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Prerequisites for successful succession in family company according to its successor

1. Introduction

Family firms are the oldest institutions in the business world; as such, they constitute one of the pillars of the world-wide economy. Their creation, operation, and collapse considerably affect the development of both national and global economies. The long-term perspective of running a business by a future generation as well as the combination of family-related and managerial functions result in distinct identities of said entities. It needs to be underlined that every fifth company of the Fortune 500 list is a company managed by members of one family. For example, one may mention such widely known trading companies as Walmart, car manufacturers like Volkswagen, Glencore – a natural resource commodities trader, Samsung – a producer of electronic goods, L'Oréal – a producer of beauty products, IKEA – a producer of furniture, and Lego – a manufacturer of toy blocks.

In the US, family businesses generate around 60% of its GDP and provide nearly 80% of new jobs. However, the study's findings show that Polish family businesses generate around 10% of Poland's GDP. Regardless of the size of a family business, its profile of production, or service, the economics literature states that succession is an indelible element for the entity to operate in its definitions of family businesses. For family businesses, succession is a prerequisite for their survival and development.

The fact that numerous Polish companies are now facing key decisions related to the transfer of power, knowledge, and property is becoming more and more obvious. The first wave of succession is coming; therefore, the company founders (those who took the risks and sacrificed their work, energy, and money

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to establish their businesses) are about to hand their companies over to their successors. The first intergenerational change is connected with the necessity of defining a new vision of the company by a senior member and the family as well as establishing new systems of values and formal regulations as to the property and power in the family firm.

Within the five years to come, 37% of the owners of Polish private businesses will plan to relinquish their power – this data can be found in the "Family Business Study" carried out in Poland by PwC (PricewaterhouseCoopers) in cooperation with the Instytut Biznesu Rodzinnego [Institute of Family Businesses]. Among those companies planning for succession over the next few years, a vast majority intends to keep the property and power in the hands of their families (75%), whereas a third are planning to pass these on to younger generations (though supported by professional managers). The findings show that more than a half of the Polish family companies covered in the study (60%) have already made their decisions as to their prospective successors (Ibrahim and Ellis, 1994, 211–212).

Succession and its planning constitute a complex process of elaborating and executing a strategic plan to transfer property and power by the owner of a family business to a chosen successor – someone who will be able to carry on the profile of the family business and expand the company in accordance with an agreed strategy.

The aim of this paper is to determine the conditions of successful succession as sought by the successors of family businesses. The following study presents research methodics as to the evaluation of the succession process combined with the author's participant observations in a researched family company as well as an in-depth particularly structured interview carried out with the successor of said company.

2. Research methods as to determinant factors of succession

The research involved the participant observation method and an in-depth semi-structured interview carried out with the successor of the family business. Within the scope of the participant observation, an observer attempts to "enter" a researched community in order to observe it "from inside" (Altkorn, 1998, 380). This method allows us to purposely register authentic the behavior of people in their natural environment. The subject matter of the process is to observe the individual behavior of the research subjects, while the observer's task involves recognizing, registering, and interpreting a subjective sense and social significance of said behavior.

The participant observation involved accompanying a respondent while she performed her daily habitual tasks The observer did not confine herself to sheer registering. Some current situation-related questions were asked in order to understand how the process was run and what motives the researched person held. The aim of the participant observation was to examine the behavior of the researched person in her natural environment, every-day situations, and events for the sake of the succession process in the family business as well as the relationship between the senior member and the successor in this company.

To this end, the author (the observer) entered into contact with the researched persons, actively participated in observed situations, and sometimes prompting the subjects by behaving in a particular way to make them act and react accordingly. However, the author did not directly influence the researched people's behavior; she merely adopted one of the roles typical for the observed situations without often disclosing her real intentions to the research subjects.

The succession process in family enterprises and emotional intelligence-related behavior are characterized by comprehensive complexity and ambiguity, which requires the researched notion to be analyzed further. To this end, qualitative interviewing was used as a research method.

The combination of interviews and observations brings numerous advantages that intertwine and allow us to comprehend other facts (www.ibrpolska.pl). Qualitative interviewing is a kind of interaction between an interviewer and a respondent. The interviewer has a general research plan; however, it is not a fixed number of questions that need to be asked in a given order and with the use of determined words. It is crucial for the interviewer to be fairly familiar with the questions to be posed; as a result, the interview may go smoothly and naturally (Babbie, 2007).

A qualitative interview is a steered and controlled conversation during which an interviewer particularly emphasizes some topics (triggered by a respondent) and consequently indicates the general direction of the conversation.

In the social science literature, one can find various interviews. The research in question involved an individual semi-structured interview (SSI). The core of said interview is to ask a series of pre-defined questions; however, a researcher is allowed to change their form and order. Thus, one may analyze the answers in depth (Promoting..., 1995). The technique of a semi-structured interview has been used to acquire some data by combining the advantages of qualitative and quantitative methods. Due to the scarce population used for selecting samples along with its specific character, the interviewer is allowed to adopt a qualitative approach and collect unique data. Nonetheless, the specific character of the researched information makes the use of a semi-structured interview scenario reasonable.

In some research studies, it is justified to select a sample on the basis of the interviewer's own knowledge on the researched population and research aims. This type of selection is called an arbitrary or purposive sample (Babbie, 2009). A purposive sampling is used when a researcher is familiar with a population, making it easy to define the individuals who are most representative of said sample. For the sake of purposive sampling, the researcher subjectively selects individuals with the aim of finding the most-useful or the most-representative ones. The selection should focus on singling out specific and characteristic respondents in order to eliminate non-competent and insipid individuals who have little to say (Bieniok, 1999).

The observations and semi-structured interview were carried out with the successor of family business P1 in January 2017. This company was selected for research purposes on the basis of the following criteria:

– a family business is a business entity in which at least two members of the family work together for the company, at least one member of the family considerably influences the managing of the company, and family members have majority interests in the company,
– the business considers itself to be a family business,
– the family business is managed by a second generation at least (there was at least one succession that took place),
– it is a corporation (a limited liability or joint-stock company) pursuant to the Polish Code of Commercial Companies,
– it has been in operation for at least ten years,
– it is classified as a small-sized or medium-sized enterprise,
– its head office is in the Polish province of Silesia[1].

The application of the above-mentioned research methods allowed the author to conduct an in-depth analysis of the area in question, with special consideration given to the following:

– a diagnosis of the factors that shaped the successor's decision as to her education-related choices,
– the influence of being raised in the entrepreneurial family on her decisions related to her professional path,
– the way the parents shaped their children's pro-business attitudes,
– the importance of the successors' competencies related to emotional intelligence,

[1] It was a deliberate decision to select this province for the sake of the research. The researcher assumed that the province of Silesia is known for its strong spirit of entrepreneurship and fixed business-related behavior patterns.

– the crucial factors determining the succession processes,
– the role of a senior member in the succession process,
– the course of the succession process.

3. Influence of being raised in entrepreneurial family on developing successor's professional career

The successor of the P1 family business confirmed that her parents had influenced her education-related decisions. She also admitted that being raised in the entrepreneurial company had a great impact on her career-related decisions. The phenomenon confirmed what is propagated in various scientific studies – the succession depends on the family values and upbringing models used by the parents (Aronoff et. al., 2012, 42).

A particular emphasis was placed on the upbringing methods used by the parents, since the methods considerably influenced the development of the entrepreneurial attitudes. This view has been shared by such researchers as E. Więcek-Janka, E. Aronoff, S.L. McClure, J.L. Ward, A. Surdej, M. Fretschner, and S. Weber (Aronoff et. al., 2012, 42; Grant, 1992). The emphasis was put on the time and interest the parents devoted to their children, which consequently forged a partner-like relationship between the parent and the child. This relationship plays a crucial role in the succession process.

As proven by other researchers, the successor highlights the importance of the educational influence of an entrepreneurial family on the future attitudes of the children (Barnes, 1988; Kałużna, 2009, 49–61). Equally important as to the shaping of the entrepreneurial attitudes are the methods indicated by Polish and foreign authors (Bennis and Thomas, 2002; Bieniok, 2007; Halter et. al., 2009; Safin, 2006, 21; Stradomski, 2010, 53):

– Parents encouraging children to succeed (especially in sports or at school).
– Learning how to be self-reliant (thanks to summer camps).
– Parents who establish specific models, set examples, and show opportunities (through their lifestyle as well as their personal and professional achievements).

The respondent highlights that her parents trusted her, that she was consequently granted a considerable amount of independence, and that she was encouraged to make her own decisions (with a special emphasis given to the consequences of said decisions). The success-related satisfaction and results of the failures (all being outcomes of her own decisions) forged her self-esteem, responsibility, and self-reliance. All of these are perceived as competencies required of contemporary managers.

In the successor's opinion, the principles and models derived from her home were the best course of her social, interpersonal, and emotional education, which prepared her to fulfill her professional and personal tasks.

As to her professional career, the respondent admits to having been forced to start working for the family business to a certain degree, mainly when one considers the point in her life when she was asked to do so (at that time, the successor was a third-year student taking a full-time course load). She admits that her concerns were mainly connected to the change from full-time studies to an individual program as well as her ability to combine studies with work, her reduction of free time, and her entrance into adult life. However, she claims that her concerns were ungrounded by giving the following examples: she achieved better marks at the university, she became more organized and orderly, and (above all) she had already acquired two years of business experience upon her graduation (which gave her a competitive edge over her fellow students). The successor underlines that she obtained her MA degree when she was already holding a managerial post.

4. Essence of successors' competencies related to emotional intelligence

The classification of successor competencies used in the succession process implies their various origins. Providing the family enterprise with multi-generational resources and development and ensuring that the enterprise is highly efficient are, to a large extent, dependent on the relevant competence potential of its successors. Those family enterprises that anticipate the succession process should focus on the competence profiles of their successors while taking into consideration the role played by the competencies related to emotional intelligence.

The significance of the competencies in this area was underlined by L. Weroniczak (among others) who enumerated the following psychological and social skills (perceiving them as necessary for creating some space favoring an intergenerational dialogue – the latter being an element of the succession process) (Więcek-Janka, 2015, 39–53):

– communication skills,
– empathic perception,
– ability to solve conflicts through cooperation,
– understanding change processes,
– seeing diversity as a resource,
– regarding the company and the family as intertwined systems.

The successor was presented with a set of competencies related to emotional intelligence. She was requested to indicate those competencies or competency groups that, in her opinion, were of considerable importance in the succession process.

Table 1 shows the competencies that were presented to the respondent.

Table 1

Competencies related to emotional intelligence

SELF-AWARENESS
ability to recognize one's own emotions
being aware of one's own feelings, values, or preferences
self-esteem
SELF-APPRAISAL
self-belief
awareness of one's own abilities and opportunities
awareness of one's own limitations
SELF-REGULATION
ability to consciously regulate one's own emotional states
ability to cope with stress
ability to adjust one's own emotions to one's own norms, principles, and values
EMPATHY
being aware of other people's feelings, values, or preferences (understanding others)
being sensitive to the feelings of other people
being willing to help and support other people
ASSERTIVENESS
ability to express one's opinions, criticism, needs, and wishes
ability to firmly say "no" in a way that does not offend other people
ability to accept criticism and evaluation
PERSUASION
argumentation skills
effective communication
ability to settle conflicts
LEADERSHIP
ability to create visions and encourage others to fulfill them
ability to win supporters
charisma
COOPERATION
ability to create bonds and cooperate with others
ability to work in a group to achieve common aims
ability to perform tasks in a group and solve problems collectively

Table 1 cont.

MOTIVATION
self-commitment
striving for success
optimistic attitude
ADAPTATION SKILLS
willingness to change
willingness to take decisions and act
willingness to act and make decisions when under pressure
DILIGENCE
willingness to take responsibility for tasks and their execution
ability to find satisfaction from performed duties
being determined in actions

Source: Author's own elaboration (based on Goleman, 1996)

The respondent states that modern successors should feature each of the above-mentioned competencies to a greater or lesser extent. She thus confirms the theory promoted by numerous authors that emotional intelligence-related competencies are crucial to the succession process (Jamer, 2006, 7–9; Marjański and Sułkowski, 2009, 31; Więcek-Janka, 2015, 39–53). Nonetheless, she particularly emphasizes that self-belief and self-esteem are also necessary for managing a family company. The respondent states that a successor should be aware of his/her abilities in order to reasonably set goals and fulfill them. However, the successor should also know his/her limits in order to make use of the knowledge and experience of his/her staff. Thus, he/she may cooperate with the staff (i.e., compensating for his/her deficits). In the respondent's opinion, creating bonds in order to achieve common aims requires certain abilities to win supporters who are charged with putting the vision into practice (i.e., some leaderships skills). The successor claims that creating visions and encouraging people to fulfill them depend on communicating in the broad sense of the word. On the other hand, persuasion is a prerequisite in each change-introduction process in a company, whereas the lack of adaptation skills in an ever-changing environment implies that the effective management and development of the company are, in her opinion, impossible. The respondent underlines that the complexity of the business environment in which modern companies operate (not only family-run ones) requires that the successors have the ability to cope with stress as well as act and make decisions when under pressure (among many other crucial advantages).

5. Significance of factors that determine succession process

In family companies, the succession should be a comprehensive, long-term, and meticulously planned process in which (apart from the formal requirements and competencies) one should take family values, the rules of behavior, and the traditions of the company into consideration.

The respondent was presented with a set of 11 factors that determine the succession process in a family company (as presented in Table 2). Her task was to indicate the factors that, in her opinion, determine the succession process to the largest extent. The successor was also encouraged to add other previously unmentioned factors that determine said process.

Table 2

Factors that determine succession process

No.	FACTORS THAT DETERMINE SUCCESSION PROCESS
1	Good relationship with parents
2	Good relationship between successor and other members of family
3	Good relationship between successor and staff
4	Good relationships with clients
5	Trusting successors
6	Faith in successor's skills
7	Encouraging successor to become familiar with business activity
8	Knowledge of trade/market
9	Trade-related experience
10	Education
11	Clear criteria of property division
12	Others (what factors?)

Source: Author's own elaboration

The successor picks out the following features as the determiners of the succession process:

– trusting the successor,
– faith in the successor's skills,
– good relationship with parents.

She says that, in her case, the above-mentioned factors considerably influenced the succession process and that each of them is directly connected with the others. In the respondent's opinion, a good relationship with the parents has an immediate impact on the trust between parents and children and vice versa – members of the family trust one another, which reinforces the bonds between them. The quality of the relationship between the company founder and its successor is also highlighted by E. Venter, C. Boshoff, and G. Maas. They claim that succession-related satisfaction is strictly connected with the existence of a positive relationship between the founder/owner and his/her successor (Weroniczak, 2012, 81). The same authors also highlight that senior members of the family company should trust their potential successor, which is also confirmed by the successor herself. She claims that a family company will be transferred by the parents to the offspring whose abilities and skills they trust. She concludes that, if the relationship between the parents and children is good, then the parents will know whether their child possesses the abilities and predilections to take over the family business or whether the child is at least wishful, able, and motivated to acquire them. The respondent particularly focuses on another group of factors of essential character as to succession:

– good relationships between the successor and the remaining members of the family,
– clear criteria as to the division of property.

Leaving the above-mentioned conditions unsatisfied is one of the most frequent reasons for the short lives of family companies (Machalica, 2012, 110).

The successor states that the family company is a specific entity where having good relationships is of crucial importance; this truth is highlighted by numerous researchers (Lewandowska et. al., 2012, 121; Meijaard et. al., 2005, 12; Moorhouse, 2000; Sobiecki and Leszczewska, 2010; Stone and Dillehunt, 1978; Sułkowski and Mariański, 2009, 39; Venter et. al., 2005, 283–303; Więcek-Janka and Hadryś-Nowak, 2016, 61–72). She perceives said relationships as a valuable capital, non-existent in other companies, the capital that allows to reach a consensus in strategic issues. The successor believes that parents play key roles in such situations, as they should make their children familiar with their own expectations, intentions, and decisions. Only then will it be possible to avoid conflicts (now and in the future).

What is more, the importance of open communication in order to reinforce the family business is emphasized by the author (Fretschner and Weber, 2013, 410–428). In many cases, the succession is not a basic problem; the core problem is the willingness to start talking about this matter. Hence, the key issue is to start

an open discussion among members of the family as to selecting a successor, even though said members are not directly engaged in the company's business activities. The owners' decisions as to succession considerably affect the financial situation of their spouses and children. This is particularly important for owners of family companies, whose decisions may influence their children's choices of careers.

The successor underlines that open communication has always been present in her family. She provides the following example – her parents had been talking about their intention to divide the property before the actual will was made. She confirms that, as a consequence, there were no misunderstandings between her and her siblings (which reinforced the whole family).

6. Role of senior members in succession process

Numerous researchers and practitioners in the family business environment hold the view that family company founders and owners are the main factors responsible for succession (Dźwigoł-Barosz, 2017, 131–133). While interviewed, the successor underlined that she was given power and ownership of the family business by her father. When asked about the role of the senior member in the succession process and his current role in the company, she stated that, despite being a formal owner of the company, her father holds an important job of a main counselor in the company.

The generation of senior members play a crucial role in the succession process. If the parents properly plan for succession, the probability of succession obstacles is reduced and the risk of deteriorating the company's situation due to management changes is minimized. Research conducted in the Swiss market confirms that emotions are the main reason why senior members are not in favor of succession (Hammersley and Atkinson, 2000, 138). Owners of family companies often delay the process of handing over their companies to successors since they experience considerable discomfort related to handing over to "foreign" hands (even if it means their own children) something that was achieved after so many years, something that became a part of themselves, something that defines their identity (Jakubowski, 2012, 73–74). It is thus necessary to take some actions that would promote the post-succession activity of the senior members of a family business, provided that they are still willing to be a part of the company. However, they would rather act as counselors than manage the companies, allowing the younger generation to show their best.

