamental determinants in moving production include the level of labour costs, the quality and qualifications of the labour force, infrastructure, the availability of supply and outlet markets, or legal and institutional conditions (Moszyński 2007). Thus, contemporary tendencies regarding the location of industrial activities indicate the connection between the suburbanisation processes and the attraction of industrial facilities to the suburban zones, especially in large cities. The phenomena cause relevant transformations of the industrial spatial structures in the region (Sikorski 2020).

The aim of this article is to assess the spatial diversity and to identify the spatial distribution of industry, as well as the directions and scales of its transformations. The inquiry is based on the processes of spatial concentration and specialisation of the industrial activity from the perspective of the intensity of research and development

(R&D) work in the areas of the Lower Silesian Voivodeship. The study is also a more in-depth identification of the conditions determining the above-mentioned processes and transformations of the spatial structures of the industry from the perspective of the impact of the research and development sphere in relation to earlier studies (Brezdeń 2019), which often showed them only in selected local spatial systems, most often of the urban type (Sikorski, Brezdeń 2021). The completed research is also supplemented by the identification of types of units in the voivodeship by the dynamics of transformations taking place in the spatial structure of the industry, related to the research and development sphere.

The scope of the analysed issues depended on the availability of the data, in particular at local level.

Research area, methods and data sources

The Lower Silesian Voivodeship is a highly diversified region considering its socio-economic development level. The region covers an area of nearly 20,000 km² and is inhabited by 2.9 million people (*Powierzchnia i ludność...* 2020). It is characterised by typically agricultural areas with low development levels (e.g. Góra County [pl. *powiat*] and Lwówek Śląski County) as well as areas with high economic activity and high development levels (e.g. areas of large urban agglomerations such as Wrocław). Furthermore, several areas in the voivodeship are characterised by heightened industrial and mining activity (e.g. Legnica-Głogów Copper Belt Area [LGOM]). The region comprises 169 municipalities [pl. *gmina*] of different sizes and characteristics.

To investigate the spatial and structural transformations of the industrial activity in the Lower Silesian Voivodeship, the location of the industrial activity was analysed based on the business entities registered in section C (manufacturing) of the Polish Classification of Activity (PKD). Spatial structures of the innovation in industry are presented by applying the classification of manufacturing from the perspective of the intensity of R&D for high-technology, medium high-technology, medium low-technology and

low-technology industries¹ (*Nauka i technika...* 2018), from both static and dynamic perspectives.

In order to diagnose the level of development and the spatial diversification of the concentration process of industrial activity, the location quotient (LQ) and Herfindahl–Hirschman Index (HHI) were applied. HHI is most frequently used in sector-specific regulation and anti-trust proceedings (Kwiatkowska 2014); yet, it is also applicable in spatial research. It is calculated as a sum of squared market shares of all spatial units in the investigated area. The value of the index ranges between 0 for unconcentrated features and 10,000 for highly concentrated features. In reality, values lower than 1,000 imply low concentration; values exceeding 1,800 indicate high concentration; and values higher than 2,500 imply a very high concentration of the studied phenomenon (Rogalski 2010).

Owing to the varying dynamics of the observed changes depending on the nature of municipalities in the researched voivodeship and in addition to the province-wide perspective, we present a detailed analysis of the investigated indicators divided into municipalities (in the case of urban-rural municipalities, divided into urban and rural areas) and areas directly affected by the largest cities in the voivodeship, i.e. Wrocław, Wałbrzych, Legnica (fundamentally, LGOM), Jelenia Góra, Bolesławiec and Zgorzelec. Given the central function of Wrocław, the capital city of the voivodeship, its impact zone was determined as far as the second ring of adjoining municipalities, whereas in the remaining cases, the impact zones comprised municipalities adjacent to large cities. The spatial scope assumed in the study can be partially attributed to the definition of a sub-urban zone offered by Straszewicz (1985: 9), who defined it as “an area directly surrounding or adjoining a large city”, while taking into account the degree of advancement of suburbanisation processes around large cities (Szmytkie, Sikorski 2020). It is in the areas of the largest cities where

¹ In accordance with the methodological recommendations concerning the statistical research on high-technology coordinated by OECD, the organisation currently applies the classification of the industry sectors based on the analyses concerning the content of the R&D component, which is also referred to in the subject literature as the classification of the industry sectors based on technological content.

most of the industrial entities concentrate and where their major transformations in terms of innovation are visible; thus, the already mentioned spatial structures are investigated in detail.

The discussion also encompasses the analysis of the distribution of industrial entity concentration based on its R&D classification and the distance from the agglomeration centre (agglomeration core). Owing to the lack of detailed geolocation data for industrial entities in section C of PKD (in Poland's Local Data Bank, data are assigned to a municipality and not to a particular settlement), a decision was made to assign to distance rings from the agglomeration centre a number of entities proportional to the area covered by the distance ring in a given municipality; for instance, if there were 100 entities in a municipality and two distance rings, then the number of the assigned entities would depend on the share of the municipality area covered by a given ring. Even though the applied method creates simplifications, its aim is not to build a detailed (quantitative) assessment of the distribution of industrial entities following the R&D classification, in particular for the municipalities adjoining the largest cities in the voivodeship; instead, it aims to demonstrate certain trends and changes occurring in the distribution of industrial entities in the investigated time period in the mentioned cities and their suburban zones.

To synthesise the results of the conducted studies, the analysis of the LQ value in a given year for a particular industry category, having as its basis the intensity of the R&D work, was combined with the change that occurred in the years 2009–2020, which allowed us to identify four types of units of the investigated phenomenon in the voivodeship. These are as follows:

- Type 1 constitutes spatial units with high LQ in 2020 ($LQ > 1$) and the positive dynamics of growth ($\Delta LQ > 0$) in the years 2009–2020. Units belonging to this group fuelled the local economy.
- Type 2 comprises units that were characterised by a low level of local concentration ($LQ < 1$) but displayed positive growth dynamics ($\Delta LQ > 0$). Units belonging to this group may potentially become the places in which the phenomenon will concentrate in the near future.
- Type 3 involves the units that displayed high LQ at the beginning of the analysed period

but their economic significance decreased considerably and they noted negative growth dynamics ($\Delta LQ < 0$).

- Type 4 constitutes units with the lowest importance to the development of the local economy, i.e. units with low values of the LQ and its negative dynamics.

Results – background

Structural changes in a given region are caused by factors affecting the market mechanism and top-down factors being a consequence of the state's industrial policy. Both of these groups are complementary and at the same time they affect the economy of a given country or region. The process of marketisation of the Polish economy resulting from the political and economic transformation of the 1990s forced the use of the economic efficiency calculation in the industry and other sectors of the economy, which resulted in, among others, the liquidation of excessive employment and the introduction of modern management methods in enterprises, including industrial ones. In the initial stage of the economic transformation, the increase in prices resulted in a reduction in demand, which also contributed to a significant reduction in the production level. Industrial enterprises also encountered difficulties in selling their products because of the growing competition created by the opening of the country's economy to imports of various goods. Enterprises that were unable to cope with the competition and adapt to the requirements of the market economy were liquidated many times (Dyduch 2005). The change of the economic system from command-and-distribution, dominated by heavy industry, to the market system contributed to the development of more technologically advanced industries. As a result, mining, metallurgy and chemical industry gained importance in favour of industries producing consumer goods. Changes in the industry division structure towards the development of industries producing goods with a higher degree of processing were beneficial from the point of view of modernity and competitiveness of the industry and the adjustment of the Polish economy to the economies of highly developed countries. It should be remembered, however, that against

the background of tendencies prevailing in developed countries, the process of deindustrialisation, characterised mainly by the liquidation of the mining industry and traditional branches of heavy industry, in Poland was also characterised by the liquidation of many plants in the electronics and armaments industries. They constituted a group of high-tech industries (Soroka 2019). The condition and shape of Polish industry was also influenced by ownership transformations, which in the first years of the systemic changes after 1989 were the main tool for transforming the Polish economy from a state-owned economy to a capitalist, market-based economy. This phenomenon was also accompanied by the inflow of foreign capital into industry in the form of foreign direct investments (Domański 2001). The above-mentioned processes also resulted in changes in the spatial structure of industry affecting the degree of its concentration, in particular regional and local systems (Stryjakiewicz 1999; Brezdeń 2016).

The described processes strongly influenced the contemporary concentration and specialisation of industry in the Lower Silesian Voivodeship. The region's location close to Poland's western border was conducive to a large influx of direct foreign investments, contributing to spatial transformations of industry structures. The south of the region (the area of the Sudetes) underwent a strong deindustrialisation owing to the dominance of traditional industries (mining, textiles). The area beyond the Sudeten belt, predominated by processing industries (mainly the Wrocław agglomeration), gained even more importance (Slenczek 1994). A strong concentration of industrial activity was also maintained in the area of the voivodeship related to the presence of copper deposits (Legnica-Głogów Copper Belt Area - LGOM), due to the wide use of copper in many branches of industry, including modern ones.

The Lower Silesian Voivodeship is still one of the most industrialised regions in Poland. With the result of over 78.9 bn PLN in 2009 and over 151.7 bn PLN in 2020, for many years it remained the fourth in the country considering the value of sold production of industry, following the Mazovian, Silesian and Greater Poland Voivodeships (*Bank Danych Lokalnych...* 2020). Taking into account the value of the sold

production of industry per inhabitant, its position is even higher; in 2020, the Lower Silesian Voivodeship occupied the third place in the country, overtaking the Silesian Voivodeship. It should be emphasised that the high value of sold production of industry in the voivodeship is accompanied by equally high dynamics of its growth, amounting to 191% in the years 2009–2020. The increase in the value of sold production of industry in the voivodeship also led to the increase in the value of sold production of industry per inhabitant. In the investigated period, it rose from 27,500 PLN *per capita* in 2009 to 52,300 PLN in 2020.

The favourable location in geographical and transport terms near the border with Germany and Czechia also makes the Lower Silesian Voivodeship a conducive environment for the development of innovative industry sectors. Well-developed transport infrastructure facilitates access to the sale markets both in the European Union (UE) and Central and Eastern Europe. This is the reason why the Lower Silesian Voivodeship belongs to, *i.a.*, the cutting edge of the Polish regions in terms of the level of innovative development. Nearly one-fourth of the enterprises operating in the region introduced at least one product or process innovation during the investigated period: a new or significantly improved product (service) or a new or significantly improved process. One of the important factors testifying to the level of support for scientific research, technological development and innovation in the region is the level of expenditure on R&D. Its value places the Lower Silesian Voivodeship among the top Polish Voivodeships. The expenditure on R&D in the enterprises constitutes more than half of all the expenditures in the region for the indicated aims (*Dolny Śląsk...* 2020). The potential for innovation of the Lower Silesian Voivodeship is also a result of a large number of employees engaged in R&D work. This number is continuously growing, amounting to approximately 1.5% of all employees (second place in Poland). Nearly 50% of the employees engaged in R&D are hired in industrial enterprises. The relationship between internal expenditure on R&D work and scientific and technical fields demonstrates that engineering and technical sciences are definitely prevailing in the voivodeship, absorbing nearly two-thirds (62.8%) of all expenditures. A

significant share of the expenditures is also spent on natural sciences (19.5% of all expenditures). It is a logical consequence of the already mentioned high participation of the enterprise sector in R&D spending. In 2020, the expenditures were mostly incurred by the enterprises operating in information and communication (28.7% expenditures of the enterprises for R&D), manufacture of motor vehicles, trailers and semi-trailers (23.6%), chemistry (9.5%) and production of machinery and equipment (7.0%). The growing economic role of Lower Silesia in Poland also results from the increasing gross domestic product (GDP) value total and *per capita* (fourth place in the country in 2018). As a consequence of the processes listed above, the economy is gradually transitioning towards highly innovative sectors. A particular role is played here by Wrocław, which is one of the largest centres of services for business in Poland; in total, 188 Shared Services Centres and Business Process Outsourcing (SSC/BPO) (data from the first quarter of 2020) operate there, hiring 51,900 employees. Wrocław is also a significant R&D centre in the country, which specialises in IT, engineering, chemistry, pharmacy, biotechnology and nanotechnology. It is also a leading Polish centre for R&D in the computer games sector as well as an attractive ecosystem for start-ups, supporting innovators who succeed on international markets (*Dolny Śląsk...* 2020). The Lower Silesian Voivodeship also constitutes one of the largest clusters of technological enterprises; statistically, there is one start-up per 4,500 inhabitants of the region. The region is further characterised by a high percentage of employees hired in technologically advanced industries and services as well as a high level of employment of information and communication technologies (ICT) workers in enterprises in proportion to the national average (36,000 specialists hired in the ICT sector). An additional factor favourable to the increase in the region's innovation is also the high quality of life, the effect of which is one of the highest proportion of households with the relatively highest income.

Results – quantification

The spatial structure of industry from the perspective of R&D intensity varies highly in the

Lower Silesian Voivodeship. It is illustrated by the value of the LQ for industrial entities divided into voivodeship municipalities in both 2009 and 2020 (Figs 1 and 2).