The above-mentioned phenomenon is confirmed by the researched successor, who explains that her father has been her mentor since the beginning of her

career. She states that observing her father in everyday situations, being encouraged to ask about his opinions, and making use of his many years of experience as a senior member and counselor have been, in her opinion, the best business school possible. She believes that their cooperation allows them to blend their various values and experiences for the benefit of the company. The successor admits that their opinions are sometimes not unanimous. She underlines, however, that it is not a matter of conflict but more a matter of having an individual overview of numerous issues. However, the issues are in line with their common vision on how the company should be developed in the long run. The successor claims that having her own private management expert in the person of her father has been a highly comfortable situation for her, as it allows her to make use of his knowledge, experience, and competencies.

The successor's professional experience has only been developed in the family business, where she has worked as an HR officer and manager of the HR Department. She emphasizes the role of her father, who gradually prepared her to take over the company. The father showed her analyses of all of the departments of the company, with a special emphasis on financial and analytical documents, budgeting, and inspection; furthermore, he gradually delegated tasks and task-related responsibilities to her.

The rationality of the above-mentioned way in which business knowledge, professional tricks of the trade, or business secrets are transferred to businessmen's children is confirmed by A. Bocheński. He claims that a family business may be an educative environment. A successor candidate employed in a company who starts from the simplest tasks and goes further up the ladder as to take up managerial positions may learn practical skills from co-workers and senior members of the family company, including cooperation skills and managerial practices remaining in compliance with the values of the family who established the company. By means of a partner-to-partner dialogue, a senior member and successor can jointly create new development trends, reconciling the experience and knowledge of the company founders with the innovativeness and energy of their successors (Bracci and Vagnoni, 2011, 8).

The successor highlights the actions taken by her father (the senior member of the company) that were mainly focused on creating her image in the company; consequently, she was able to take over the helm of the company. She gives examples of such actions: publicly emphasizing her role in the company among colleagues and business partners as well as highlighting her independent successes achieved while performing her tasks, among others. She also states that the reasons and outcomes of her failures were only discussed with her father on a face-to-face basis. The successor claims that these actions were of great help

for her, not only to establish her authority but also to forge her self-esteem and willingness to further improve her competencies.

Transferring knowledge to a successor is not an easy task – it is a rather lengthy process of raising a child and preparing him/her to take the company over. The owners of family companies have many opportunities to transfer knowledge to their children (Bocheński, 2016, 14):

- the upbringing process may involve transferring business knowledge, professional tricks of the trade, or business secrets to the children;
- employing a child in the company and encouraging him/her to perform the simplest tasks and proceed as far as accepting managerial positions may provide the child with numerous practical skills;
- in the preliminary period in which a successor acts as chairman, the successor should be supported by means of mentoring and counseling, by experience swap, or through learning practical aspects of management.

The observations and interview carried out in said family business proved that all of the above-mentioned assumptions were used in the succession process. It should be drawn to the readers' attention that similar actions as to succession planning were taken by senior members and successors of Polish SMEs (Adamska et. al., 2014), who had reviewed the first issue of an innovative tool – *Przewodnik po sukcesji w firmach rodzinnych* [Guide on succession in family companies].

On the basis of the interview with the successor and the observations carried out in the P1 family business, one may conclude that the succession process included the following four phases elaborated by S. Goldstein (Jaskiewicz et. al., 2014, 29–49):

- initiation: a period during which the children or potential successors familiarize themselves with the way in which the family business is operated;
- selection: a period during which the young generation is assessed and future leaders are subsequently selected. The core factors are their commitment and skills;
- education: a period when all of the attention is focused on developing the skills of future successors;
- sheer succession: a period when young successors are given any and all rights and obligations (power).

The analysis of the succession process in said family business proves that the successful implementation of the successor means not only transferring professional knowledge but also a skillfully inducting the successor into the family business (Miller and Rice, 1967, 44).

7. Conclusion

As the market economy relies on family firms to a considerable extent, the succession problem has become common and pressing (Danco, 1975). The experience shows that 50% of family firms will be able to deal with succession-related problems, whereas as few as 15% of the companies will manage to hand the company over to a third generation (Tomski, 2011, 147).

Over the last few years, the owners of family businesses in Poland have systematically become more and more aware of the role of succession. The entrepreneurs have found out that inheriting a company is an inevitable process. Furthermore, they should not assume that the next generations will be willing to actively participate in the succession process. On the basis of the reference literature, one can presume that a family company based on common values is one of the best education methods for children. Working for a family company allows young people to fulfill their professional ambitions. Owing to the expert knowledge acquired while studying, they are given an opportunity to develop the company and maximize profits. Young people are more ready to take risks and more open to new ideas and innovations. Their parents' experience combined with the next generation's commitment and readiness for changes often bring about outstanding results. According to the managers of the family business under study, this multi-generational cooperation for the sake of the company is deeply inspiring. Parents can see that this investment is reasonable, as many generations will benefit from the companies (Lansberg, 1983, 39–49).

The research conducted by the author in the P1 family company shows that the parents' influence on their children's educational paths was of critical importance. It also shows that the successor's upbringing in the family company shaped her professional decisions considerably. The applied research methods indicate that an entrepreneurial company greatly affects the career-related decisions of successors and the development of entrepreneurial attitudes. The research also showed that it is essential to have competencies related to emotional intelligence in the succession process. The importance of the factors shaping the process in the largest extent is underlined.

On the basis of the conducted interview and observations, the succession process was shown along with a special emphasis on its four phases. Furthermore, the key role of a senior family in the succession process was highlighted. It needs to be emphasized that succession is not a one-time event. Succession is a long process that involves transfer of knowledge, power, and ownership (Adamska et. al., 2014; 30). The complexity of the process proves that all of the succession-related actions were properly planned. In order to ensure the

continuity of the competent behavior, it is necessary that both senior members and successors are fully committed; thus, the family companies will be able to operate in the long run.

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Izabela Jonek-Kowalska*

Exposure of Polish enterprises to risk within business cycle

1. Introduction

In modern economies, sudden and deep changes of the business cycle are relatively frequent; these changes spread quickly and adversely affect regional and global development opportunities due to the progressing globalization of economies and internationalization of business activity. This is confirmed by such events as the global crisis of 2007 or economic collapses in such countries as Argentina, Island, Cyprus, or Greece. In economies with relatively short free-market traditions, such business cycle fluctuations are a substantial threat to the economic stability, entrepreneurship, and the desired level of economic growth constituting the necessary condition for the transformation of an economy from the level of an emerging one to a developed one. The Polish economy is surely such an economy, which has only been functioning as a free-market economy since 1989.

The aforementioned circumstances require the monitoring of economic changes and their impact on the operations of enterprises and their financial results. Therefore, the goal of this article is to assess the exposure of Polish enterprises to the risk related to changes in the economic situation. To attain the goal set in this manner, the article is divided into two parts. The first one covers conceptual issues connected with the shaping of economic risk in the business cycle and enterprise behavior in this cycle. The second one presents the methodology of assessing the exposure of Polish enterprises to risk within the business cycle.

The conducted research shows that the financial results of Polish enterprises undergo intensive changes over time, which attests to a rather high level of economic risk accompanying their activity. They also strongly correlate with changes

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in the GDP, which means that, at present (and most likely in the future), they will be prone to variations in terms of the business cycle.

2. Behavior of enterprises in business cycle vs. economic risk

Changes in the economic situation materially affect the entrepreneurship, activity, financial standing, and results of enterprises (Bayar et al., 2018, pp. 248–263; Firlej, 2008, pp. 151–158). Thus, the demand for goods and services increases as part of the operating activity in the situation of an economic recovery, which positively affects production and investment plans (Bachmann et al., 2013, pp. 217–249; Kayo and Kimura, 2011, pp. 358–371). In order to meet growing market needs, enterprises are producing more; this results in the growth of their volumes and revenues from the sales of products (also including services), goods, and materials. As a result of the increase in production volumes, the growth of sales revenues is also accompanied by increases in product manufacturing costs (including service provision costs) as well as the value of the sold materials and goods; however, the said increase is less intensive as a rule, which allows enterprises to significantly increase their financial results from sales (Adamowicz and Walczyk, 2009, pp. 139–156) and reap the benefits of the market prosperity (Hübner et al., 1994; Motoki and Gutierrez, 2015, pp. 47–59).

During a period of recession, however, market enthusiasm and optimism are reduced; this is accompanied by a decrease in the demand for goods and services. Under such conditions, both prices and sales volume fall, resulting in a reduction of revenues from sales and, consequently, a deterioration in the financial results from sales. Meanwhile, enterprises very frequently do not recognize the symptoms of an imminent crisis in the initial phase of a recession and do not abandon ambitious production plans, which leads to overproduction, increases in the stocks and costs of their maintenance, and an oversupply on the market. Under such economic conditions, it is initially necessary to reduce costs by means of diminishing production volumes, subsequently reducing employment; this results directly from the reduction of the sales volume forced by the market (Bachmann and Bayer, 2014, pp. 1392–1416; Matkowski, 2002, pp. 26–34).

In financial activity, the effects of shaping the capital structure and investments of a financial nature are shown by the level of financial costs and revenues. During a period of recovery, enterprises have as a rule increased the opportunities of their own internal financing in the form of growing net profits. Hence, the financial costs related to financing the acquisition of their own external capital and external third-party capital may be lower during this period than at a time of recession

(when difficulties in generating positive financial results are higher), forcing enterprises to reach for external financing sources; this increases the level of their financial costs. In the case of financial revenues that can be generated from the interest on granted loans and from the cash means accumulated on current and term deposits or that can reflect the revenues related to the disposal of financial investments, financial revenues may increase during a period of recovery, whereas they may diminish their value during a downturn (Sierpińska and Jachna, 2007). Decreasing financial revenues and increasing financial costs during the period of a recession adversely affects the generated value of the operating results. As a result, the business activity result and the gross result may be reduced (Bławat et al., 2017, pp. 159–181; Jakimowicz, 2003, pp. 47–62).

As mentioned hereinabove, the financial results of enterprises may change as a result of changing economic conditions during a business cycle. Taking account of the fact that economic risk is defined as the possibility of an adverse deviation of a result from the planned effect, one may assume that the variability of financial results of enterprises expresses the level of economic risk accompanying the conduct of the business activity. As regards the whole economy, in turn, the synthetic measure of its effectiveness is the Gross Domestic Product; therefore, its variability enables us to determine the general economic risk.

Having regard to the theoretical assumptions concerning the behavior of enterprises during a business cycle, economic recovery should be linked to a reduction of general economic risk, which should also have a positive impact on the safety of the conduct of the business activity. An economic crisis, however, results in an increase of general economic risk due to the accompanying reduction of the GDP, which adversely influences the financial results of enterprises and increases the economic risk of their activity.

3. Methodology

In the assessment of general economic risk and economic risk accompanying the activity of enterprises, the coefficient of Variation (1) has been used, being a commonly used risk measure on an ex post basis calculated for the purposes of the Gross Domestic Product and financial results of Polish enterprises, respectively.

$$v = \frac{s}{\overline{x}} \cdot 100\% \tag{1}$$

where:

s – standard deviation of sample,
$\overline{x}$ – arithmetic mean of sample.

In addition, the chain dynamics indices (2) were calculated in order to assess the intensity of changes observed over time for both variables mentioned above, subsequently assessing their mutual links by means of the Pearson correlation coefficient (3), which will enable us to answer the basic research question asked in this article: Do changes in the GDP reflect the level of general economic risk significantly related in statistical terms to changes in the economic results of Polish enterprises, which in turn are a measure of economic risk accompanying the conduct of business activity in the microscale?

$$i_{t/t-1} = \frac{x_t}{x_{t-1}} \tag{2}$$

where:

x_t – value of variable x during period t,
x_{t-1} – value of variable x during period $t-1$.

$$r_{xy} = \frac{\text{cov}(x, y)}{s_x \cdot s_y} \tag{3}$$

where:

cov(x,y) – covariance of x and y variables,
s_x, s_y – standard deviations of x and y variables.

As mentioned earlier, the direct risk measurement was based on the net financial results of Polish enterprises whose changes over time reflect the economic risk accompanying the business activity. In addition, the financial liquidity ratios, debt ratios, and profitability indices were also used to assess the risk with regard to other determinants of the risk level. This enabled an assessment of not only the resultant effects of enterprise activities within the business cycle but also an assessment of the financial situation and risk connected with the possibility of losing financial liquidity. The ratios used in the assessment as well as the methodology for their calculation are presented below.

For the measurement of liquidity-related risk, current ratio (4) and quick ratio (5) were used:

$$CR = \frac{CA}{CL} \tag{4}$$

where:

CA – current assets,
CL – current liabilities.

$$QR = \frac{CA - I - STP}{CL} \tag{5}$$

where:

CA – current assets,
I – inventories,
STP – short-term prepayments,
CL – current liabilities.

The current ratio reflects the ability to finance current liabilities after liquidating all current assets. It is accepted that its normal value should be between 1.5 to 2.0. If the current ratio is lower than 1.5, the enterprise has no financial liquidity, whereas if it is greater than 2, there is a so-called excess liquidity (an excess of current assets relative to current liabilities), which may generate high actual costs of maintaining such assets (the costs of warehousing and financing short-term accounts receivable) or additional alternative costs connected with their possession (the cost of lost investment possibilities).

In the case of quick ratio, inventories and short-term prepayments are deducted from the pool of assets due to the difficulty of liquidating these assets (e.g., problems with the sale of the finished products), with only the most liquid current assets in the form of short-term accounts receivable and short-term investments left in the numerator of the ratio. As a result, the normal value for this ratio is lower than in the case of the current ratio; this is sufficient when its value oscillates around 1.0, which means that all current liabilities can be paid back with the most-liquid current assets (Bławat et al., 2017, pp. 9–39).

During a period of economic recession, financial liquidity usually decreases due to the increasing level of current liabilities and difficulties with acquiring assets to settle them. Eventually, its loss becomes one of the key causes of enterprise bankruptcies (Chen, 2012, pp. 3346–3365; Radde, 2015, pp. 192–207; Roggi and Giannozzi, 2015, pp. 327–342). During a period of economic recovery, the financial liquidity of enterprises is maintained at a normalized level; if additional current assets are accumulated, it may result in excess liquidity (both in the current ratio and quick ratio). It can thus be assumed that, during a period of economic recovery, enterprises have no problems with maintaining financial liquidity.

The issue of financial liquidity is related to the issue of an enterprise's indebtedness. As mentioned earlier, an increase in short-term debt is not conducive to sustaining financial liquidity. Meanwhile, there may be an increase in both short-term debt and long-term debt during a period of recession due to the limited inflow of capital in the form of a positive and increasing financial result. With a growth in the debt level, there is an increase in an enterprise's funding risk, which is measured by means of debt ratio (6) and debt to equity ratio (7) in the

assessment of the financial situation (Bordo and Meissner, 2012, pp. 2147–2161; Sierpińska and Niedbała, 2003, pp. 216–262).

$$DR = \frac{TL}{TA} \tag{6}$$

where:

TL – total liabilities,
TA – total assets.

$$DER = \frac{CL}{E} \tag{7}$$

where:

CL – current liabilities,
E – equity.

In the case of debt ratio, it is recommended that this should not exceed 65% of the value of the total assets, which directly results from two basic financing rules stating that an enterprise's fixed assets should be financed with equity capital; if this is insufficient, it can be increased by long-term liabilities, thus forming the so-called fixed capital. If the fixed capital does not cover the value of the fixed assets, an enterprise is exposed to an excessive funding risk, which may lead to disruptions or losses of the continuity and stability of the sources of financing for its business activity.

Associated with the debt ratio is the debt to equity ratio, which reflects the proportions of the capital structure broken down into equity capital and borrowed capital represented by liabilities and provisions for the liabilities. In order to maintain a safe level of debt, it is recommended that the value of this ratio should not exceed 1.0 in large enterprises. In small- and medium-sized enterprises, a value of 3.0 is permissible. Above these limits, capital structure is regarded as unstandardized and poses a risk to the further existence of an enterprise. It is worth adding at this point that, during a period of recession and difficulties with increasing equity capital, capital structure changes as a result of adverse external conditions and the value of both of these ratios increases. During an economic recovery, adverse external stimuli are limited, and an enterprise can form its capital structure more consciously and more independently from external circumstances (Falk, 1986, pp. 1096–1109; Konopczak et al., 2010, pp. 7–31).

As the level of the financial results of an enterprise changes in a business cycle, profitability indices change as well (An et al., 2017, pp. 131–152; Margaritis and Psillaki, 2015, pp. 621–632). In this paper, these are quantified by determining the return on total assets (8), return on equity (9), and return on sale (10).

$$ROA = \frac{NFP}{TA} \tag{8}$$

where:
NFP – net financial profit,
TA – total assets.

$$ROE = \frac{NFP}{E} \tag{9}$$

where:
NFP – net financial profit,
E – equity.

$$ROS = \frac{NFP}{R} \tag{10}$$

where:
NFP – net financial profit,
E – sale revenues.

As the net financial result is present in the numerator of all of the ratios, one can conclude that, during a period of recession when there is stabilization or a decrease in the net financial result, there is also a decrease in the return on assets, return on equity, and return on sales. However, it should be noted that this will happen only when the rate of decrease of the values present in the denominator is lower than the rate of decrease of the net financial result. During a period of economic recovery when the results are improving and their growth rate is faster than the rate of increase in assets, equity, and the return on sales, profitability (expressed by ROA, ROE, and ROS) increases (Bloom et al., 2017, pp. 391–415; Dyduch et al., 2013, pp. 34–41; Kotowska et al., 2017, pp. 89–101; Tian, 2015, pp. 227–249).

4. Research results

4.1. Economic risk in context of net financial result

Figure 1 shows the changes in the GDP in the nominal prices in Poland during the period under analysis; these changes determine the course of the changes in the business cycle.

According to the data shown in Figure 1, the level of economic growth was positive during the entire analyzed period (ranging from 1.68 to 11.01%). Nonetheless, during the years of 2000–2015, periodical downturns in the business cycle occurred in 2005, 2010, and 2013. In turn, periods of intensive economic recovery

occurred in 2004, 2007, and 2011. It should also be noted that, during the years of 2011–2015, the growth rate of the GDP clearly lowered as compared to the period covering the years of 2001–2010; this attests to the systematic slowdown of the development of the Polish economy in the most recent period.