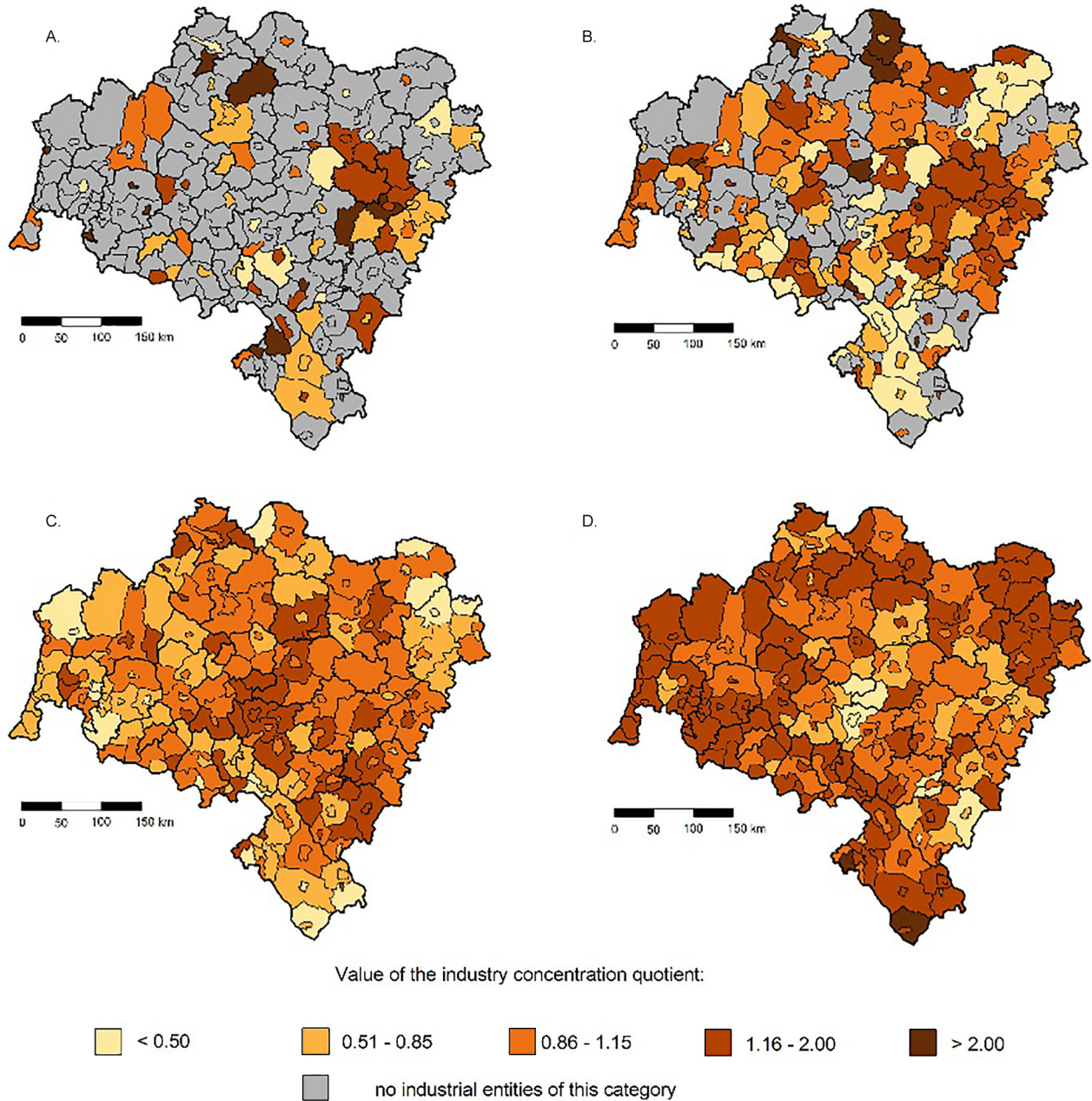
In the voivodeship, the area where high-technology industry clearly dominates is emerging, which is related to the Wrocław metropolitan area; the significance of other more peripheral areas is also growing, e.g. municipalities where LGOM is located as well as Jelenia Góra and Kłodzko. The results of the spatial analysis of the distribution of LQ values for industrial entities by the intensity of R&D work demonstrate that manufacturing in the voivodeship diffuses ('infiltrates') downwards the hierarchical urban system, from larger to smaller centres. It is mostly true for the industry characterised by a lower intensity of R&D work, i.e. medium high-technology and low-technology industries in particular (*cf.* Figs 1 and 2). The infiltration of industry in the voivodeship is expressed in the spreading municipalities with the increasing LQ value for the medium high-technology industry over the 2009–2020 period, as well as in the 'shift' of the low-technology industry towards far more peripheral areas. The process of industry dispersion is currently caused by the increasing labour costs as well as the emergence of development thresholds in large urban agglomerations (Moriarty 1991). This process is also connected to the product life cycle (Vernon 1960), which is confirmed by processes identified in the Lower Silesian Voivodeship, in particular those relating to medium-low and low technologies. However, the process of the industry infiltration downwards the hierarchical urban system is more complex.

The observed changes are accompanied by the movement of industrial activity towards peripheral areas of individual urban complexes in the region. It mostly concerns medium low and low-technology industries (Figs 3 and 4C, D). This process is especially visible in the Wrocław agglomeration. The analysis of the LQ for the concentration of industrial entities by the intensity of R&D work indicates the peculiar significance of the urban core environment, which creates conditions conducive to high-tech activities (Figs 3 and 4A). The highest values were mostly characteristic of Wrocław, where the LQ value was twice as high as the mean for the whole region. Wrocław stands out on the map of the

Polish IT sector. The city is considered to be one of the most developed and innovative IT ecosystems in the country. Owing to numerous investments of both foreign and Polish enterprises, the market is on the wave of economic growth, and its attractiveness is not declining. The history of the Wrocław (Lower Silesian) IT market began in 1963 with the production of the Odra computer by Elwro Company. Until the 1990s, Wrocław

had been the only Polish city where computers were produced on a mass scale.

The key segments of the Lower Silesian IT market currently comprise programming, IT services and production of computer equipment. Even though the last segment holds the largest share in the whole sector, it is the two remaining segments that are characterised by a regular, high increase over the last few years and



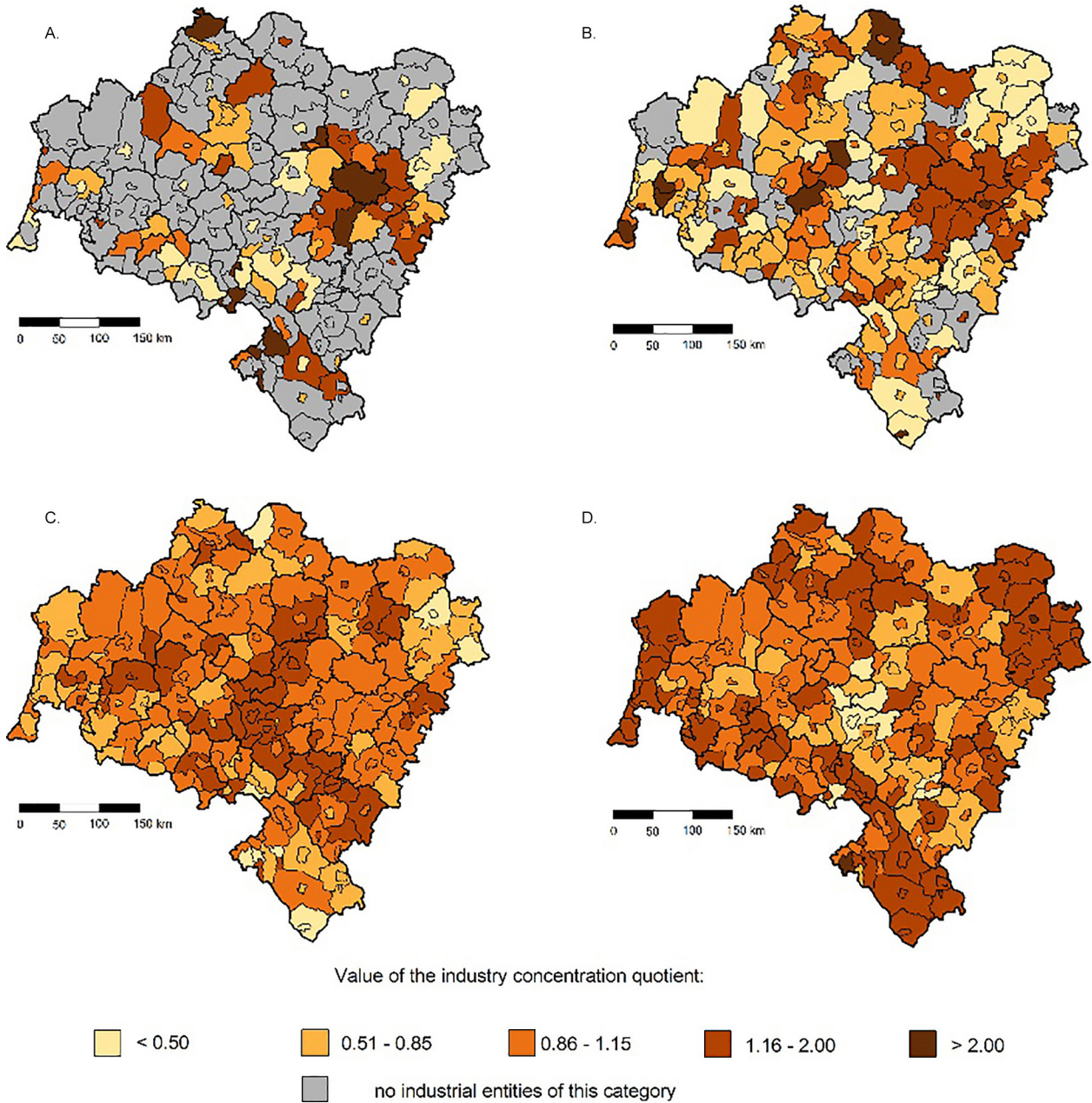
A - high technology, B - medium high-technology, C - medium low-technology, D - low technology

Fig. 1. Concentration of industrial entities by the intensity of R&D work (A – high, B – medium high, C – medium low and D – low technology) in the Lower Silesian Voivodeship in 2009.

Source: own study based on the Local Data Bank.

better immunity to the business cycles, owing to which they are perceived as the directions of future development on the IT market. Favourable perspectives on the development of this line of industry are also the effect of the changes occurring in the economy due to the coronavirus disease 2019 (COVID-19) pandemic. The demand for programmes and IT tools supporting work in companies offers a wide array of opportunities

for further development in the ICT industry. The effects are also visible as the income of Lower Silesian ICT enterprises has grown significantly in comparison to that in 2019, even though the crisis in the market affected other businesses. The experiences brought by the COVID-19 pandemic may positively influence the development of automatisisation, informatisation and remote work. Resultantly, the ICT industry in the Lower



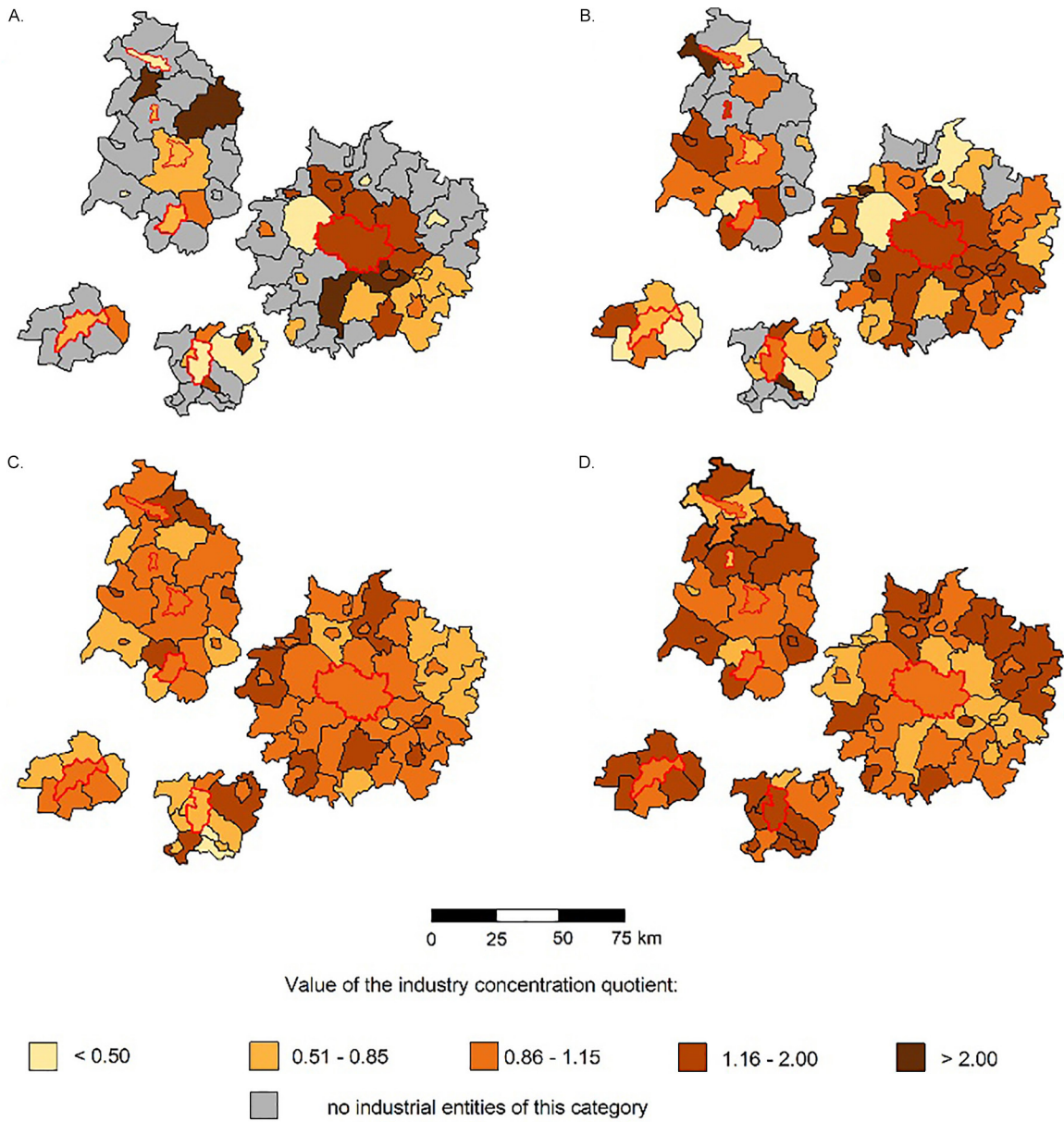
A - high technology, B - medium high-technology, C - medium low-technology, D - low technology

Fig. 2. Concentration of industrial entities by the intensity of R&D work (A – high, B – medium high, C – medium low and D – low technology) in the Lower Silesian Voivodeship in 2020.

Source: own study based on the Local Data Bank.

Silesian Voivodeship is characterised by continuous growth also in terms of the number of its business entities; since 2009 their number has tripled in the Lower Silesian Voivodeship. It should also be emphasised that in the last decade, well-known international corporations opened their branches and development centres in the city, for instance, Atos, Google, HP Enterprise, HP Inc., IBM, Nokia, Opera Software and Tieto.

Technologically advanced industry is characterised by high expenditures and requires highly specialised technology and well-qualified staff. Such environment is present in the central part of the urban industrial agglomeration (Moriarty 1991; Renski 2008). Lower concentration of the industrial entities in the core with its simultaneous increase in the areas of the first and the second rings took place in the case of entities characterised by lower technological advancement.