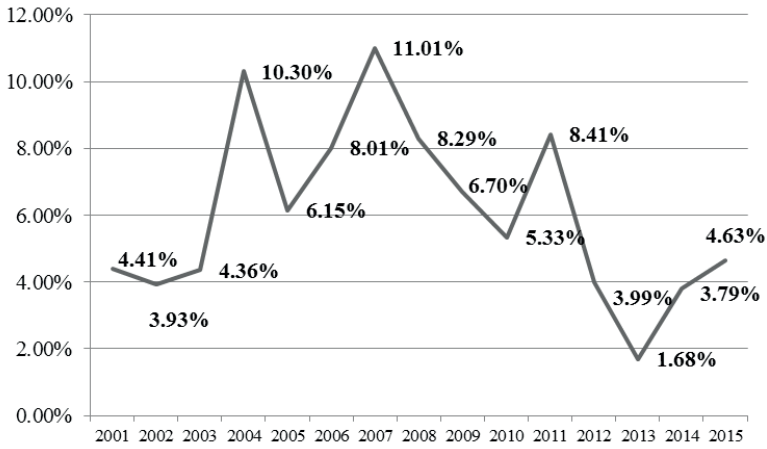

Figure 1. Changes in GDP in Poland during years of 2000–2015 [shown in percentage values]

Source: own study based on data from Central Statistical Office

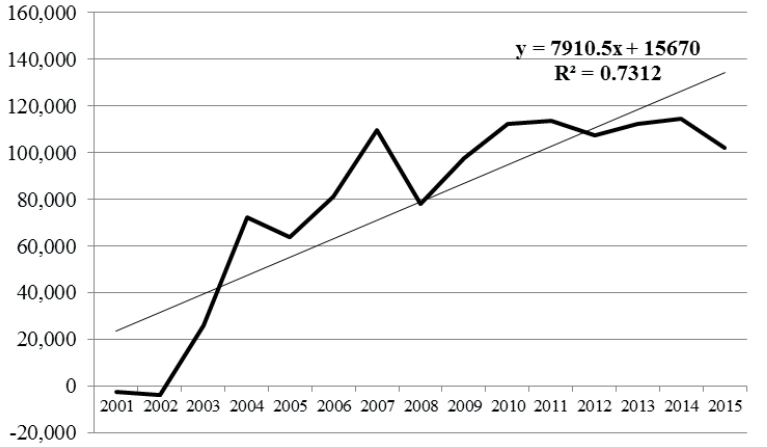

Figure 2. Net financial results of Polish enterprises in Poland during years of 2000–2015 [in millions – PLN]

Source: own study based on data from Central Statistical Office

Figure 2 presents the value of the financial results of Polish enterprises in Poland during the years of 2001–2015. The data contained in this figure shows that it changed according to a well-adjusted linear upwards trend; however, the rate of increase in the financial results has clearly lowered over the last five years.

For the purpose of assessing the variability of both parameters determining the risk level and factors affecting the financial results of Polish enterprises within the analyzed period, Table 1 presents the coefficients of variation for all of the variables under study.

The data contained in Table 1 shows that the highest variability (and, at the same time, the economic risk) is characteristic of the net results of Polish enterprises, which are both exposed to the general economic changes and shaped by the number of determinants of a significant level of variability (said determinants include, first and foremost, the sales revenues and costs of goods and services sold). The financial revenues and costs related to the formation of the capital structure are also characterized by great variability over time, which results from both the changing need for capital within the business cycle and changes to the interest rates. The GDP's coefficient of variation is below 30%, which reflects a lower risk level than in the case of the variables listed above and relating to the activity of the enterprises. Therefore, it can be stated that the general economic risk is lower than the economic risk of the operation of the enterprises within the period under analysis.

Table 1

Coefficients of variation for variables under study [for net financial result and its determinants in percentage values]

GDP	Net result	Sales revenues	Costs of goods and services sold	Other operating revenues	Other operating costs	Financial revenues	Financial costs
27.85%	52.40%	30.77%	31.22%	17.27%	20.09%	29.63%	29.03%

Source: own study based on data from Central Statistical Office

Table 2 contains an assessment of the links of the economic risk under analysis to changes in the GDP (expressed by means of Pearson correlation coefficients). The data contained therein shows that the other operating revenues and costs are not significantly related to the economic situation; this is a result of their incidental nature and minor importance in shaping the final net financial result.

The variability of the GDP determines the net financial results of Polish enterprises to the largest extent. It affects the level of revenues from the sales and their own costs of the goods and services sold to a slightly lower but important and still-significant extent. The economic situation is uninterestedly related to financial

revenues, whereas it does not determine the financial costs; in this case, it results from the systematic cutting of interest rates by the Polish Central Bank within the analyzed period for the purpose of triggering the economic activity of enterprises.

Table 2

Pearson correlation coefficients between GDP and net financial result of Polish enterprises and its determinants

Net result	Sales revenues	Costs of goods and services sold	Other operating revenues	Other operating costs	Financial revenues	Financial costs	Net result
0.8842*	0.7644*	0.7526*	–0.0392	0.2337	0.6664*	0.2973	0.8842*

* significance level $p < 0.05$

Source: own study based on data from Central Statistical Office

4.2. Economic risk in context of liquidity, debt, and profitability

The second part of the research deals with the measurement of economic risk in the context of the economic financial situations of Polish enterprises. Figure 3 presents the results of the assessment of the current ratio and quick ratio conducted in the first of three sub-areas of the research.

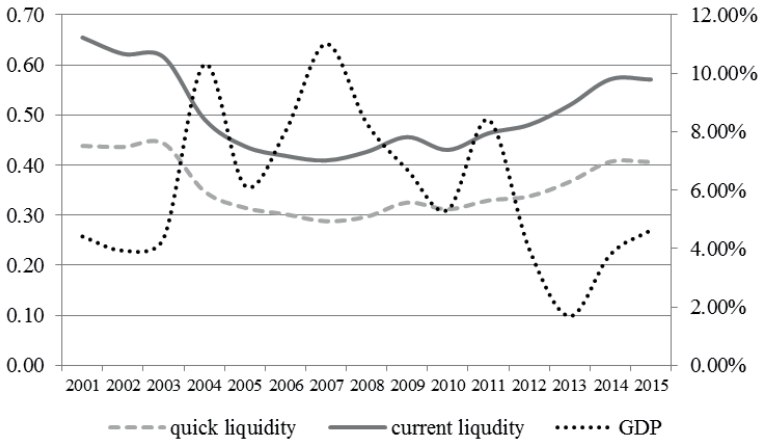

Figure 3. Current ratio and quick ratio of Polish enterprises in Poland and GDP during years of 2000–2015

Source: own study based on data from Central Statistical Office

The measurement of financial liquidity shows that Polish enterprises do not maintain liquidity norms over the whole period under analysis (which are 1.5–2.0 for the current ratio and 1.0 and more for the quick ratio). Polish enterprises are able to settle from 29% to 44% of short-term liabilities with their current assets and from 41% to 65% of these liabilities with the most-liquid assets; these are comprised by short-term accounts receivable and short-term investments. Generally, this level is insufficient for the ability to settle current liabilities positively.

The values of both the ratios similarly change over time, which means that the level of inventories does not have a significant impact on the differences in the assessments of the current and quick ratios. From 2006 onward, there is a significant decrease in financial liquidity due to an intensive increase in the short-term liabilities of the enterprises analyzed. A systematic deterioration of the situation in this regard continues until 2006, when both ratios record the lowest values during the period under analysis. Starting in 2007, both the current and quick ratios systematically increase over time; this is mainly due to a significant increase in the current assets, which increases the size of the assets that may be used to pay off short-term liabilities. However, none of the ratios reach the postulated standardized values. This low liquidity is to a large extent the result of a low level of current assets and their decreasing share in the structure of the total assets, as the indebtedness of Polish enterprises is not excessive and does not exceed the recommended limits (as will be shown later in this paper).

It is also worth highlighting the fact that the decrease in liquidity during the first half of the period under analysis takes place when the GDP growth rate decreases, which confirms the adverse impact of the economic conditions on the situations of Polish enterprises. During the second half of the period under analysis, these relationships are no longer so pronounced, but they are still statistically significant and show positive moderate correlation (Tab. 3). One can thus conclude that the financial liquidity of Polish enterprises changes over time in parallel with the changes in the economic situation.

Table 3

Pearson correlation coefficients between GDP and financial condition of Polish enterprises

Current ratio	Quick ratio	Debt ratio	Debt to equity ratio	ROA	ROE	ROS	Current ratio
−0.6400*	−0.6195*	−0.3433	−0.3400	0.5507*	0.5477*	0.4872*	−0.6400*

* significance level $p < 0.05$

Source: own study based on data from Central Statistical Office

As mentioned earlier, the debt ratio of Polish enterprises is not excessive and does not exceed the recommended limits; that is, 60% of the financing of the total assets with borrowed capitals (Fig. 4). Apart from the first three years of the period under analysis, the degree of covering assets with total liabilities does not even exceed 50%, and its value over time is characterized by a very low variability of 3 percentage points maximally. This provides stable foundations for financing economic activity, as is also confirmed by the debt to equity ratio (which only exceeds the recommended value of 1.0 during the period of 2001–2003). During the remaining period, the total liabilities are fully secured by the equity of the enterprises analyzed (representing 79% to 88% of the value of such capital).

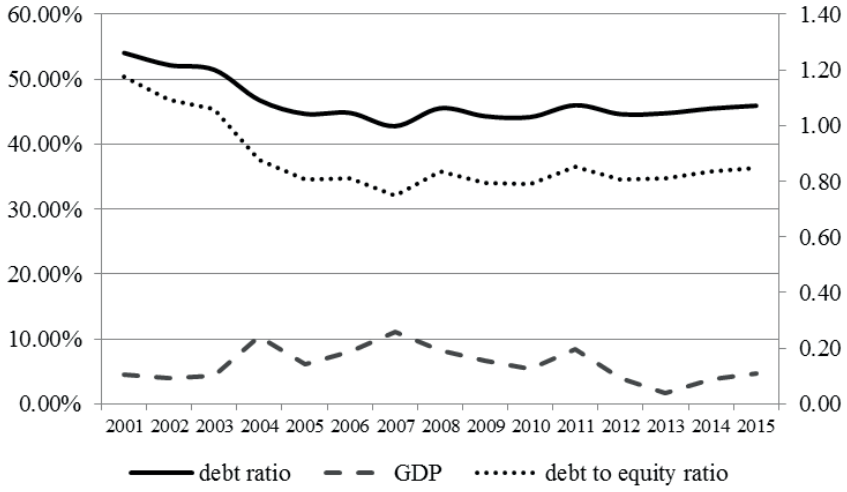

Figure 4. Debt ratio and debt to equity ratio of Polish enterprises and GDP in Poland during years of 2000–2015

Source: own study based on data from Central Statistical Office

The changes in debt in enterprises are not significantly and substantially correlated with the changes in the GDP, which is reflected by the Pearson correlation coefficient contained in Table 3. Thus, enterprises' decisions as to the formation of capital structure are not determined by changes in the economic situation; this may be due to their long-term character and strategic importance, which is not directly affected by the economic situation expressed only in the form of change in the GDP growth rate (which more or less signals economic growth). However, it is worth noting that, despite the significance of the identified correlations, these are negative. This means that, if the economic situation deteriorates, there may

be increases in debt and funding risk due to the decreased financial results and, thus, enterprise equity.

As stressed in the theoretical part and that presenting analysis of financial results of Polish enterprises during the period of 2001–2015, changes in the economic situation have a significant impact on the financial results of enterprises through their determinants; i.e., revenues and costs. An additional and universal measure of assessing the financial results of enterprises is profitability (which has been calculated for three basic determinants of economic activity further on in the paper); that is, return on assets (ROA), return on equity (ROE), and return on sale (ROS). Figure 5 presents the above-mentioned profitability indices for Polish enterprises during the period of 2001–2015.

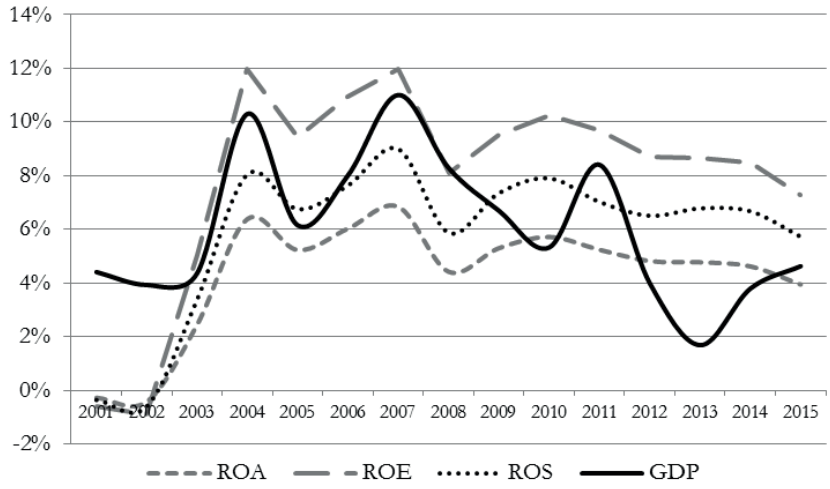

Figure 5. ROA, ROE, and ROS of Polish enterprises in Poland and GDP during years of 2000–2015

Source: own study based on data from Central Statistical Office

The data presented in Figure 5 shows that all three categories of profitability were correlated and changed in the same direction (although with different amplitudes). This means that profitability strongly depends on a financial result. Until 2004, profitability was systematically and quite sharply growing, as was the GDP; i.e., it reflected the changes in the economic situation. Then, during the period of 2004–2005, the ratios decreased, only to increase again with the growth of the GDP in 2007. Starting in 2008, the amplitude of the profitability fluctuations significantly decreased, and its changes were less clearly correlated with the changes in the GDP.

The lowest and most negative profitability was recorded by Polish enterprises during the period of 2001–2002. At that time, the business activity of the enterprises analyzed generated losses in statistical terms. On the other hand, the highest profitability was recorded in the following years: 2004, 2007, and 2010. During these years, 1 Polish zloty invested in total assets brought a net profit of around 6 groszy, 1 Polish zloty of equity generated a net profit of around 11 groszy for its owners, and 1 Polish zloty of net return on sales resulted in a net profit of 8–9 groszy. Despite the quite good values of profitability realized by Polish enterprises during the period of 2009–2015, it is worth highlighting that the financial results and profitability indices decreased over the last three years of the analysis, which may indicate a slight deterioration of the financial situation of the entities under analysis and their abilities to generate financial profits.

As a result of the above-mentioned circumstances and that fact that the indicators take into account not only financial results but also values of the total assets, equity, and return of sales, the relationships between ROA, ROE, ROS, and the GDP growth rate are much weaker than in the case of the absolute values of the financial results (Tab. 3). However, all of the correlations that have been found are statistically significant and indicate a moderate relationship between GDP changes and the profitability of Polish enterprises during the period of 2001–2015. The strongest relationship with changes in the economic situation is shown by the return on assets (ROA) due to the relatively slow changes over time in enterprise assets. Similar is the strength of the relationship between GDP changes and the return on equity (ROE). The lowest value of correlation coefficient (indicating the weakest relationship) is shown by the return on sales (ROS).

5. Conclusions

The research made shows that the financial results of Polish enterprises undergo intensive changes over time, which attests to a quite high level of economic risk accompanying their activity. They also strongly correlate with changes in the GDP, which means that, at present (and most likely in the future), they will be prone to variation in terms of the business cycle. The sales revenues and their own costs of the goods and services sold (i.e., the strongest determinants of the net financial result) are also characterized by average variability and high correlation with the GDP. Other operating revenues and costs as well as financial costs remain invulnerable to variations in the GDP, showing that the less important determinants of the effectiveness of enterprises do not depend on general economic factors.

With respect to the financial situation analyzed in the second area of the relationships between risk and the business cycle, statistically significant relation-

ships were identified in the case of financial liquidity and profitability. They are, however, weaker than those found for the net financial results and their determinants. The weaker correlation of the profitability indices and financial liquidity ratios with the business cycle results mainly from their relativity in the form of the simultaneous dependence on two variables, part of which are moderately correlated with GDP changes. In the case of financial liquidity, it refers to short-term liabilities, whereas in the case of profitability, it refers to the denominators of the ratios used to measure it (which include total assets, equity, and return on sales, respectively).

This is similar with financial decisions and their consequences. Insensitive to changes in the economic situation are such determinants of capital structure as total liabilities and long-term liabilities as well as the financial costs accompanying their regulation. As a result, all debt ratios are not significantly statistically correlated with GDP changes.

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Odra River in Lower Silesia: probabilistic analysis of flood risk dynamics as part of sustainable development of water management

1. Introduction

One of the most common natural catastrophes in Poland are, undoubtedly floods. The uneven distribution of time and the areas of precipitation as well as climatic changes are contributing to the more and more often and violent occurrences of the maximum flow of rivers, which increases flood damage. Inadequate land management and the unjustified belief in the effectiveness of technical flood control measures can also contribute to flood damage.

The development of water management, including flood protection, should be carried out in a sustainable way by integrating social, environmental, and economic objectives. In flood protection, those measures that are least invasive to the natural environment should be used first; in particular, non-technical flood protection methods (e.g., flood risk assessment and management as well as the proper definition and management of flood plains). One of the bases for the sustainable development of water management is the preparation of models, which help us calculate the likelihood of maximum flow and identify areas most at risk of flooding. Based on these, the proper spatial policy and prevention of flood effects will be possible.

This article presents a probabilistic analysis carried out for the flood risk dynamics for a selected area of the Odra River basin. The authors based their risk dynamic assessment on the results of the distributions of the maximum values for a selected hydrological characteristic – the flow rate. Based on the daily flow data collected at a hydrological station on the Odra River in Malczyce from the years of 1994–2013, 30-day flow maxima were set individually for four 5-year periods. Then, a probabilistic model of maximum flow was developed based on these peaks for each 5-year period. The resulting models were used to estimate flood risks and for an analysis of the dynamics for the studied area.