A - high technology, B - medium high-technology, C - medium low-technology, D - low technology

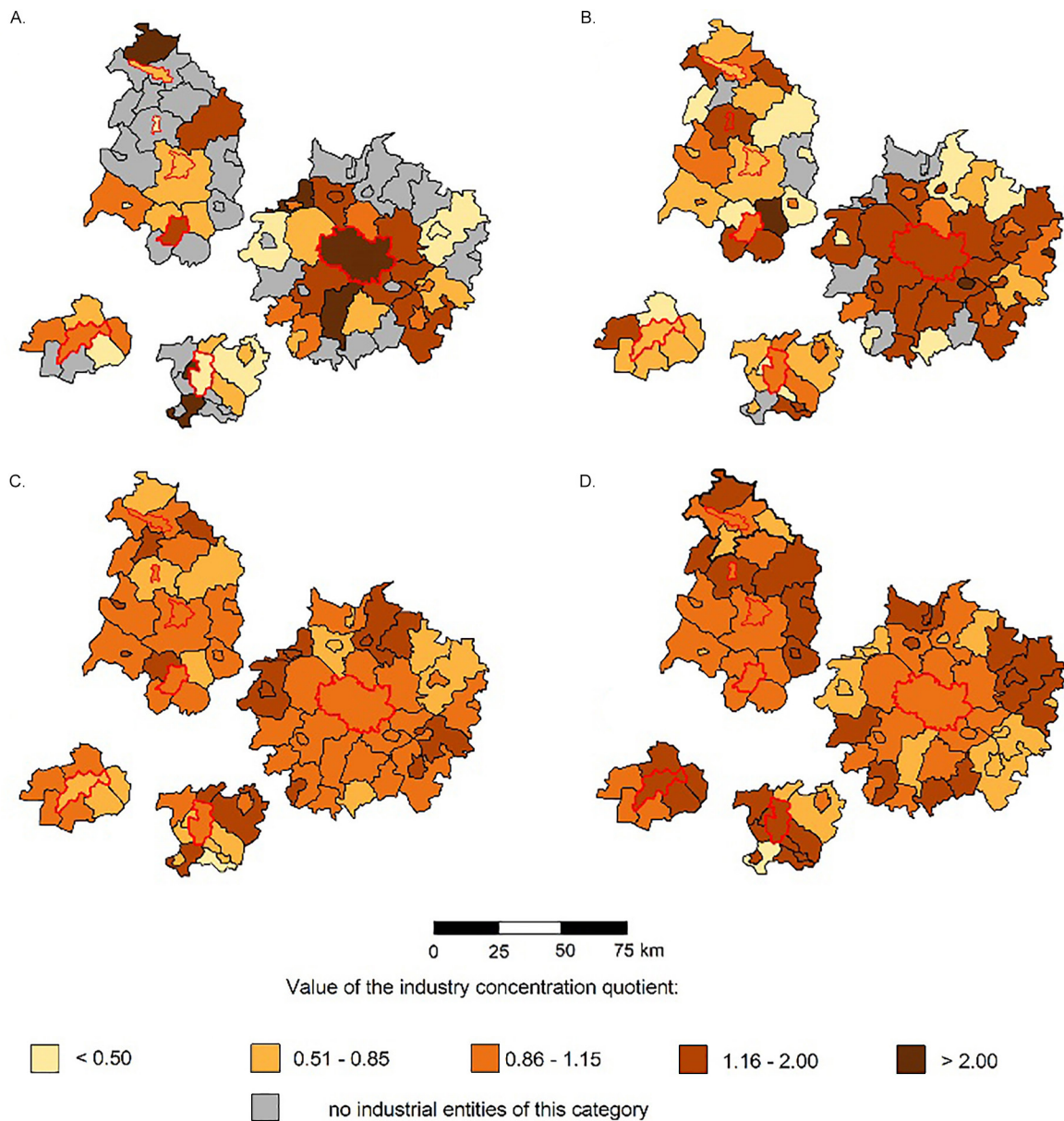
Fig. 3. Concentration of industrial entities by the intensity of R&D work (A - high, B - medium high, C - medium low and D - low technology) in the largest cities and suburban zones in the Lower Silesian Voivodeship in 2009.

Source: own study based on the Local Data Bank.

It should be also emphasised that the area of Wrocław's first ring was characterised by a concentration level of high-technology and medium high-technology entities that was higher than the average in the region. It confirms the gradually increasing significance of the direct support of a large city as an environment conducive to innovative activities near a central city.

The automotive industry and related cooperating industries play a significant role in the

current spatial changes in the industry structure considering the intensity of R&D work. The manufacture of motor vehicles, trailers and semi-trailers is part of medium high-technology industries. Most of the entities in this category are located in the vicinity of the largest urban centres in the voivodeship, i.e. Wrocław, LGOM and Wałbrzych, which results in the growing number of municipalities with higher LQ values for medium high-technology industries in the



A - high technology, B - medium high-technology, C - medium low-technology, D - low technology

Fig. 4. Concentration of industrial entities by the intensity of R&D work (A - high, B - medium high, C - medium low and D - low technology) in the largest cities and suburban zones in the Lower Silesian Voivodeship in 2020.

Source: own study based on the Local Data Bank.

suburban zone of the named centres (*cf.* Figs 3 and 4B). Owing to proliferating investment projects in the automotive industry and cooperating industries in the discussed area, a Lower Silesian Automotive Cluster of sorts is emerging in the voivodeship (Table 1).

In the investigated period, there is also a noticeable gradual change in the concentration of industrial activity in the voivodeship: its meaning is growing in the rural areas and in the municipalities comprising the suburban zones of the largest agglomerations in the voivodeship. This is particularly true for medium high and medium low technology (Fig. 5B, C). Regarding this category of industry, the changes in concentration are the most visible in a significant spatial shifting towards the hinterlands of not only the largest cities but also smaller urban centres. On the other hand, there is a gradual deconcentration of high-technology entities towards the suburban

areas of the largest agglomerations in the region (Fig. 5A).

Overall, in the years 2009–2020, the level of industrial activity concentration was further diffusing in the voivodeship, even though the low concentration of industrial entities had already been reached in 2009. It is evidenced by the decreasing value of HHI, which dropped from 836 in 2009 to 714 in 2020 (Table 2). However, the concentration processes of industrial entities in the voivodeship are much more complex when it comes to the distribution of entities from the perspective of R&D intensity.

The distribution of the high-technology industrial entities is indicative of tendencies that stand in opposition to the fundamental process of decreasing the spatial concentration of industry in general. In their case, there was a marked tendency to increase in concentration; the HHI values for this category of entities had already been very high in 2009, and they were continuously

Table 1. Selected companies working within the Lower Silesian Automotive Cluster in the Lower Silesian Voivodeship in 2020.

Company	Location	Area of economic activity
Aircom Automotive	Pietrzykowice	Production of tyre repair kits
BASF Polska	Środa Śląska	Production of car catalysts
Eldisy Polska	Komorniki (Środa Śląska)	Production of sealing elements
Sika Automotive Złotoryja	Złotoryja	Production of bitumen mats for companies in automotive industry
Faurecia Automotive Polska	Legnica, Wałbrzych, Jelcz-Laskowice	Design and production of car equipment elements (car seats, technologies of emission control, car interiors, IT solutions)
Gates Polska	Legnica	Production of rubber stripes and wires
GOTEC Polska	Komorniki (Środa Śląska)	Processing of surface of undercarriage elements
Hester	Pieszycy (Dzierżoniów)	Production of technical fabrics
HMT Heldener Metall Technik	Środa Śląska	Sheet metal forming
Pittsburg Glass Works	Komorniki (Środa Śląska)	Production of car glass
Pneumat System	Wrocław	Production of pneumatic systems
Ritex Logistics	Gniewomierz (Legnica)	Transport, freight, logistics
Sanden Manufacturing Polska	Polkowice	Production of compressors for car AC
Schurholz Polska	Komorniki (Środa Śląska)	Production of coachwork, elements of undercarriage, interior and parts for electronics
Sitech	Polkowice	Production of metal chassis for car seats
Voestalpine Rotec	Komorniki (Środa Śląska)	Production of steel and aluminium elements
Wezi-tec	Legnica	Production of car modules
Autoliv	Oława, Jelcz-Laskowice	Production of car safety systems (seat belts, airbags)
Mobile Climate Control	Oława	Production of vehicle A/C and heating systems
Mercedes-Benz Manufacturing Polska	Jawor	Production of engines and batteries for electric cars

Source: own study based on *Dolny Śląsk...* 2020.

growing in 2020. Therefore, the spatial structure of the high-technology industry in the voivodeship shifts towards the distribution of an oligopolistic nature. The remaining levels of industrial

activity by the intensity of R&D work have been subject to indisputable dispersion. It is visible not only in the case of low-technology industries but also in medium low and medium high ones.

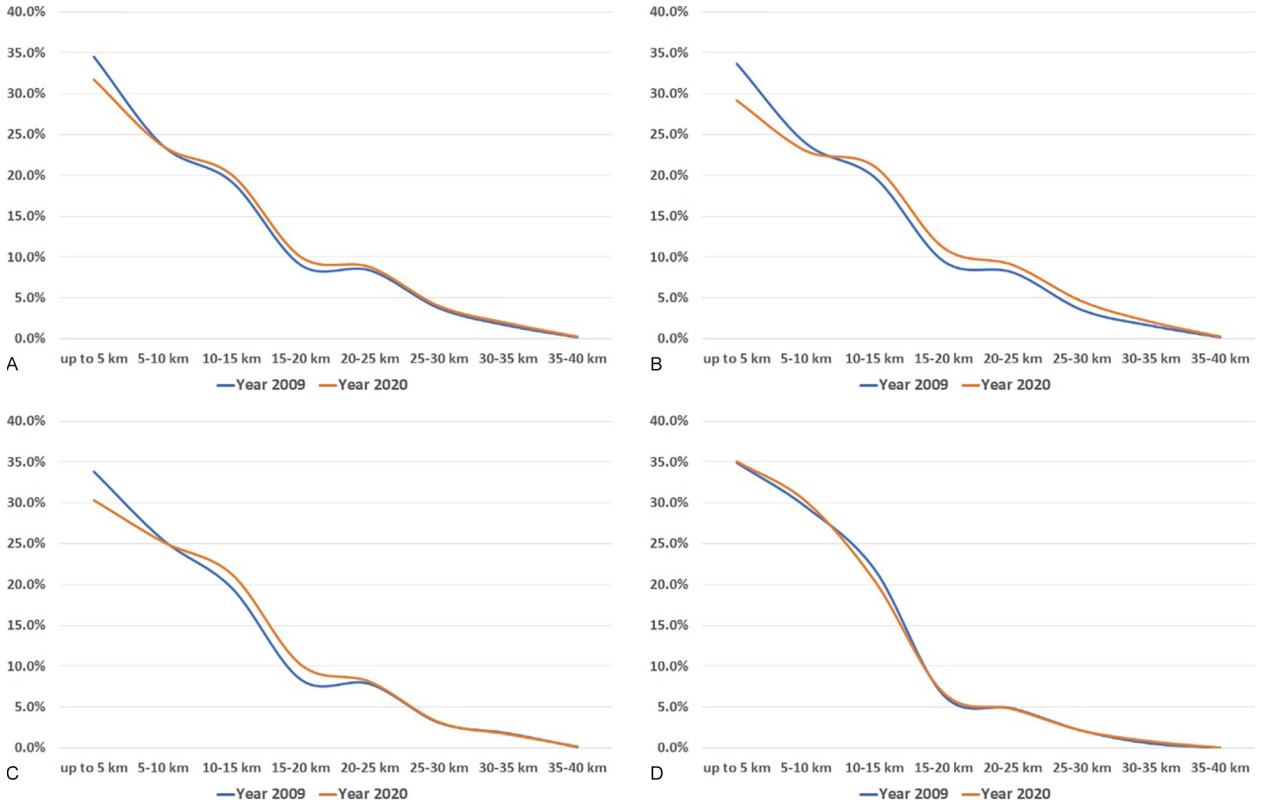


Fig. 5. Changes in the distribution of industrial entities of A – high, B – medium high, C – medium low and D – low technology in the largest cities in the region depending on the distance from the core centre in the years 2009–2020.

Source: own study based on the Local Data Bank.

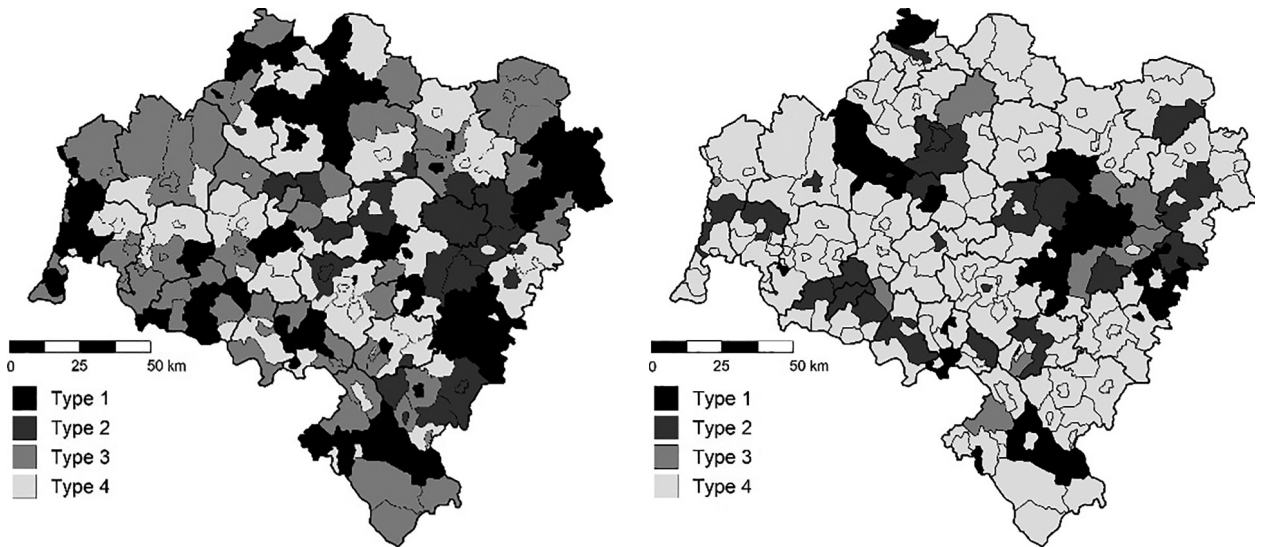


Fig. 6. Types of units based on the LQ value in 2020 and its change in the years 2009–2020 in the Lower Silesian Voivodeship for high-technology – A and low-technology – B industries.