2. Floods, their negative consequences, and risk of occurrence

In Poland, one of the most frequently occurring natural catastrophes (both locally and nationally) are floods. Their negative consequences are one of the barriers to economic growth. This barrier has a rather complex character resulting from various conditions and causes. The possibility of floods and the unpredictability of the phenomenon are external causes, which are largely unaffected by human nature. Total flood prevention is not possible. Most often, the size of the event is so large that it cannot be prevented by any available methods. It is not possible to forecast the occurrence of floods well in advance, which would allow for actions to minimize the negative consequences. Accurate forecasting is only possible a few days in advance. It is also believed that the size and frequency of floods will increase due to climate change.

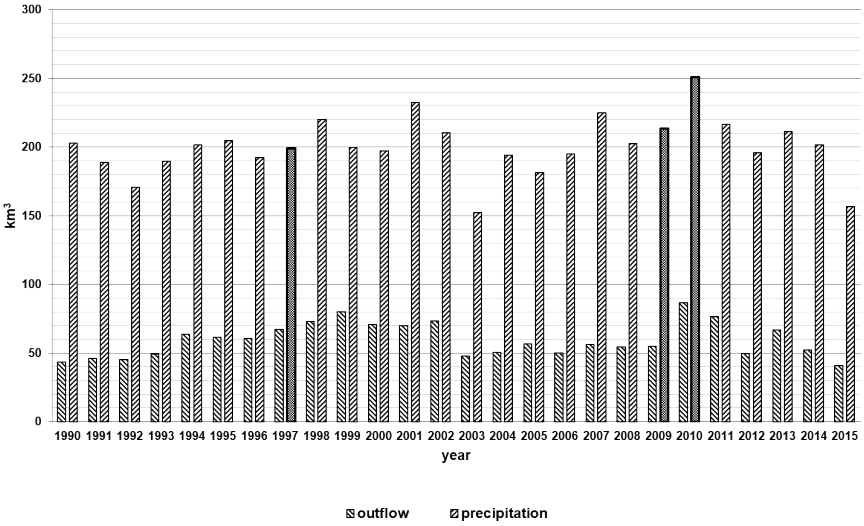

Figure 1. Precipitation and water outflow – 1990–2015

Source: own study based on www.stat.gov.pl

While the total precipitation has not changed significantly (Fig. 1), the number of days with high-intensity (often torrential) floods has increased (Nachabe and Paynter, 2001). According to numerous forecasts, these processes will intensify (Ustawa z dnia 18 lipca 2001...; IPCC 2007), and others. Several times (in 1997, 2010, and 2011), Poland has suffered catastrophic floods, resulting in significant

structural and social damage. The losses resulting from the floods in 2010 in Poland totaled 12.5 billion PLN, of which private property losses accounted for nearly 2 billion PLN (Biedroń and Bogańska-Warmuz, 2012).

Human activity also contributes to increasing flood damage. The increasing scarcity of available space leads to increased use of any yet-to-be-developed areas. This shortage may be due to the following:

– landforms – narrow valleys, surrounded by steep slopes,
– flood hazard – floodplains,
– land use restrictions related to special protection areas, such as Natura 2000,
– existing buildings.

It seems that pressure for the further development of floodplains will increase. The development of floodplains may cause catastrophic damage. Particularly vulnerable to damage is the technical infrastructure, such as sewage treatment plants (Halama, 2012).

Not to forget that ecological awareness in Poland is still relatively low, there is also the lack of basic knowledge as well as the legacy of past beliefs and convictions. Due to these, people in Poland widely believe that safety and security issues are primarily in hands of the authorities. There is no obligation for individual insurance, and voluntary insurance is very often not obtained. After a flood, the expectation that the government and/or local authorities will provide compensation for flood damages is widespread.

Risk management is not easy to accept (Yen, 1988); therefore, the introduction and enforcement of land use restrictions of floodplains is rather difficult (Halama, 2013a). Chaotic local spatial planning and the frequent lack of restrictions seem to favor potential investors (Halama, 2016) who plan to develop floodplains.

Another factor contributing to the increase of flood damage is the immense and completely unjustified belief in the effectiveness of the technical methods of flood damage prevention. The lack of understanding that the risk of flooding cannot actually be eliminated is also problematic.

Flooding is generally unpredictable; however, it is possible to estimate flood risk depending on factors such as the following:

– location,
– hydrological conditions,
– terrain relief,
– occurrence of flood types.

According to the literature (Ciepielowski, 1999; Koncepcja przestrzennego zagospodarowania kraju..., 2012), the risk of flooding is high in southern and southwestern Poland (Fig 2). The catchment areas of the upper Vistula and Odra Rivers have often suffered catastrophic floods.

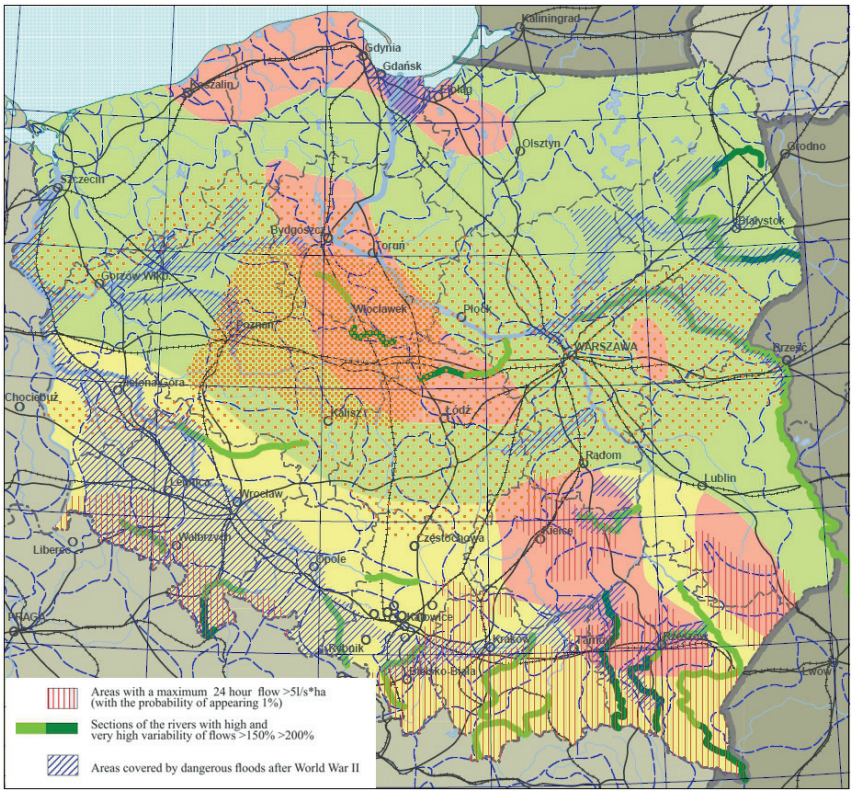

Figure 2. Regionalization of floods in Poland

Source: own study based on [24]

Since the risk of flooding cannot be completely removed, humans can only look to minimize its negative consequences. There are two main solution groups to reduce flood damages:

1. Technical solutions that affect the quantity and speed of surface water flow, such as the following examples:
   – construction of retention reservoirs and dry retention reservoirs,
   – increase of natural retention,
   – construction of flood embankments;
2. Non-technical solutions include the following:
   – flood risk assessment,
   – properly implemented spatial policy, where floodplains are included in local spatial development plans.

At present, the greatest controversies are caused by large-scale investments such as the construction of large retention reservoirs. The significant environmental impact, objections from ecological organizations, and the need for mass expropriation do not support such investments. An alternative to large reservoirs are small retention reservoirs (Halama, 2013b), but their numbers and pace of construction are not sufficient.

In sustainable water management, non-technical methods are slowly becoming the preferred method of flood protection. This is reflected in the legal system and the directions of its changes.

3. Sustainable development of water management

The origins of the policy of sustainable development trace back to the 1980s. The first significant document of international importance in this field was the so-called "Report Bruntland" (then called "Agenda 21"). Others then followed. In simple terms, sustainable development is a socio-economic development that integrates economic, social, and political activities. According to (Lorek, 2002), the aim is to preserve the environmental balance and sustainability of the natural processes and preserve the environment for the present and future generations.

In the many definitions of sustainable development (all cannot be presented here due to the limits of this article), there are a few common terms:

– sustainability – the need to maintain balance between economic growth and environmental protection,
– durability,
– self-sustainability – respect for natural resources makes further development and growth possible.

Sustainable development can also be seen as a set of socially superior objectives; among these, the most important are as follows:

– prosperity (material and social),
– justice,
– safety and security.

In its most developed form, sustainable development (understood as integrated order) is defined as the integration of five orders (Lorek, 2002):

– ecological governance,
– economic order,
– social order,
– spatial order,
– institutional and political order.

Ecological and environmental order is often combined and referred to as environmental-spatial order. This includes issues such as ecological spatial planning and flood protection (as part of water protection).

Sustainable development has also been defined in the Parliament Act of April 27, 2001 (Ustawa z dnia 27 kwietnia 2001 r. Prawo ochrony środowiska) (Uchwała nr 239 Rady Ministrów..., 2012). This should be understood as "such socio-economic development that integrates political, economic, and social activities, preserving the environmental balance and sustainability of basic natural processes". Sustainable development should ensure the ability to meet the basic needs of today's and future generations. The need to comply with the above rules is also stated in Article 5 of the Constitution of the Republic of Poland (as the superior law).

The principles of sustainable development have also been included in water management (which also includes flood protection). In recent years, there have been significant changes in the approach to flood protection caused by the accession of Poland to the European Union and the need to adopt EU law into Polish legislation.

The most important EU Directives whose implementation has caused changes in the approach to flooding protection are as follows:

– Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (called the "water framework directive"),
– Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (called the "flood directive").

The most important Polish legal acts regulating the planning and development of floodplains are as follows:

– Ustawa z dnia 18 lipca 2001 r. Prawo wodne (Dz.U., nr 115, poz. 1229, z późn. zmian.): in text "The Water Law Act";
– Ustawa z dnia 27 marca 2003 r. o planowaniu i zagospodarowaniu przestrzennym (Dz.U., nr 80, poz. 717, z późn. zmian.): in text "The Spatial Planning Law Act".

Replacing the traditional flood protection methods, they introduce "flood risk management." Previously, the preferred technical methods such as the construction of flood embankments or retention reservoirs are now being gradually replaced by flood risk management (in particular, in the spatial planning of floodplain areas). It is now required to prepare flood risk maps and maps of those areas at risk of flooding. The Water Law Act (Uchwała nr 239 Rady Ministrów..., 2012) places a greatest emphasis on the spatial development of river valleys or floodplains

[Art. 88k.] as a means of protecting people and property against floods. The technical measures only complement the preferred methods.

In areas with the highest risk of flooding, it is forbidden to perform construction work and other activities that impede flood protection or increase flood risk (e.g., the construction of buildings). Flood risk areas with a probability of 1% and 10% are areas of special flood risk for which the erection of buildings is prohibited (Uchwała nr 239 Rady Ministrów..., 2012).

For flood risk areas, it is required to coordinate the study of the spatial planning conditions and directions[1] (as well as local spatial development plans) with the relevant director of the regional water management board[2].

It is evident that flood damage protection under sustainable water management is presently focused on "moving people away" from water through flood risk assessment and proper local spatial planning. For this purpose, it is necessary to calculate the maximum flow as well as define those areas at risk of flooding.

4. Applications of probabilistic models for extreme values in environmental analysis

The use of statistical models and modeling techniques in determining and identifying environmental hazards is widely used in environmental engineering and is a popular tool for engineering in broad environmental management (Zwoździak, 2017).

The very rich and comprehensive bibliography of the literature on the theory of extreme value distributions and their applications consists of more than 1100 positions counting from the beginning of the 20th century until the beginning of the 21st century. There is no way to present them all, as it would require a separate multi-volume monograph devoted solely to the subject study. The vast amount of literature indicates the great interest in this field of science as well as its wide application; therefore, only selected items will be presented in this chapter that, in the author's opinion, had a significant impact on the development of the theory and are closely related to the issues raised in the article.

The first to use extreme values in studying floods was probably Fuller (Fuller, 1914). The systematic development of a general theory of extreme values, however, is associated with the work of Bortkiewicz, which concerned the distribution range in a random sample from a normally distributed population. This work is very important, since the author introduced and clearly defined the concept of distribution of the highest value for the first time here (Bortkiewicz, 1922).

[1] Polish "studium uwarunkowań i kierunków zagospodarowania przestrzennego".
[2] Polish "dyrektor regionalnego zarządu gospodarki wodnej".

Gumbel first drew the attention of engineers and statisticians on the possibility of use the formal theory of extreme values for certain distributions that were previously regarded as empirical. He applied the distribution of extreme value to the analysis of streamflow in the US in 1941 (Gumbel, 1941). In the course of his research, Teodorovic acquired the observed frequencies of N(T), meaning the number of days during a period that was T days long when the water flow in the Greenbrier River in West Virginia exceeded 17,000 cubic feet. The period of his observation took 72 years (from 1896 to 1967). He then compared the observed the frequency with theoretical Poisson distributions. In the results, it could be seen that the discrete observations of N(T) for a studied river and a given climate can be very well modeled with Poisson distributions (Todorovic, 1979).

In the 1970s through the 1990s, many papers were written on the subject of applying elements of the extreme value theory to solve problems associated with floods. Pericchi and Rodriguez-Iturbe conducted research based on the data of the daily water flow in the Feather River in Oroville, California, USA. The data collected came from the years of 1902–1960.

From this data, they selected the annual flow peaks and fitted the Gumbel distribution to their empirical distribution. In addition to this, they proposed schedules in their work such as gamma (Person Type III), gamma-log (log – Pearson Type III), and log – normally for the analysis of selected peaks. The use of probability distributions for the flood frequency estimation was also illustrated in Greis and Wood's work (Greis and Wood, 1981). Rossi proposed a two-component extreme value distribution to analyze the frequency of flooding. At the end of the twentieth century (after the great flood that caused huge losses in the US Midwest), Hipel presented the use of extreme value theory in the analysis of flood events in his work. He presented a thorough analysis of emergency levels being exceeded over 100 years in the context of the flood of 1993.

In their article, Katz and His co-authors presented a comprehensive study using the distributions of extreme values on the hydrological data collected in Fort Collins, Colorado, USA (Katz et al., 2002). Engeland, Frigessi, and Hisdal presented the analysis of flood and drought risks using generalized extreme value distributions and Pareto. They conducted their research on data concerning the streamflow of the Ha River in southwest Norway (Engeland et al., 2005). In their work, Bordi and His co-authors analyzed the wet and dry periods in Sicily. For this purpose, they applied monthly rainfall maxima (Bordi et al., 2007). Yurtal et al. compared the method of maximum likelihood in their work to the weighted method of moments for estimating the parameters of the hydrological data distribution probability obtained from measuring stations on the Ceyhan River in southern Turkey (Dogan et al., 2010). After a great number of floods in the Czech Republic, Holičky and Sykora used log-normal distributions and Persona III in their research to estimate the flood risk for cultural heritage sites

(Holický and Sýkora, 2010). Nachabe and Paynter conducted their research using a generalized distribution of extreme values on hydrological data from selected lakes in southwestern Florida (Majewski and Walczykiewicz, 2012). In their studies, Chaibandit and Konyai analyzed the hydrological data obtained on a monthly basis from six stations on the Yom River. The study used the distributions of extreme values, normal distribution, and log-normal distribution as well as the return period method (Chaibandit and Konyai, 2012). In their studies, Arns et al. estimated flood risk by approximating the probability of achieving a certain water level in rivers (Arns et al., 2013). Charon et al. compared a very large number of probability distributions used to model wind speeds. The data came from nine meteorological stations in the United Arab Emirates (Charon, 2015).

One of the co-authors of this study has been conducting research on the probabilistic measurement of flood risk in Lower Silesian rivers since 2010. The results of these studies are presented in the following works: (Kuźmiński, 2012; 2013a; 2013b; 2013c; 2013d; 2013e; 2014).

Since 2015, the authors have been conducting research on the measurement of flood risk dynamics in the rivers of Lower Silesia using selected models of extreme value distributions. The results of these studies are presented in the following publications: (Kuźmiński et al., 2016a; 2016b; 2016c).

4.1. Maxima

We assume that the y_i observations are the maxima, that

$$y_i = \max\{x_{i1}, ..., x_{im}\}, \qquad i = 1, ..., n, \tag{1}$$

where x_{ij} may not be observable. In the case where x_{ij} are observable, the selection of certain maxima from certain sets *with m* number of elements is a form of selection of the upper extreme values from a data set. This method is called the block method or Gumbel method (Kuźmiński, 2013b).

The block maxima method requires defining the time horizon (the block) and calculating the maxima of the tested variable for the said horizon. Most commonly, blocks of one year, half a year, a quarter year, a month, or a shorter length of time are used depending on the research needs. For data in the form of hydrometric parameters, blocks of the mentioned above size are used. The block size cannot be too small to prevent the occurrence of the relationship between the maximum values of the neighboring blocks of time. A ten-day period is considered to be the minimum limit value of the size of the time block for which the independence of the neighboring maxima can be accepted (Engeland, 2005).

There can also be cases when, during long-lasting floods, the risk of the dependence even between the maxima of adjacent blocks of time may occur. In

such situations when such a relationship between the variables under consideration occurs, it is necessary to apply the cumulative distribution of extreme values for dependent random variables for the analysis of the distribution of the maximum values.

At this point, one more fact deserves attention; namely, that observations *yi* are the embodiments of random variable M_m defined by the following formula:

$$M_m = \max\{X_1, ..., X_m\}. \tag{2}$$

In the studies conducted for the purpose of this article, a 31-day block was used (heretofore referred to as a "monthly block" for simplicity).