LQ – location quotient

Source: own study based on the Local Data Bank.

Table 2. HHI value for the industry by the intensity of R&D work in the Lower Silesian Voivodeship in the years 2009–2020.

Level of technology	2009	2020
	HHI value	
Industrial entities total	836	714
High technology	2,974	3,372
Medium high technology	1,479	1,404
Medium low technology	879	646
Low technology	669	630

HHI – Herfindahl–Hirschman Index.

Source: own study based on the Local Data Bank.

The entities constituting the driving force (Type 1) of the regional economy in terms of high-technology industries are located in the Wrocław metropolitan area, which comprises not only the agglomeration core, i.e. the city of Wrocław, but also numerous rural areas of the municipalities in its close neighbourhood, such as Kobierzyce, Kąty Wrocławskie, Mietków, Sobótka, Oława, Brzeg Dolny and Oborniki Śląskie. Furthermore, the distribution of Type 2 municipalities indicates a favourable neighbourhood for the adjoining units; it confirms that the choice of location for high-technology entities should consider not only the characteristics of the areas where the new enterprises are to be located but also the neighbouring areas. Types 3 and 4 constitute mostly municipalities lying beyond these growth poles, which the agglomeration cores are, and located too far away from them to draw from the neighbourhood effect (Fig. 6).

Discussion

Peculiar spatial and structural transformations of industrial activity have been noted in the investigated area. However, the conducted analyses indicate that they were only selective, i.e. the most radical changes occurred primarily around the largest urban agglomerations and in their immediate surroundings (in the suburban zone). The main factor modelling the perceived changes was the gradual process of concentration and specialisation of industrial activity in the investigated voivodeship as well as the process of suburbanisation. As has already been stated, the observed tendency is present in all developed industrial countries; yet, the scale and the speed of these transformations vary significantly

(Winiarski 2002; Coenen et al. 2014; Brezdeń, Szmytkie 2019; Kourtit, Gordon 2019).

Despite the noted changes, the highest concentration of industrial activity in the region is still observed in the cores of urban agglomerations (Fig. 5). In comparison to 2009, there is a current trend of the growing significance of industrial activity concentration in the suburban zones located 10 km or farther away from the centre of an urban agglomeration. Apart from the gradual process of specialisation and concentration, the observed changes are influenced by various factors, including the deglomeration of industrial activity from large city centres and the relocation of this form of economic activity to suburban zones (Sikorski 2020). The results of the aforementioned processes is an increase in the dispersion of industry in the region (Arauzo-Carod 2021).

The phenomenon of suburbanisation processes and the (often industrial) economic activity occurring simultaneously characterises the areas surrounding many urban centres. Each city has its own features determining the process of industrial restructuring depending on the historical background of the city, its economic base and the quality of the socio-cultural environment (Ernst et al. 1996). The location attractiveness of suburban zones is based on the quality of the economic resources available therein. The quality of these resources may be a factor stimulating the development of a suburban zone or its development barrier (Poniatowska-Jaksch 1998).

The contemporary process of industrialisation of suburban zones is characterised by a peculiar phenomenon: an increase in the concentration of industrial activity, which, instead of occurring in the immediate vicinity of a large urban centre, takes place a certain distance away from its administrative borders. This is confirmed by the spatial distribution of industrial entities given the intensity of R&D work in the voivodeship. The observed spilling of industrial activity is visible not only in the Wrocław agglomeration but also in many smaller urban centres in the voivodeship. It is based on the growth of a suburban zone and also overlaps with the previous processes of industry deconcentration that took place in larger and smaller urban industrial agglomerations towards their satellite cities (Morrill 1992; Slenczek 1996).

Simultaneously, the indicated regularities point towards the growing importance of suburban zones as areas of intensive diffusion of industrial activity from the central hub, the effects of which comprise larger industrial areas (Rudewicz 2016). In the Wrocław agglomeration, an important role is played additionally by a high supply of free warehouse, production, logistic and service areas in Bielany Wrocławskie (Kobierzyce municipality in the first ring of the agglomeration). However, the business environment institutions are more and more often established not only in large urban centres (Wrocław) but also in subregional centres, for instance, Legnica, Jelenia Góra, Wałbrzych, Świdnica, Głogów and Lubin. Entrepreneurs may also find support from this kind of institutions in smaller towns such as Dzierżonów, Kłodzko and Złotoryja. Due to the institutional support in the areas located farther away from the agglomeration cores, the location elasticity of the higher-technology industries is increasing.

From a short-time perspective, the filtering process may be assessed positively. It contributes to the industrialisation of the less-developed areas and is conducive to an income increase in the region. It should be kept in mind that the diffusion towards the peripheral centres concerns mostly maturing industries, which implies the concentration of medium low-technology and low-technology industries in these areas. The process results in relatively low wages and slowing down innovation. From a long-time perspective, the consequences of downward filtering of industry may thus turn out to be negative. The research conducted in the USA (North Carolina) indicates that there were significant differences in the location and shifts of the industry, which relocated more frequently to the less urbanised areas with lower wages (Moriarty 1983). There were also differences in the location behaviour. Local enterprises remain in local centres; state enterprises prefer less urbanised areas that are located farther away; foreign enterprises are usually located in a random manner, without a visible tendency.

The process of industry dispersion is currently caused by the increasing labour costs as well as the emergence of development thresholds in large urban agglomerations (Moriarty 1991). This process is also connected to the product life

cycle (Vernon 1960), which is confirmed by the processes identified in the investigated Lower Silesian Voivodeship, in particular those relating to medium low and low-technologies. However, the process of industry infiltration downwards the hierarchical urban system is more complex, which is confirmed by the results of the analyses of the main cities in the region and their suburban zones. An important aspect of the changes in the industry spatial structure in the voivodeship is thus a marked movement of the industrial activity towards peripheral areas of individual urban complexes in the region. It mostly concerns medium low and low-technology industries (Figs 3 and 4C, D). This process is especially visible in the Wrocław agglomeration. The analysis of the LQ for the concentration of industrial entities by the intensity of R&D work indicates the peculiar significance of the urban core environment, which creates conditions conducive to high-tech activities (Figs 3 and 4A). The highest values were mostly characteristic of Wrocław, where the LQ value was twice as high as the mean for the whole region. It results from the size of Wrocław and the function it performs in the economic system of the whole voivodeship. The city of Wrocław is the main labour market in the region; thus, it has a vast impact zone comprising two rings of municipalities located around the city. These processes are not so marked in the case of other agglomeration complexes in the voivodeship. However, there is a perceptible diffusion of the industry infiltration processes towards the hinterlands of smaller cities, LGOM and the Jelenia Góra agglomeration in particular (Figs 3 and 4C, D). It concerns mostly medium low and low-technology industries, though there are certain symptoms indicating the increasing role of high-technology industries in the case of some LGOM centres (Figs 3 and 4A). It results from the fact that a central city may still draw more innovative entrepreneurs. For a long time, cities have been considered a mixture of innovation (Vernon 1960; Brouwer et al. 1999; Campi et al. 2004). Owing to the risks related to product development, new enterprises located in the city core may be more likely to fail but they may also have a higher potential to grow (Renski 2008).