4.2. Probabilistic models of maxima values

In the probabilistic studies of maxima distributions for hydrometric data, it is suggested to first apply the Gumbel distribution, which is one of the three types of extreme value distributions (Ustawa z dnia 18 lipca 2001 ...). The 1983 report from the IACWD (US Interagency Advisory Committee on Water Data – Hydrology Subcommittee) recommends the Persona III distribution with the log-normal transformation for long-term data to predict flood events as well as the log-normal distribution.

According to the theorem concerning the types of extreme value distributions, the distributions of extreme values are described by one of three distribution functions from the family of extreme value distribution functions (Kuźmiński, 2013a).

Additionally, if random variable X has distribution function F, then random variable $(\mu + \sigma X)$ has the distribution function where μ and $\sigma > 0$ are the parameters of position and scale, respectively. Combining the above two statements results in a very broad family of distribution functions for the extreme value distributions defined by the following formulas:

$$\text{Gumbel } (\text{EV0 or Type I}): \; G_0(x) = \exp\left(-e^{-(x-\mu)/\sigma}\right), \; -\infty < x < \infty, \tag{3}$$

$$\text{Frechet } (\text{EV1 or Type II}): \; G_1(x) = \exp\left(-\left(\frac{x-\mu}{\sigma}\right)^{-\alpha}\right), \text{ for certain } \alpha > 0, x > 0, \tag{4}$$

$$\text{Weibull } (\text{EV2 or Type III}): G_2(x) = \exp\left(-\left(-\left(\frac{x-\mu}{\sigma}\right)\right)^{\alpha}\right), \text{ for certain } \alpha > 0, x \le 0. \tag{5}$$

Broadening the classic family of distribution functions of the extreme value distributions by the parameters of position and scale (as has been done and

presented in Models (Biedroń and Bogańska-Warmuz, 2012; Bordi et al., 2007; Bortkiewicz, 1922)) significantly expands the spectrum of possibilities related to the modeling of the maximum value distributions of various random variables. Taking advantage of the parameterized distribution functions of the maximum value distributions, a theoretical distribution function that describes the distribution of the studied value of the maximum characteristic at a very large degree of compliance can be very precisely matched.

In the research that was conducted for this article, a tool in the form of an empirical distribution function was used to visualize the empirical distributions of the maximal values of specific hydrological characteristics.

Estimation methods and tests of significance

To estimate the parameters of the maximum value distributions from the family of distribution functions of the distributions described by Formulas (3), (4), and (5), the maximum likelihood method was applied for the purpose of our research. This method provides effective results in specific cases. These cases concur with the cases considered in (Kotz and Nadarajah, 2005). Parameter γ*estimator* exists for $\gamma > -1$, and for $\gamma > -0.5$, the variance has asymptotically normal distribution.

In order to verify the hypotheses concerning the compatibility of the studied empirical distributions with the selected theoretical distributions of the maximal values described in the paper, the following compliance tests were applied: chi-square, Kolmogorov–Smirnov, and Anderson–Darling tests.

In addition, within the family of distributions of extreme values described by Formulas (3), (4), and (5), the credibility quotient test is used to verify hypothesis H_0: $\gamma = 0$; i.e., that the tested distribution is better-described by the Gumbel distribution against an alternative hypothesis H_1: that the tested distribution is better tested by other distributions of this family. The test statistics for this test are described with the following formula:

$$T_{\mathrm{LR}}(x) = \frac{\prod_{i \le n} g_{\hat{\gamma},\hat{\mu},\hat{\sigma}}(x_i)}{\prod_{i \le n} g_{0,\tilde{\mu},\tilde{\sigma}}(x_i)} \tag{6}$$

from $(\hat{\gamma},\hat{\mu},\hat{\sigma})$ and $(\tilde{\mu},\tilde{\sigma})$ representing the sets of the maximal likelihood estimators in the EV0, EV1, and EV2 models described by Formulas (3), (4), and (5). Since the sets of the parameters are 2- and 3-dimensional, it is known that the test statistics have an asymptotically chi-square with one degree of freedom. Consequently, the *p*-value has the following formula:

$$p_{\mathrm{LR}}(x) = 1 - \chi_1^2(T_{\mathrm{LR}}(x)) . \tag{7}$$

The significance level is achieved with higher accuracy using Bartlett's adjustment, which consists of replacing the TLR test statistics with the statistics given by formula TLR / (1+2.8/*n*). In this case, the p-value has the following formula (Kuźmiński, 2013d):

$$p_{LR}(x) = 1 - \chi_1^2(T_{LR}(x) / (1 + 2.8 / n)) \tag{8}$$

5. Analysis of flood risk dynamics – experimental

5.1. Hydrological data

In a study conducted for the purpose of this article, one particular hydrometric parameter was used – the flow measured in units of m^3/s (Bajkiewicz-Grabowska and Mikulski, 2011). The daily flow of the Odra River measured at hydrological stations located in Malczyce were collected for the study during the time period from January 1, 1994, through December 31, 2013 (which provides a sample size of $n = 7305$). The time horizon studied was divided into four periods with lengths of five years each: Period I spans the years of 1994–1998; Period II spans the years of 1999–2003; Period III spans the years of 2004–2008; and Period IV spans the years of 2009–2013.

Using the block method described in the previous section, the 30-day maxima were selected from the daily flow. With these assumptions, Formula (1) takes the following form:

$$y_i = \max\{x_{i1}, ..., x_{i30}\}, \qquad i = 1, ..., 60 \tag{9}$$

for the maxima of the tested data for each of the four periods.

5.2. Theoretical and empirical probabilistic models for maxima

To depict the empirical probability distributions of the 30-day maxima from the four studied periods, a commonly used tool in the form of an empirical distribution function was used. Additionally, the chart of the empirical distribution function for each period includes a distribution function of an optimally matched distribution of the theoretical maxima. These graphs are shown in Figure 1.

In the data from Period I (1994 through 1998), there is one maximum – $q_{VII,97} = 3020$ m^3/s; this is from July 1997, when the historical flood of the Odra River basin took place. In the graph shown in Figure 3 for Period I, there is an empirical distribution function shown (which was removed without this observation). For comparison, Figure 4 shows a graph of an empirical distribution

function for the data from Period I, including all of the maxima with the optimally matched theoretical distribution function.

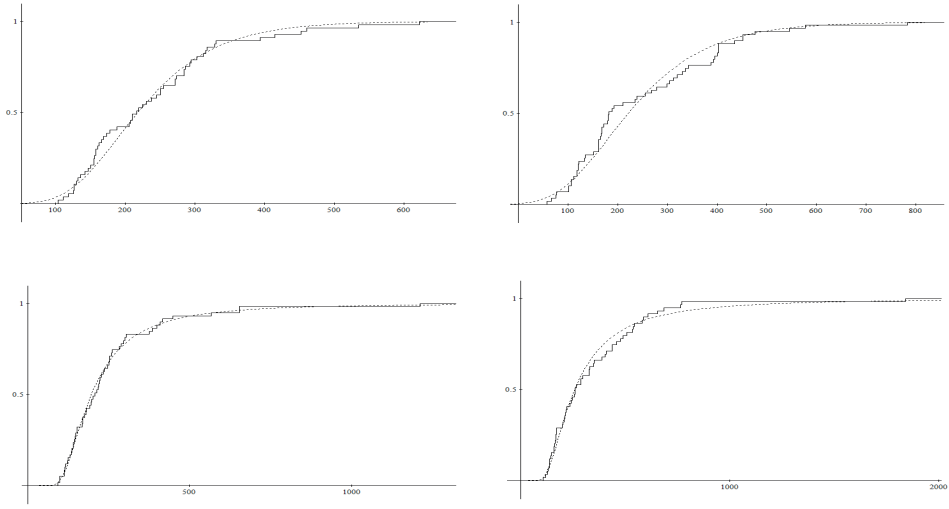

Figure 3. Empirical distribution functions of 30-day flow maxima distributions for data from Malczyce for Periods I-IV (solid line) and distribution functions for theoretical maxima distributions (dotted line). Period I – chart in upper left corner; Period II – chart in upper right corner; Period III – chart in bottom left corner; and Period IV – chart in lower right corner

Source: own materials

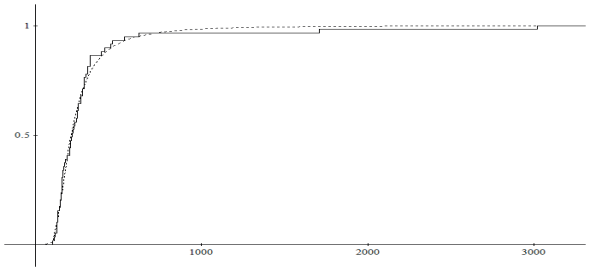

Fig. 4. Empirical distribution function of maxima distributions for Period I, including data from July 1997 (solid line) and distribution function of theoretical distribution

Source: own materials

By using the highest likelihood method, the parameters of the theoretical distributions optimally suited to the empirical distributions of the studied maxima for the four periods were estimated. In the case of Period I, the maxima distribution parameters excluding and including the observation of the $q_{VII,97}$ = 3020 m^3/s maximum were estimated (Tab. 1).

Table 1

Values of estimators of theoretical distribution parameters for flow maxima for studied periods

Periods	Estimator values
1994–1998 (excluding $q_{VII,97}$)	$\hat{\mu}_I$ =190.5 $\hat{\sigma}_I$ = 74.3
1994–1998 (including $q_{VII,97}$)	$\hat{\mu}_I$ = 0 $\hat{\sigma}_I$ = 183.5 α = 2.463
1999–2003	$\hat{\mu}_{II}$ =182.85 $\hat{\sigma}_{II}$ =105.42
2004–2008	$\hat{\mu}_I$ = 0 $\hat{\sigma}_I$ = 129.1 α = 2.824
2009–2013	$\hat{\mu}_I$ = 0 $\hat{\sigma}_I$ = 215.2 α = 2.04

Source: own materials

In the cases of Period I (excluding the $q_{VII,97}$ maximum observation) and Period II (the Gumbel distribution), the distribution function described by Formula (3) turned out to be the optimally suited distribution for the empirical distribution of the 30-day flow maxima. For Period I (including the $q_{VII,97}$ maximum observation) as well as Periods III and IV (Frechet distribution), the distribution function described by Formula: (4) turned out to be the optimally suited distribution.

The charts of the empirical distribution functions of the studied maxima for the periods under consideration along with the theoretical distribution functions of the respective distributions indicate the very good fit of the theoretical distributions (Figs. 1 and 2). In order to confirm the goodness of fit of the empirical distributions with the matched theoretical distributions resulting from a visual assessment of the given distribution function graphs, the following commonly used goodness of fit tests were performed: the Anderson–Darling and Kolmogorov–Smirnov tests. The results of the tests for the distribution in all of the analyzed periods in the form of the *p-value* shown in Table 2 confirm the very high goodness of fit of the chosen theoretical distributions with the corresponding empirical distributions.

Table 2

p-value values of compatibility tests for maxima distributions

Period	Test	
	KS	A − D
1994–1998 (excluding qVII, 97)	$p_v = 0.6208$	$p_v = 0.7998$
1994–1998 (including qVII, 97)	$p_v = 0.763$	$p_v = 0.8429$
1999–2003	$p_v = 0.6271$	$p_v = 0.5849$
2004–2008	$p_v = 0.9776$	$p_v = 0.9918$
2009–2013	$p_v = 0.6208$	$p_v = 0.7998$

Source: own materials

In addition, to confirm the validity of choosing the appropriate distributions of extreme values for the respective studied periods, a likelihood ratio test within the family of distributions of extreme values described with Formulas (3) through (5) was conducted (which was described in Section 3.4). The values of *p-value* calculated from Formula (8) are presented in the following table (Tab. 3).

Table 3

p-value values for likelihood ratio test in family for family of extreme value distributions

Periods	*p-value*
1994–1998 (excluding qVII, 97)	$p_v = 0.128$
1994–1998 (including qVII, 97)	$p_v = 0.000$
1999–2003	$p_v = 0.115$
2004–2008	p_v=0.000
2009–2013	$p_{v=}$ 0.000

Source: own materials

5.3. Risk assessment of flood risk during analyzed periods

This section consists of two main parts. In the first part, the flood risk measures will be calculated during the studied periods. The second part of the section contains an analysis of the dynamics of the examined risk.

Defining the concept of risk proves to be difficult each and every time; providing a clear and precise definition is impossible. Risk is defined on the basis of various branches of knowledge and theories, including economics, behavioral

sciences, legal sciences, psychology, statistics, insurance, probability theory, and others. According to the authors, the following two definitions of risk are most suitable for determining flood risk: the first treats risk as the possibility or likelihood of loss (e.g., due to flooding (Jedynak, 2001), while the second assumes the risk to be the probability of a system failure or the failure of its p_f element, which may be equated with the flooding in particular cases (Ustawa z dnia 27 marca 2003...).

In this paper, the probability of exceeding a certain water flow level (q) by the maximal daily water flow from the time horizon assumed in the study was adopted as the measure of flood risk in the studied area based on the aforementioned two definitions. A time horizon of 30 days was chosen for the purpose of this study.

To measure the risk measure, the maximal water flow from the June 2010 flood (namely, $q_{VI,2010} = 1840$ m^3/s) was chosen.

According to Formula (2), the maximum 30-day flow is a random variable denoted by $M30$. Table 4 presents the results of the calculations of the risk measures constituting the probability to exceed flow $q_{VI,2010}$ by random variable M_{30} for all of the studied periods.

Table 4

Measures of flood risk for Odra River in Malczyce

Periods	Risk measure		
	$P(M_{30} > q_{VI,2010})$	dynamics indexes $I_{t/t-1}$	percentile changes +/–
1994–1998 (excluding qVII, 97)	0.0000002	–	–
1994–1998 (including qVII, 97)	0.003414655	–	–
II: 1999–2003	0.000001490	7.45	645
III: 2004–2008	0.000551176	369.1	3691
IV: 2009–2013	0.012475177	22.63	2163

Source: own materials

Additionally, Table 4 contains the indexes of the dynamics of changes in the flood risk over the period of 1994–2013. The results clearly show a strong upward trend of the risk. The flood risk during Period II increased by as much as 645% as compared to Period I; during Period III, it increased by 3691% in relation to Period II; and during Period IV, it increased by 2163% as compared to Period III.

6. Conclusions

Poland's water resources are characterized by uneven temporal and spatial distribution. In addition, climate change has contributed to the increasing occurrence of maximum flow in rivers. Inadequate land management and the unjustified belief in the effectiveness of technical flood control measures can contribute to flood damage. Sustainable water management should be implemented through the integration of social, environmental, and economic objectives.

The factors described in this paper include environmental protection requirements, while the appropriate planning serves to program and coordinate actions to achieve or maintain at least a good ecological status through the continuous improvement of environmental resources, taking into account measures to reduce flood risk in the Odra River basin. Sustainable development is, therefore, a set of orders such as natural, socio-demographic, economic, and spatial.

The activities aimed at achieving ecological and economic effectiveness apply when choosing the methodology of implementing planned environmental protection and flood risk management projects.

Flood protection measures should primarily use solutions that are least invasive to the natural environment, especially non-technical flood protection methods (e.g., flood risk assessment and management, the appropriate flood planning, and development). Undoubtedly, the basis for planning in water management is the preparation of models and, subsequently, determining the probability of the occurrence of maximum flow.

Three action instruments can create an integrated a flood safety system:

– investment engineering,
– economic engineering,
– financial engineering.

Investment engineering is not the only recipe for flood safety, as integrated investment, economic, and financial approaches altogether give a sense of security to the public in areas directly affected by floods as well as the adjacent areas. By applying a risk measure in the form of the probability of flood hazard, the interdependence between sustainable development and economic interest is taken into account.

The use of flood risk models can be similar to a classic cash flow strategy, using derivative instruments such as loans, subsidies, setting interest rates on loans, and insurance.

Using a probabilistic risk assessment, soft behavior can be followed by social behavior training to minimize flood damage.

The analysis of historical data based on the years of catastrophic flooding is not a measure or forecast related to the occurrence of subsequent floods. Using

risk as a tool gives us the ability to plan anti-flood activities and, at the same time, allows us to secure the financial resources for liquidation. It is possible to plan the construction of adequate flood protection infrastructure in both hard and soft operations.

Probabilistic models of the maximum values for selected hydrological characteristics (maximum daily flow and daily water status) provide an effective tool for supporting the entire flood risk management process in the context of socio-economic consequences. Extreme value models were widely used for flood risk measurement and evaluation in the 20th century and still are in the 21st century (Fuller, 1914), (Todorovic, 1979), (Holický and Sýkora, 2010), and (Arns et al., 2013).

On the basis of selected probabilistic models, the flood risk measures in the form of the probability of exceeding certain values were calculated by the hydrological characteristics of Q (in m^3/s). Using the obtained risk measures in the four analyzed periods, its dynamics were analyzed. The results showed a very strong upward trend of this risk.n

Additionally, to illustrate the influence of the maximum flow of July 1997 (the historical flood date in Poland; i.e., qVII, 1997 = 1840 m^3/s for Period I), the risk measure was calculated based on a model whose parameters were estimated without observing the maximum of 1997. The same measure was calculated on the basis of a model estimated on the basis of a complete data set. Significant differences in the results shown in Table 4 show how the extreme observations exert on the model. In the flood risk dynamics analysis, the result obtained from the model without qVII 1997 was taken.

The widespread multidimensional flood models used in the United States and Europe are characterized by large computational space and extended analyses of the results. On the other hand, using a probabilistic measure of risk is undoubtedly a complement to global analyses and directions of flood control. Not only do both models complement each other, they can also be calibrated for data quality.

Reinforcing flood risk management plans and flood hazard maps into tools in the form of probabilistic flood risk measurements will allow for extensive spatial and temporal planning.

The analysis of risk dynamics allows for the timely updating of the planning documents described above.

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Cluster as place of efficient diffusion of knowledge. Experiences of Lower Silesia

1. Introduction

It is widely believed that functioning within a cluster structure (broadly understood as a geographical concentration of interconnected entities that compete with one another but also cooperate (Porter, 2001) allows its members to achieve a number of benefits. These include a reduction in the costs, time, and risk of business operations (including R&D), the opportunity for obtaining public funds, or the possibility of gaining new sales markets. Above all, however, the potential of clusters is emphasized as places where the "combination of mind-power" and knowledge diffusion occur, which makes politicians perceive this form of cooperation between organizations as a tool for creating competitive advantages for a whole country.

Despite the widespread belief of the important role of clusters in the development of both the entities located within them as well as entire regions, the conclusions from many studies indicate that benefits in the form of the increased diffusion of know-how do not have to be achieved *per se*. Achieving them depends on a number of factors, such as the area of activity of the entities located in the cluster, the level of development of the cluster, the economic policy approach to supporting cluster initiatives (Yström and Aspenberg, 2017), the degree of the presence of R&D institutions in the cluster (Jankowska, Pietrzykowski, 2013; Mowery, Ziedonis, 2001), and the degree of domination of micro and small enterprises or even the specifics of values and behavioral patterns of the societies of the countries from which a specific cluster originates (Nishimura and Okamuro, 2011).

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The lack of conclusions as to the extent to which the functioning within a cluster has a stimulating effect on the efficiency of knowledge diffusion between its members also results from the lack of one knowledge diffusion measure possible for use under any conditions. This results from the fact that some researchers use more-direct measures of know-how diffusion, while others infer the occurrence of spillovers from more-direct indicators.

The most-direct measures of knowledge diffusion include all measures based on citations as well as surveys and direct interview data. In the case of citation-based measures, it is assumed that the citing party has used the concepts and ideas of the cited party; hence, knowledge flow has occurred from the citing entity to the cited one. Although frequently very subjective, the data and information obtained from direct interviews and surveys are somehow obviously treated as evidence for the occurrence of knowledge-transfer processes.

In the indirect approach, knowledge flow is measured from the perspective of the effects they cause. Since the circulation of know-how is expected to translate into an increase in productivity and innovation, many researchers consider total factor productivity or the number of inventions, patents, or other innovation indicators as measures of knowledge diffusion. Although widespread in the literature on the subject, it should be emphasized that such an approach has its opponents, who make a clear distinction between innovation processes and knowledge-transfer processes. Since a visible effect of knowledge exchange is also various kinds of joint "creations" (e.g., inventions jointly generated by different individuals or organizations), these are also used as measures of knowledge diffusion. It is worth emphasizing that joint works have an advantage over other indirect measures because they are associated with a greater probability that knowledge flow actually occurred. Unlike other indirect measures, joint works are associated with a greater degree of certainty that knowledge flow actually occurred.

Studies in which the problems of Polish clusters are addressed tend to be focused on the role they play in promoting competitiveness and innovation of their constituent enterprises. However, analyses that directly assess the effectiveness of cluster structures in stimulating the processes of knowledge diffusion are usually based on survey data. There is a lack of studies in which the scope of knowledge diffusion within the cluster is assessed on the basis of the number of citations; i.e., the *de facto* most-direct measure of know-how transfer. In this work, the author makes an attempt fill this gap.

This study contributes to the existing literature mainly through the use of patent citations[1] and the number of inventions created jointly by cluster participants to estimate the scale of knowledge diffusion within Polish clusters.

[1] Patent citations were used to estimate knowledge flow for the first time by Jaffe, Trajtenberg, and Henderson (1993).

The paper focuses on two objectives. The first of these is to examine to what extent those enterprises located in Lower Silesian clusters benefit in the form of knowledge diffusion from other cluster members and what factors stimulate the occurrence of these benefits. The second objective is to compare the results in terms of the effectiveness in promoting knowledge diffusion achieved by clusters from Lower Silesia with the achievements of the Aviation Valley from Podkarpackie Voivodeship, which is considered to be an excellent example of close cooperation between science and business as well as the activity of the enterprise sector in innovation processes in Poland. The comparative analysis of both voivodeships (one of which is considered a model to follow when it comes to R&D cooperation within the cluster) allows for a better assessment of the role of clusters from Lower Silesia in promoting the exchange of expertise and know-how.

For the purposes of this article, it is assumed that the measure of effectiveness of Lower Silesian clusters in stimulating the processes of knowledge diffusion among enterprises located in the clusters is the number of patent citations and number of joint inventions. In the study, our own conducted research has been focused on a quantitative and qualitative analysis of domestic and international patent applications filed by enterprises operating in the clusters covered by the study (in terms of the number of inventions they cited that belonged to entities located in the same cluster and the number of inventions created together with other entities from the same cluster).

2. Role of clusters from Poland in promoting diffusion of knowledge in light of literature research

From the perspective of modern economies, innovation is a particularly desirable process. However, due to the fact that traditional ways of creating innovation turn out to be insufficient, new types of institutional solutions have been created in this area. One of these is clusters created by geographical concentrations of independent entities from three different environments (referred to as the triple helix: business, research, and development) and the administration sector (Etzkowitz, Leydesdorff, 2000), which remain in the relationship of coopetition; i.e., competition and cooperation at the same time.

The success of clusters in increasing innovation activity is based primarily on the geographical proximity of the cluster members in the sense that it is important for the creation of close social relationships and promotes *face-to-face* contact. On the one hand, they are particularly important for acquiring tacit knowledge (Agrawal et al., 2006; Azoulay et al., 2011; Baptista, 2000; Bodas et al., 2013; Ceci, Iubati, 2012; Cooke, Wills, 1999; Oettl, Agrawal, 2008), and on the other hand,

they promote research cooperation, which results in a faster and more effective flow of knowledge (Marshall, 1920; Maskell, 2001) as well as the internalization of the effects of R & D (Spence 1984). Consequently, participation in a cluster not only stimulates innovation (Delgado et al., 2010; Delgado et al., 2014; Johnnessen, 2009) but also leads to an increase in the competitiveness and internationalization of cluster entities (Gorynia, Jankowska, 2007; Jankowska, Götz, 2016; Jankowska, Götz, 2017) and can also facilitate the transformation of business models towards Industry 4.0 (Götz, Jankowska, 2017). It follows from the above, therefore, that one of the most important benefits of cluster membership is the ability to draw on the knowledge of its participants; many of the other benefits are derived from this in a way.

Although there are voices saying that the reliance on localized knowledge can only lead to a "closure" of the cluster and a lack of new ideas, which can result in the closeness between cluster members becoming an obstacle in raising their innovation rather than being an advantage (Bathelt et al., 2004; Maskell et al., 2006; Morrison et al., 2013), these are aimed not so much at discouraging mutual knowledge sharing within a cluster but at emphasizing that it should not be limited only to the cluster members.

The potential of clusters in creating new knowledge has also been noticed in Poland, which would like to duplicate the success of other countries in the effective combination of business, universities, and government. As research results show, this has been partly successful, although the results of Polish clusters cannot be easily confronted with the achievements of the most well-known groupings in the world. First of all, the reason is that the first clusters in Poland began to form much later than in other regions of the world; hence, they are still in the embryonic phase.

Generally, as the results of most case studies, survey studies, or studies using the in-depth interview method show, participants of Polish clusters undertake cooperation with other cluster members (Główka, Jankowska, 2014; Gorynia, Jankowska, 2008; Jankowska, 2013; Jankowska et al., 2017), but it always takes a different form and is shaped on a different level in terms of its strength and frequency (Plawgo, 2014; Plawgo et al., 2013, p. 48); thus, both the potential of this cooperation in promoting knowledge-diffusion processes and the effectiveness of these processes are varied. Typically, cooperation within Polish clusters takes the form of cooperation of an organizational nature, under which companies sign joint purchase agreements, for example (Ratajczak-Mrozek, 2012). This is definitely less frequently undertaken in the area of innovation and technology (Hołub-Iwan, Małachowska, 2008, p. 58); therefore, enterprises are more willing to cooperate than to share their knowledge (Dyba, 2016). There are still problems

with initiating and building cooperation between entrepreneurs and R & D sector entities (Bembenek, 2016); this is associated with the circulation of the most specialized and tacit knowledge. It should also be emphasized that the majority of studies addressing the problems of intra-cluster cooperation do not compare the results achieved in this area by clusters with the results of other types of network organizations. A few of them, however, regard clusters as less effective sources of cooperation (Ratajczak-Mrozek, 2012).

Due to the fact that knowledge diffusion promotes innovation processes, the increase in innovation and competitiveness of entities is interpreted as evidence of the occurrence of spillovers. From this perspective, the contribution of clusters in stimulating innovation and competitiveness can also be, by implication, a contribution to promoting knowledge-transfer processes. The of studies on Polish clusters find a positive correlation between membership in a cluster and competitiveness (Jankowska et al., 2017), but others emphasize the fact that this does not directly result from cooperation (Gorynia, Jankowska, 2008). Due to the fact that innovation is determined by the processes of knowledge diffusion to a greater extent than competitiveness, it is more difficult to point out analyses that explicitly confirm the thesis that the geographical concentration of competitors stimulates innovation. The final conclusions also depend on what type of innovations are the subject of the research: whether those solving a technical problem (*de facto* inventions) or another type (e.g., new products, new organizational solutions, new forms of expansion, etc.). While coopetition within Polish clusters releases the innovative potential of enterprises in the latter case (Dąbrowska, 2014; Jankowska, 2013; Kowalski, 2012; Stanienda, 2014), this is not so obvious in the former (Kowalski, 2012; Niklewicz-Pijaczyńska, Wachowska, 2014).

3. Scope and method of research

The empirical research basically covers enterprises from two clusters: the NutriBioMed Cluster and the Innovative Cluster for Power Generation and Energy Utilization in Mega- and Nano-Scale (Mega Nano Energy Cluster). The main criteria for the selection of clusters for the sample was (primarily) the location of the majority of the key partners (as well as the founders) of the cluster in Lower Silesia and (secondarily) the above-average degree of total inventive activity of the participant enterprises of the cluster. Additionally, the analysis covered the Aviation Valley Cluster from Podkarpackie Voivodeship, whose achievements in promoting knowledge flow between its member enterprises constitute a reference point for the results achieved in this regard by the clusters from Lower Silesia.

Of all of the enterprises belonging to the three indicated clusters, only those that created the cluster and generated at least one invention throughout their entire lifetimes were selected for the research sample. Enterprises that joined the cluster structure at a later date are not included in the analysis. Such a procedure is aimed at the comparability of the results of individual enterprises located in the same cluster, especially from the perspective of two periods: "before" and "after" the creation of the cluster. Although the sample selection method used has consequences for the interpretation of the results, they seem insignificant as related to the clusters covered by the analysis. This is mainly due to the fact that the enterprises that are most successful in terms of inventiveness are at the same time key participants and founders of the cluster. There are, in fact, a few enterprises that can boast of inventions but find themselves outside the research sample. In the end, the research sample consisted of 18 enterprises, of which 8 formed the NutriBioMed Cluster, 5 the Mega Nano Energy Cluster, and 5 the Aviation Valley Cluster.

The analyzed enterprises from the NutriBioMed Cluster include the following: POMONA Company Sp. z o.o.; BIOCHEFA Farmaceutyczny Zakład Naukowo-Produkcyjny; Przedsiębiorstwo Wielobranżowe FUTURUM Sp. z o.o.; Zakłady Jajczarskie OVOPOL Sp. z o.o.; Przedsiębiorstwo Handlowo-Produkcyjno-Usługowe TRANSVET Sp. z o.o.; TECHNOX Sp. z o.o.; FINEPHARM S.A.; and TRONINA Przedsiębiorstwo Handlowo-Wdrożeniowe. The analyzed enterprises from the Mega Nano Energy Cluster include the following: Zakład Budowy Urządzeń Spalających ZBUS COMBUSTION Sp. z o.o.; ABB Sp. z o.o.; KGHM CUPRUM Sp. z o.o. Centrum Badawczo-Rozwojowe; Elektrownia TURÓW S.A.; and KGHM Polska Miedź S.A. Meanwhile, the enterprises from the Aviation Valley Cluster covered by the analysis include the following: Polskie Zakłady Lotnicze Sp. z o.o.; Wytwórnia Sprzętu Komunikacyjnego PZL-ŚWIDNIK S.A.; Wytwórnia Sprzętu Komunikacyjnego PZL-RZESZÓW S.A.[2]; Wytwórnia Sprzętu Komunikacyjnego PZL-KROSNO S.A.; and ULTRATECH Sp. z o.o.

This study utilized the method of quantitative and qualitative analysis of patent applications filed in the national and international procedure (PCT[3]) by enterprises belonging to the sample. The patent applications were analyzed first in terms of the number of inventions created by these enterprises in cooperation with other cluster members (both with entities within the sample and outside) and subsequently by the sources of cited knowledge (excluding self-citations at the level of the applicant); more specifically, in terms of the extent to which the enterprises in the sample refer in their patent applications to the knowledge or

[2] The current name is: Pratt & Whitney Rzeszów S.A.

[3] The *Patent* Cooperation Treaty.

achievements of other cluster members (both belonging and not belonging to the sample). In the end, 431 patent applications were analyzed, of which 323 belong to the enterprises from the Mega Nano Energy Cluster, 60 from the NutriBioMed Cluster, and 48 from the Aviation Valley Cluster; as the patent citations are concerned, only those applications have been analyzed thus far (in such cases, a description of the state of the art is disclosed[4]).

The data used in the analysis of the national applications was taken from the knowledge stock of the Polish Patent Office, and those used in the analysis of the international applications came from the resources of the World Intellectual Property Organization (WIPO).

The analysis has been made separately for two periods. The first one was for the years before the creation of the cluster; more precisely, the periods of up to 2007 for the enterprises from the NutriBioMed Cluster, up to 2006 from the Mega Nano Energy Cluster, and up to 2002 from the Aviation Valley Cluster. The second period was from the creation of each cluster up to 2017; i.e., the years of 2008–2017 for the NutriBioMed Cluster, 2007–2018 for the Mega Nano Energy Cluster, and 2003–2017 for the Aviation Valley Cluster.

4. Patent cooperation of enterprises located in Lower Silesian clusters: research results

The study of cooperation in the field of creating inventions and then filing them for patent protection covered clusters from Lower Silesia representing various industries. The area of activity of the NutriBioMed Cluster includes high technologies in food processing and biotechnological processes, nutraceuticals, and biomedical preparations, while the entities from the Mega Nano Energy Cluster deal with the development and implementation of innovative clean energy production technologies using various sources on the micro and macro scale as well as the improvement of the efficiency of its use. The clusters mentioned above differ not only in their areas of activity but also in the degree of inventive activity, although it should be emphasized that both are very good in this respect as compared to other Lower Silesian clusters.

[4] In some cases, only the information on the very fact of filing the invention for patent protection by a specific entity – including the number and date of application as well as other basic information – is given to the public, but the detailed description of the invention is not disclosed (including the description of the state of the art, in which references to the achievements of predecessors are found). There may be different reasons for this situation, with the still-unfinished patent procedure being the most common one for the national procedure.

Table 1

Number of patent applications from Lower Silesian clusters during periods before and after creation of cluster

Patent category	NutriBioMed Cluster				Mega Nano Energy Cluster			
	"before" cluster		"during" cluster		"before" cluster		"during" cluster	
	Qty.	[%]	Qty.	[%]	Qty.	[%]	Qty.	[%]
Total patent applications	23	100	37 (+61%)	100	276	100	47 (–83%)	100
Total joint applications, incl.:	13	–	17 (+31%)	–	16	–	10 (–38%)	–
• total with other cluster participants	10	43.48	13 (+30%)	35.14	6	2.17	1 (–84%)	2.13
• total with entities from outside	3	13.04	4 (+0%)	10.81	10	3.63	9 (–10%)	19.15
Total independent patent applications	10	43.48	20 (+100%)	54.05	260	94.2	37 (–86%)	78.72

Source: development and calculations based on own research

Up to 2017, the analyzed enterprises from the NutriBioMed Cluster generated a total of 60 inventions, while those from the Mega Nano Energy Cluster generated as many as 323 (Tab. 1). Despite these differences, the members of both clusters set the cooperation in the field of implementation and execution of projects as their main objective, with the emphasis on cooperation between science and economy as well as integration of the participants through the transfer of knowledge from academic centers to business units (*see* official websites of the clusters). Setting such priorities clearly indicates that the cooperation – owing to which the knowledge diffusion occurs – is considered by both clusters covered in the study as the key factor for the development, innovation, and competitiveness of the organizations.

It should be expected, therefore, that the entities forming the clusters mentioned above will undertake joint activities not only in the area of current minor initiatives but will, above all, combine their brainpower in order to create new breakthrough technical solutions (which undoubtedly include inventions). Unfortunately, the analysis of the patent documents of the member enterprises of the clusters mentioned above does not fully confirm these predictions, indicating that the entities continue to treat their cooperation with relative distrust (at least when it comes to cooperation in the field of creating inventions).

On the basis of the data and information from the Polish Patent Office and WIPO, it may be said that only slightly more than 2% of the inventions of the enterprises from the research sample in the Mega Nano Energy Cluster and slightly more than 35% in the NutriBioMed Cluster were created in cooperation with the other cluster members. Moreover, in the Mega Nano Energy Cluster, the number of these joint inventions decreased when compared to the period preceding the creation of the cluster in both absolute and percentage terms (Fig. 1, Fig. 2, Tab. 1).