The selective interest in certain areas of the Wrocław agglomeration results from specific conditions. In the concentration process of a

given industrial activity, a special role is played by the location factors for economic activity (e.g. the location of main routes, economic functions of the centres that perform the role of satellite cities in the Wrocław agglomeration, the spatial distribution of subzones to special economic zones or institutional forms of support for innovation, e.g., technology parks). The industrialisation of suburban zones that takes place only in such areas results in the phenomenon of growing specialisation (Filion 2001). Thus, the analyses presented above indicate that the phenomenon of relocation and spatial infiltration of industry in particular agglomerations of the voivodeship proceeds in a highly selective manner. The processes of concentration and relocation of industrial entities in the Wrocław agglomeration are more complex and internally diverse than elsewhere. Simultaneously, the indicated regularities point towards the growing importance of the suburban zones as areas of intensive diffusion of industrial activity from the central hub, the effects of which comprise larger industrial areas (Rudewicz 2016). In the case of the Wrocław agglomeration, an important role is additionally played by the high supply of free warehouse, production, logistic and service areas in Bielany Wrocławskie (Kobierzyce municipality in the first ring of the agglomeration), where two motorways meet: the east-west axis of the A4 (Berlin-Kiev) and the north-south axis of the A8 (Wrocław-Poznań-Gdańsk and Wrocław-Łódź-Warsaw). Multifunctional centres (such as technology parks), which are often established in the areas of subzones to special economic zones, offer the possibility to pursue 'built-to-suit' investment projects (based on the assumption that the building is designed and built specifically to suit the needs of a given renter) for warehouse, production, logistic and service areas; thus, favourable conditions are created for the high- and medium high-technology industrial entities.

Similar processes also occur in the case of smaller urban complexes in the voivodeship, i.e. some municipalities in the area of LGOM agglomeration (Legnica, Polkowice, Chojnów, Kotła and Pęcław), Jelenia Góra agglomeration (Mieroszów, Jeźów Sudecki and Mirsk), Wałbrzych agglomeration (Szczawno Zdrój) and Kłodzko agglomeration (Duszniki Zdrój and Łądek Zdrój), as well as in the rural areas around Zgorzelec. A crucial

role is played by the business innovation centres or business consulting services, which offer support to the entrepreneurs, e.g., during...the process of establishing, running and developing an enterprise or in terms of training, consulting and implementing projects based on modern technologies, R&D services, etc. These institutions and companies mostly comprise technology parks, science parks, science and technology parks, technology transfer centres, technology incubators, business incubators, chambers of commerce, self-governments of entrepreneurs, training and consulting centres and loan and guarantee funds. This can be exemplified by the Lower Silesian Technology Park 'T-Park' in Szczawno Zdrój, the Legnica Technology Park in Legnica, or the Nowa Ruda Industrial Park and Nowa Ruda Business Incubator by Regional Development Agency 'AGROREG' in Nowa Ruda. However, a suburban zone is usually a much more favourable environment for medium low and low-technology industries, which is evidenced by the high LQ values for low-technology industrial entities (Fig. 6B, cf. Renski 2008). The infiltration of the low-technology industries takes place not only into the areas of suburban zones but also into farther peripheral areas of the investigated voivodeship – unit types 1 and 2 (Fig. 6B).

In general, the transformations observed in the Lower Silesian Voivodeship occur similarly to other examples from the world. The transformations of the industry occurring in the first ring of the largest urban agglomerations, which are based on a similar feature characterising the agglomeration core, constitute a distinguishing feature of the investigated region. This is particularly true for the suburban zone of Wrocław, distinguishing it from many cities in Western Europe or North America (Boiteux-Orain, Guillain 2001; Coffey, Shearmur 2002). The progressing processes of suburbanisation in the regions of many cities, including smaller ones, affect the changes in the pattern of economic activity distribution from a monocentric system to a polycentric one (Frenkel 2012).

Conclusion

The Lower Silesian Voivodeship is characterised by significant spatial diversity of the

industry concentration and specialisation processes. In general, the level of concentration of industrial activity in the voivodeship continued to reduction in the years 2009–2020. However, the concentration processes of industrial entities in the voivodeship are much more complex when it comes to the distribution of entities based on the intensity of R&D work.

In the case of high-technology industries, concentration processes are very clear and on the rise; the spatial structure of the high-technology industry in the voivodeship heads towards a distribution reminiscent of oligopoly. The remaining levels of industrial activity, as reckoned based on the intensity of R&D work, are subject to indisputable dispersion. It is visible not only in the case of low-technology industries but also in medium low and medium high ones, the special role in which is played by the automotive industry. The highest increases in the high-technology manufacturing entities are characteristic of the largest urban complexes, the Wrocław agglomeration in particular; these areas are also the contemporary driving forces for the industry in the voivodeship. This process is accompanied by the decline in the significance of the southern part of the region, in which deindustrialisation of low-technology industries takes place. However, good raw material conditions for the development of the industry that has been liquidated dominate in this part of the region, yet the restoration of the industry based on a more modern processing industry takes place on a much smaller scale.

The high dynamic of the industrial entity growth usually occurs in the suburban zones of the largest cities in the voivodeship, in particular Wrocław. However, internally, the area is significantly varied, and the scale of the processes depends on a city's size.

We observe the relocation of industrial entities, including the technologically advanced ones, to the first ring of the Wrocław agglomeration, which is evidenced by highly dynamic growth in the number of entities, while the central hub continues to hold a dominating position. Less technologically advanced industries tend to locate themselves in the peripheral areas of the second ring. These processes are not so marked in other urban complexes in the voivodeship. However, there is also a noticeable diffusion of the industry

infiltration processes towards the hinterlands of smaller cities.

Thus, the analyses presented above indicate that the phenomenon of relocation and spatial infiltration of industry in the selected agglomerations in the voivodeship proceeds in a selective manner. Consequently, the structure of the high- and low-technology industries is more stable in the voivodeship in terms of their spatial distribution; much more significant spatial transformations involve medium high- and medium low-technology industries.

Location factors for economic activity play an important role in the concentration process of industrial activity. Examples of these factors include the location of main routes and economic functions of the centres that perform the role of satellite cities in the Wrocław agglomeration, in particular the spatial distribution of subzones to SEZ or technology parks. They result in the growing functional specialisation of individual spatial units and higher location elasticity of the industry in the voivodeship.

The results of the obtained research can be helpful in formulating the appropriate directions of economic policy, especially in the field of industrial and spatial policy. Owing to the fact that the processes of relocation and spatial infiltration of industry in individual areas of the voivodeship are selective and have not yet been fully crystallised (especially regarding high-tech industries), they require further and in-depth analyses. All the more so today, after the pandemic crisis, when there is a debate on the reconstruction and recovery of the industry in Europe or in the USA. The aforementioned issues may therefore be important in the process of re-industrialisation.

Author's contribution

The authors contributed equally to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. The authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors have no conflict of interest to report.

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