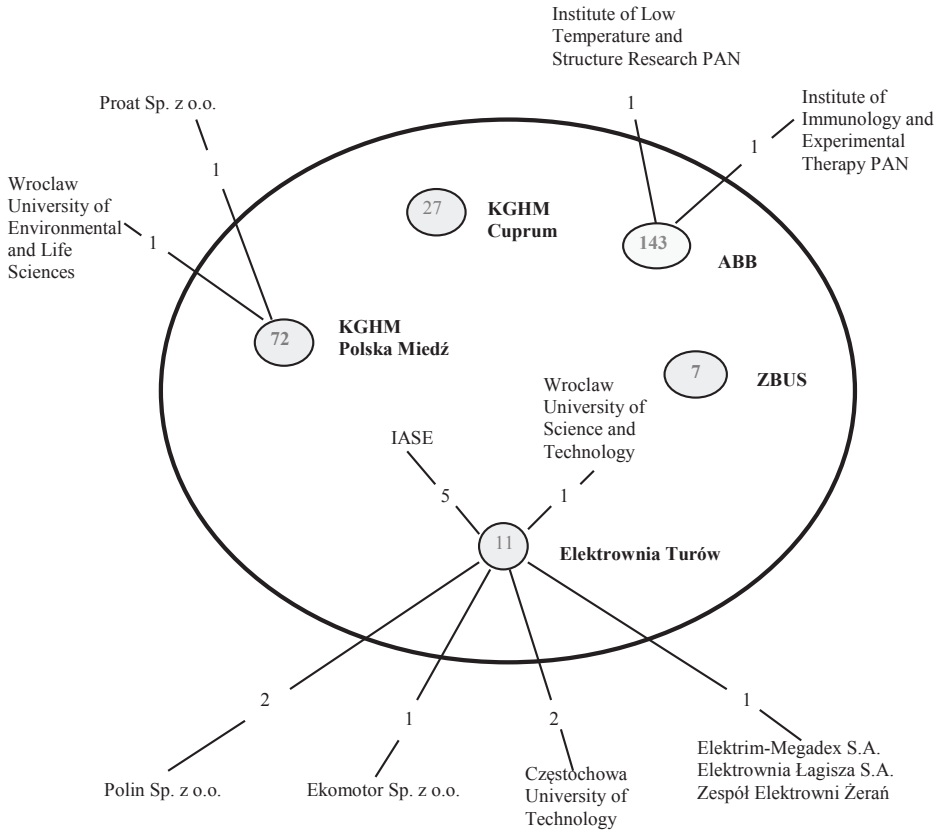

Figure 1. Joint patent applications of enterprises from Mega Nano Energy Cluster during period before creation of cluster

Legend: Numbers in circles indicate numbers of independent patent applications of enterprise; numbers between lines indicate numbers of applications filed jointly by entities connected by lines; inside large circle are all analyzed enterprises belonging to cluster as well as other cluster members with which patent cooperation was observed; outside large circle are entities not belonging to cluster

Source: developed on basis of own research

In fact, this means that the creation of the cluster not only failed to contribute to the intensification of the cooperation processes in the area of creating inventions, but the previously existing linkages between the enterprises currently forming the Mega Nano Energy Cluster and other existing cluster participants were also broken.

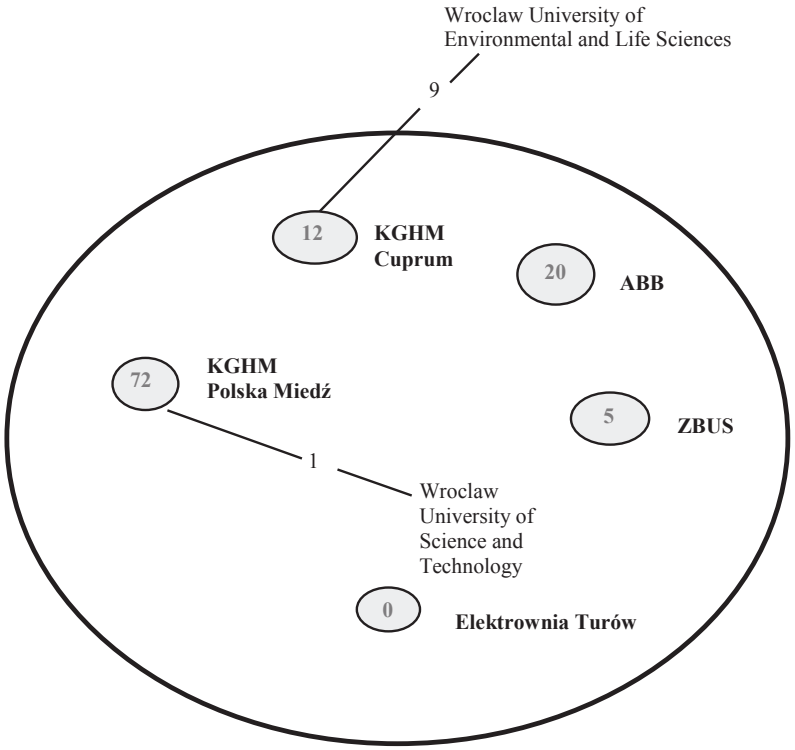

Figure 2. Joint patent applications of enterprises from Mega Nano Energy Cluster during period after creation of cluster

Legend: *see* Figure 1

Source: developed on basis of own research

While the enterprises from the Mega Nano Energy Cluster covered in the analysis had co-authored a total of 16 inventions during the period before the creation of the cluster (5.8% of the total number of inventions, including 6 with entities currently participating in the cluster – 2.17% of the total number of inventions), the total of co-authored inventions decreased to 10 during the subsequent

period (21.27% of the total number of inventions), including those generated with other cluster members (1 – accounting for just 2.13% of the total number of inventions) (Tab. 1). The decrease in the number of jointly created technical solutions results primarily from the general downward tendency in the inventive activity of the enterprises forming the cluster, which results, among others, from shorter time of functioning within the cluster than in the previous period. However, based on the obtained results in percentage terms, it is difficult to conclude that being a part of the cluster promotes knowledge-transfer processes.

Although the number of patent applications co-owned in the NutriBioMed Cluster is greater than that of the Mega Nano Energy Cluster (and it has additionally increased over time in absolute terms), it is also difficult to speak about the key role of cluster initiatives in facilitating knowledge flows in this case (measured by the number of joint inventions). This is due to the fact that, in relative terms, the enterprises from the NutriBioMed cluster showed less involvement in the joint inventive activity with other entities from the cluster than during the period when they did not constitute a formal grouping as of yet. Up to 2007, inventions co-authored with other cluster members accounted for slightly more than 43% of the total number of inventions, while during 2008–2017, this number was slightly above 35%. Similar to the case of the Mega Nano Energy Cluster, the bottom-up initiated cooperation in creating breakthrough innovations did not begin to visibly develop after these same entities decided to sign a formal cooperation agreement.

It should be emphasized, however, that the NutriBioMed Cluster demonstrates a greater potential for patent cooperation (unlike the Mega Nano Energy Cluster); with the creation of the cluster, the network of mutual connections between its participants grew (Figs. 3 and 4). While it was possible to observe ties connecting only two enterprises with two R&D entities during the period before the formation of the grouping, patent cooperation was undertaken by as many as five enterprises from the sample together with three academic centers and a technology park after the creation of the cluster.

Generally, with a relatively small degree of inventive activity of the enterprises belonging to the Lower Silesian clusters and, as a consequence, the small research sample consisting of only 13 enterprises from 2 clusters and a relatively small number of cases of jointly undertaken activities in the field of generating inventions by these enterprises, it is difficult to unambiguously indicate the factors that stimulate knowledge-diffusion processes within the cluster. Nevertheless, it seems that neither the size nor the degree of internationalization of the inventive output of these enterprises have any effect on the number of technical solutions jointly created by them and, thus, on the strength and scope of the knowledge diffusion within the cluster. For instance, among the enterprises from the Mega Nano Energy Cluster, the leader in undertaking R&D cooperation with other participants

of the cluster is Elektrownia Turów (with a relatively small number of inventions and not having a single PCT application), while the ABB company (which has the largest number of national and international applications) does not enter into any patent cooperation with entities from the same cluster. The case is similar in the NutriBioMed Cluster, in which, on the one hand, among enterprises engaging in joint R&D work there are both those which have international applications as well as those which do not have them at all, and on the other hand, among enterprises that have only independent patent applications there are also those which both have and do not have any PCT applications.

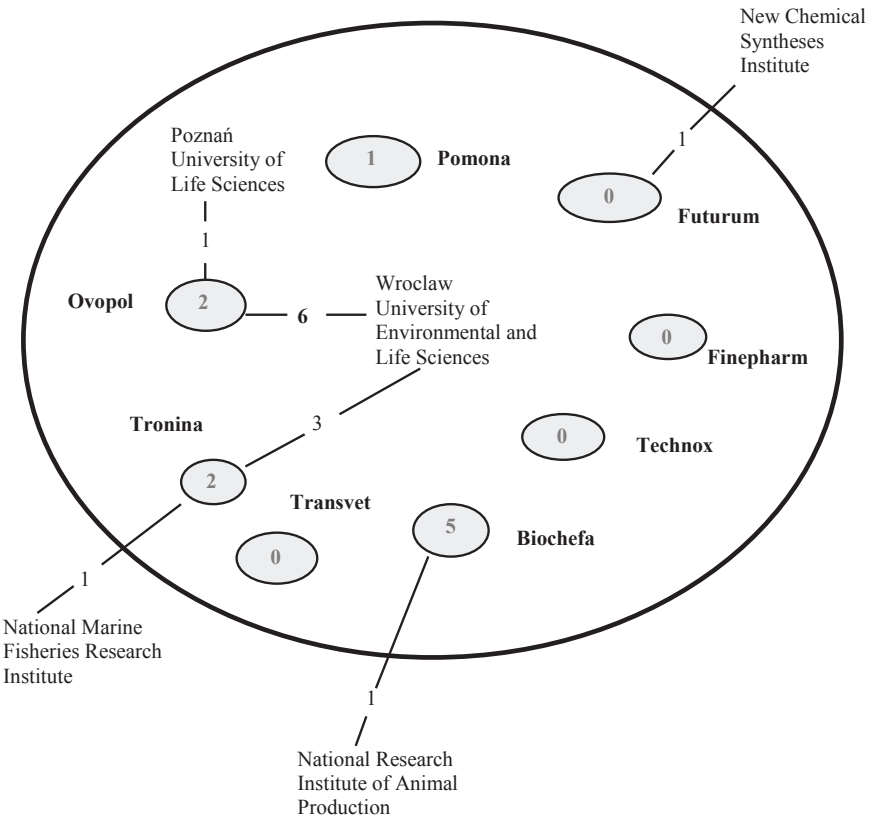

Figure 3. Joint patent applications of enterprises from NutriBioMed Cluster during period before creation of cluster

Legend: *see* Figure 1

Source: developed on basis of own research

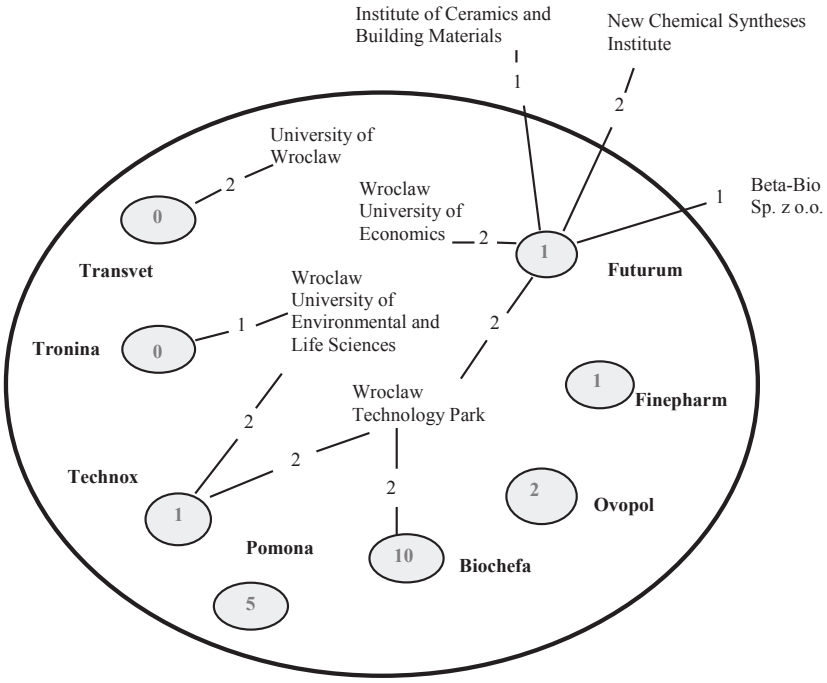

Figure 4. Joint patent applications of enterprises from NutriBioMed Cluster during period after creation of cluster

Legend: *see* Figure 1

Source: developed on basis of own research

5. Patent citations of enterprises from Lower Silesian clusters: research results

Just as the extent to which the enterprises covered by the study undertake patent cooperation with other cluster participants is small, the number of enterprises covered by the study that refer to the achievements of other cluster members in their patent applications is also small (with the enterprises from the NutriBioMed Cluster achieving better results in this respect).

The analysis of the national and international patent applications has shown that in the case of the enterprises from the NutriBioMed Cluster the number of cited inventions belonging to other cluster members increased (even significantly

in percentage terms) and also a network of mutual citations was initiated. Moreover, the enterprises began not only to refer to knowledge from the sphere of science but also to the achievements of the business sector. This is undoubtedly a signal that the knowledge flow between cluster members began to occur. Nevertheless, one should be careful about drawing final conclusions since the number of patent citations continues to be small and disproportionately smaller than the number of citations of know-how coming from outside the cluster (Figs. 5 and 6).

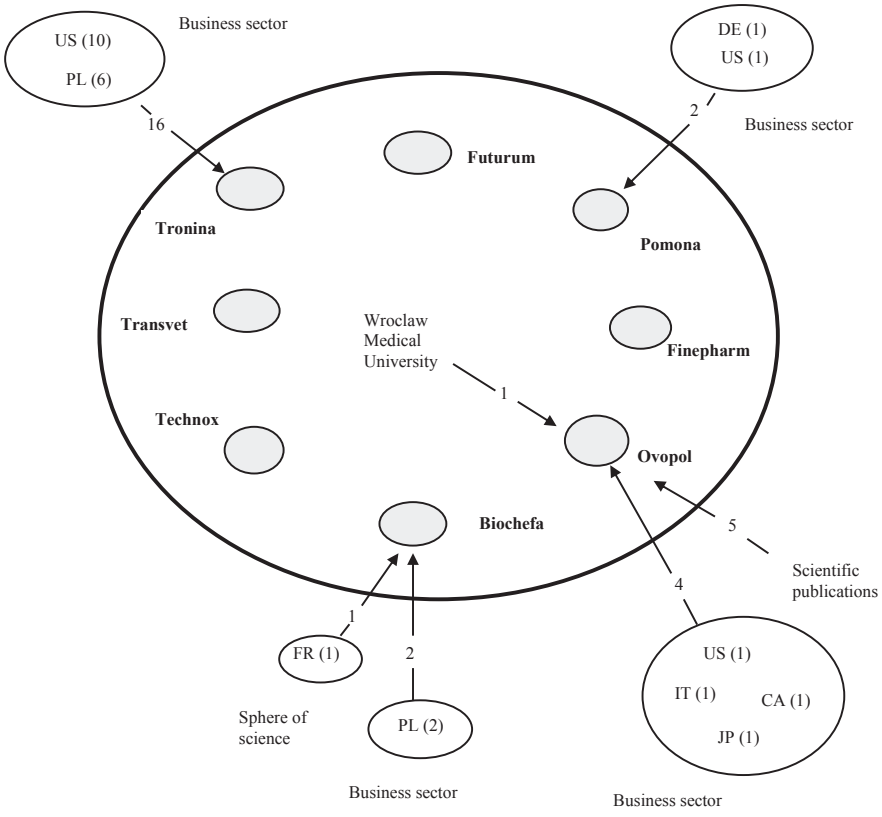

Figure 5. Patent citations of enterprises from NutriBioMed Cluster during period before creation of cluster

Legend: arrow shows direction of knowledge flow (from cited to citing entity); numbers in middles of arrows indicate number of citations; inside large circle are all analyzed enterprises belonging to cluster and other cluster entities that were source of knowledge for enterprises; outside large circle are entities not belonging to cluster.

Source: developed on basis of own research

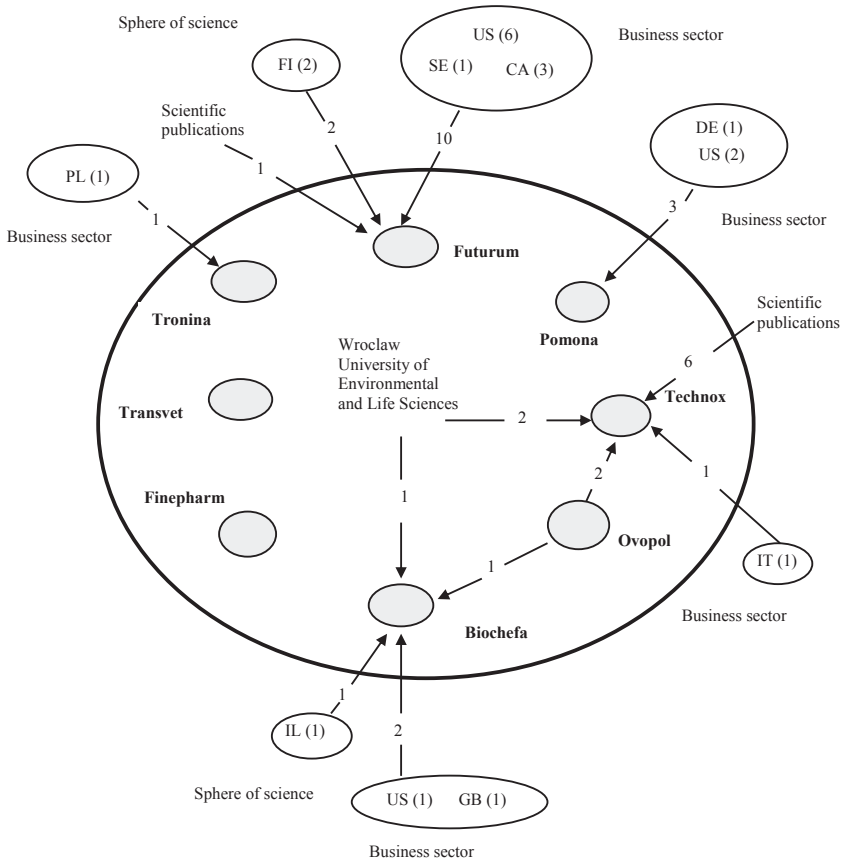

Figure 6. Patent citations of enterprises from NutriBioMed Cluster during period after creation of cluster

Legend: *see* Figure 5

Source: developed on basis of own research

During the period preceding the creation of the NutriBioMed Cluster, only one citation referred to knowledge created within the current cluster (3.2% of all citations), whereas the number of such citations increased to six after the initiation of formal cooperation (18.2% of all citations). In addition, before the creation of the cluster, only one enterprise had cited an invention of the academic center currently belonging to the cluster, whereas a total of two enterprises began to base their inventive activity on the knowledge created by their cluster partners during the subsequent period (both the other enterprises and the academic center).

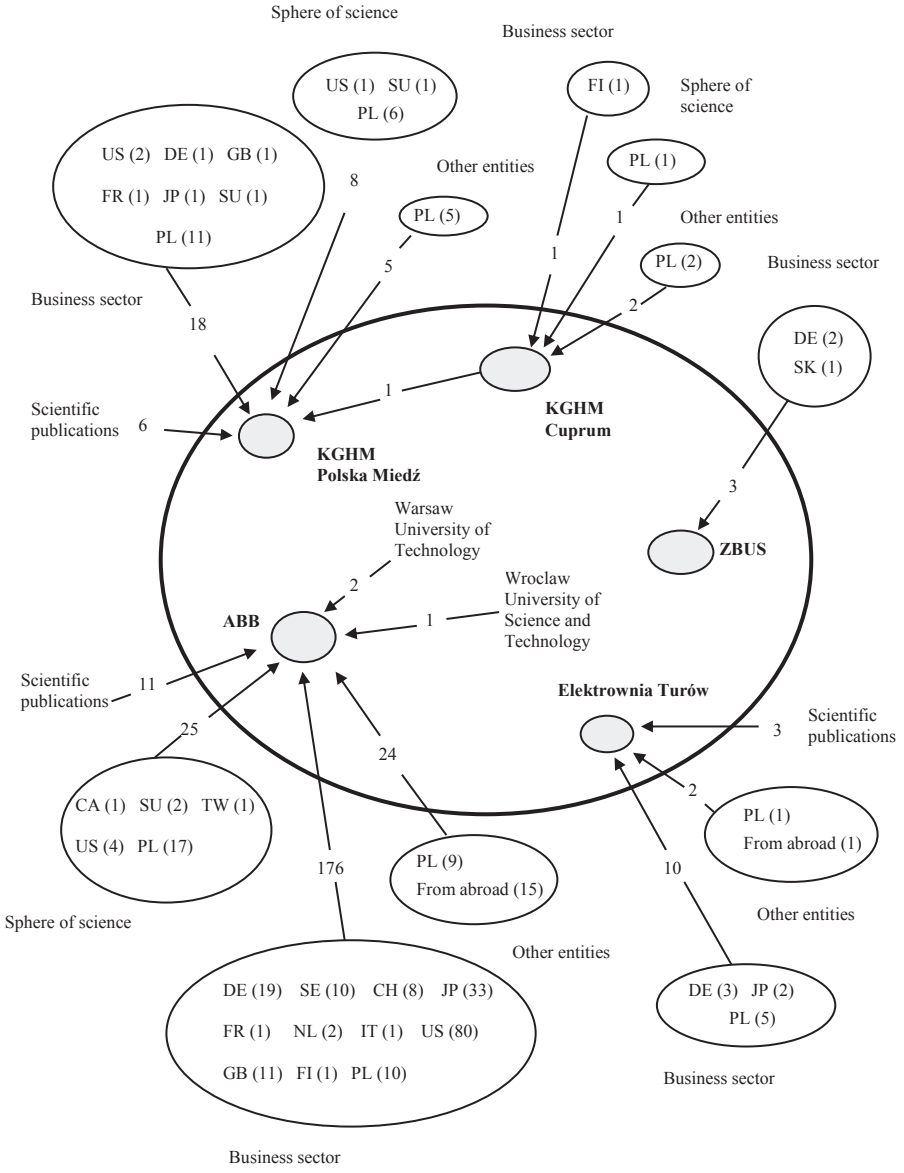

Figure 7. Patent citations of enterprises from Mega Nano Energy Cluster during period before creation of cluster

Legend: *see* Figure 5

Source: developed on basis of own research

Unfortunately, the results for the enterprises from the Mega Nano Energy Cluster are less optimistic than for the NutriBioMed Cluster. Although the enterprises from this cluster show very large absorption abilities (acquiring knowledge from around the world), they do not refer to technical solutions of entities with which they signed formal cooperation agreements in their patent applications. Surprisingly, they do not even use the know-how of the Wroclaw University of Science and Technology in generating inventions, which has enjoyed the status of a leader in terms of the number of patents obtained in Poland for years within the frames of the national procedure; however, they follow the patterns developed in national research units and academic centers not belonging to the cluster to a large extent (Figs. 7 and 8).

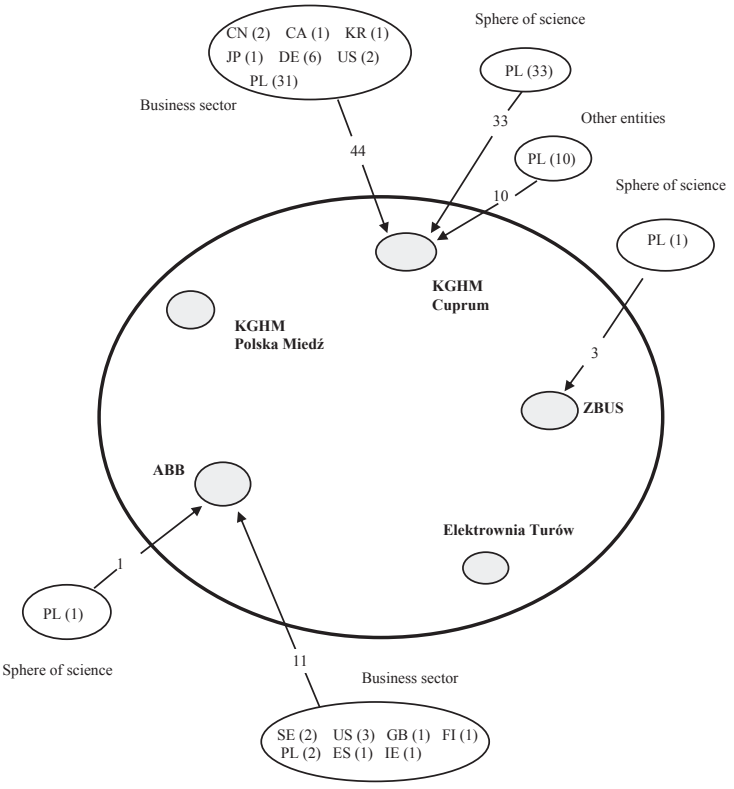

Figure 8. Patent citations of enterprises from Mega Nano Energy Cluster during period after creation of cluster

Legend: *see* Figure 5

Source: developed on basis of own research

To sum up, it may be concluded that, among the two Lower Silesian clusters, the enterprises from the Mega Nano Energy Cluster show a definitely larger inventive activity, both during the period preceding the creation of the cluster and at the time of the functioning of a formal grouping. Unlike the enterprises from the NutriBioMed Cluster, however, their inventive output has decreased over time. Moreover, despite the huge advantage they have over enterprises from the NutriBioMed cluster in terms of the number of inventions created, they show a smaller number of technical solutions created along with the other cluster members; therefore, it may be presumed that the strength and scope of their knowledge diffusion are smaller than within the NutriBioMed Cluster. And finally, they do not refer to the know-how of other cluster members in their patent applications during the lifetime of the cluster (which is contrary to the enterprises from the NutriBioMed Cluster); this also suggests that the scale of knowledge diffusion within the Mega Nano Energy Cluster is negligible.

6. Intra-cluster diffusion of knowledge: Lower Silesian clusters against background of Aviation Valley

The Aviation Valley is the most powerful Polish industrial cluster and, at the same time, "the only Eastern European cluster with such potential and growth" (Kulczycka, 2017). It is "(...) the pride of southeastern Poland. It is also a very beautiful example of cooperation between many Polish businesses and institutions whose purpose is joint success" (Stepaniuk, 2018).

The above statements are just two of many expressions referring to the success of the Aviation Valley that appear in scientific and journalistic literature. They are usually accompanied by "impressive" numbers showing the value of turnover, sales and exports as well as the size of employment and scale of investment of its members.

Despite the important role played by the Aviation Valley in the development of the entire Podkarpackie Voivodeship and the strong ties that connect its members, the enterprises covered by the study from this cluster demonstrate a small degree of patent cooperation; they do not undertake such cooperation with cluster partners at all and do not refer to their know-how in their patent applications either. This is true for both the period preceding the creation of the cluster and the years afterwards. Perhaps, therefore, this cooperation between the various entities of the Aviation Valley as well as their mutual exchange of knowledge and expertise do apply to the most valuable and most protected know-how of the enterprises.

In terms of the knowledge flow measured by the numbers of joint inventions and patent citations, the enterprises from the two Lower Silesian clusters covered by the study are better than the enterprises from the Aviation Valley. It should be assumed that the former achieve greater benefits in the form of the diffusion of precious know-how; although, as the data shows, the lack of cooperation in the field of creating inventions did not prevent the latter from achieving tangible successes. Nevertheless, developing joint innovative solutions could move them to a higher level of innovation that translate into even greater benefits.

7. Conclusions

It is widely believed that the key factor for the success of a cluster is the cooperation between its members, which results in the mutual exchange of knowledge and expertise. Although the members of the Lower Silesian clusters undertake a number of joint initiatives, there is still much to be done in the area of building and strengthening their cooperation in innovation.

The analysis of the national and international patent applications belonging to the enterprises from the NutriBioMed Cluster and Mega Nano Energy Cluster from Lower Silesia has shown that only a few enterprises undertake patent cooperation with the other entities from the cluster (albeit to a limited extent). The number of inventions co-authored with the partners from the cluster accounted for only 2.13% of the total number of all inventions of the enterprises in the case of the Mega Nano Energy Cluster and 35.14% in the case of the NutriBioMed Cluster. The result achieved by the enterprises from the NutriBioMed cluster could actually be regarded as satisfactory if not for the fact that this patent cooperation was more intensive during the period before the creation of the cluster. Namely, joint patent applications among the organizations currently belonging to the cluster accounted for 43.48% of the total inventive output of the enterprises at that time. This means that the signing of a formal cooperation agreement did not translate into a greater involvement of the enterprises in the joint inventive activity that would strengthen the knowledge-transfer processes. The enterprises from the Lower Silesian clusters not only do not acquire the valuable knowledge of their partners through direct contacts, but they also do so to a small extent by following their accomplishments (which is reflected in the small number of cited inventions belonging to the other cluster members). Of all the references of the enterprises from the NutriBioMed Cluster to other's knowledge, only six were citations of cluster members' know-how, while the enterprises from the Mega Nano Energy Cluster did not cite their cluster partners at all (with their

inventive activity based only on internal sources of knowledge or ones located outside the cluster).

Due to the small number of joint inventions and references to the knowledge of the other cluster members, it is difficult to identify the factors that stimulate knowledge flow within the cluster. It does not seem, however, that the size of the inventive output nor the degree of its internationalization are important here. On the other hand, it seems that the intensity of the knowledge transfers may depend on the number of R&D institutions in the cluster since the mutual exchange of knowledge is more intensive in the NutriBioMed Cluster (which has more of them) than in the Mega Nano Energy Cluster.

Although the research sample is too small for the results to be extended to the entire population of clusters, it seems that the potential of Polish clusters in promoting knowledge-diffusion processes is not sufficiently utilized. This is true not only for the analyzed clusters from Lower Silesia but also to the Aviation Valley, which is considered an enclave of innovation in Poland. The reason is that the enterprises from the Aviation Valley Cluster are even less interested in cooperation in the field of generating inventions and in referring to the know-how of their partners than the Lower Silesian clusters.

The most disturbing result of the study, however, is that the enterprises still do not see the benefits resulting from intra-cluster knowledge diffusion and regard cooperation with other cluster member as being of little importance or even risky from the point of view of innovation and competitiveness. This makes them approach it with suspicion, which makes it difficult for them to achieve benefits in the form of synergy effects.

The results of the analysis undertaken in this paper may be useful from the perspective of future studies, which could be extended to the entire population of Polish clusters. Then, it would be possible to better capture the relationship between the industry in which the clusters operate or the policies toward the clusters and the processes of knowledge diffusion, for example.

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Patterns of technological accumulation in European Union countries

1. Introduction

The importance of technological accumulation in manufacturing processes, technological advantage are a noticed issues in economic studies from the beginning of their development. At first, the contamination mechanism of industrial creativity was not noticed directly, its impact on the total productivity of production factors, usability, and the emerging economic value based on the process of knowledge accumulation. The second half of the twentieth century brings a deep reflection, mainly under the influence of dynamic structural changes in the global economy, on the possibilities of the description and inclusion of the issue of knowledge and its use in manufacturing processes to economic theory (Lucas, 1988, 1990; Romer, 1990; Grossman, Helpman, 1991; Mankiw et al., 1992; Barro and Sala-i-Martin, 1991, 2004).

An example of an R&D product that is highly saturated in knowledge and having the potential for commercial exploitation is a new technology included in the patent description. In a legal sense, a patent is a right to the exclusive use of a new solution of a technical nature. This is considered to be one of the strongest intellectual property rights. In the scientific sense, it is the culmination of R&D activities. In economic terms, this is one of the stages of the innovation process. From the point of view of the person who is the owner, it is a resource and a potential market value. It has a relatively high ability to transform into a production factor. The properties of the patent description and exclusive rights (patent – understood in the strictest sense) cause that the patent information

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constitutes a bridge between the results of the R&D activities and their potential economic exploitation.

A patent is a collection of accumulated industrial knowledge that has the ability to influence the course of management processes. It is an economic category ascertained in both normative and positive economics. In the first case, it is considered on the level of institutional solutions (optimal patent policy, the effectiveness of patent systems, external effects); in the second case, it is considered as a measure of the dynamics and direction of changes in an economy.

It is a regularity that R&D activity and then patent and implementation activity are not symmetrically distributed within particular countries (or regional economies). Hence, the actual and important research issues are questions about (1) the reasons for the spatial differentiation of the effects of the innovation processes and policy, (2) adequate, national, and regional development strategy (specialization vs. diversification), or (3) the relationship between the 'success' nations and their neighbors (knowledge spillover effect vs. depletion effect).

This paper is an indirect response to the above-mentioned fundamental research questions. The scope of the research process presented in this paper is focused directly on the following issues: the structure of the distribution, directions, and dynamics of the developed technologies within the economies of the selected European Union countries, use of patent information to the patterns of technological accumulation, and a new approach to selecting and positioning smart specialization.

Techniques and production technology are micro-economic characteristics, and their transposition to the macro level raises many problems. Recognizing that technology means all processing of tangible and intangible assets into usable goods (in particular, that it constitutes an accumulated stream of scientific and technical knowledge on the practical use of the achievements of a specific area of science in industry, transport, medicine, etc.), its transposition and aggregation in macroeconomic terms will rely on the summing up of unit records of the rise of new scientific and technical knowledge within sectors, industries, or areas of technological development. It is assumed that individual records materialize the process of growing industrial knowledge and potential technological development. They lend themselves to quantification. The technological learning process favors the creation of technological potential, understood as a set of the technical and process solutions available to domestic businesses.

This terminological context leads to two main research goals; these are the identification of technological accumulation in selected European Union countries and the assessment of the differentiation of potential technological comparative advantages in the international system. In order to achieve the defined scientific objectives, the WIPO Technology Concordance Table and Balassa's Revealed Comparative Advantage (RCA) are used.

The structure of the study is as follows. Section 2 discusses the literature in the field of technological accumulation. Section 3 describes the methodology and primary data used to achieve the goal of the study. Step 4 presents the results of the empirical analyses. The last section is a summary of the study.

2. Literature review

The accumulation of the capacities and capabilities of technological development embodied in title deeds for new technical solutions has been more dynamic in recent decades, with radical changes in the approaches and methods for carrying out manufacturing processes that are increasingly based on intangible resources. It should be clearly stated that, depending on the cultural or institutional circumstances, the accumulation process has a different course and different dynamics. "It seems justifiable to assume that the relationship between technological change and the cultural and institutional characteristics of a given nation is one of the most important causes of the observed differences in the rates of inventiveness and economic growth between countries" (Gomułka, 1998).

The economy is a complex adaptive system that changes over time. Hence, the need for a constant search for more-perfect research procedures relevant to a given stage of development (or, more specifically, methods for explaining these complexities as well as their causes and effects).

The research on the results from the relationship between scientific achievements, industrial developments, and structural changes in an economy initiated by J. Schumpeter (1934) emphasize particular skills and technological competence as a prerequisite towards obtaining comparative advantages (Malerba, Orsenigo, 1995). Compared with the traditional assumptions (R. Torrens, then D. Ricardo), the theory of comparative advantage should be now regarded as a logically cohesive structure of generalizations that explain the mechanism of the mutually beneficial exchange of goods under the conditions of diversified costs and applicability of specific technologies for the production of a given good (or bundle of goods).

In the original version, the leads in an industry, sector, or national economy stem from the relative abundance of certain types of resources and their use in the (spatial) distribution process of labor. In 1776, A. Smith introduced the concept of absolute advantages, which are based on specialized production resulting in advantages in terms of cost and performance. In 1817, D. Ricardo argued that an absolute difference in production costs is not necessary for the exchange to be profitable. Cost differences and comparative advantages create the directions of trade flows. It is ultimately the level of the relative alternative cost of production of a given good that can determine the benefits of the exchange. It should be emphasized that differences in the relative costs of production (which are vital

to the development of exchange) are the result of the differences in the level of technology used in production, productivity, and wages. D. Ricardo's theory is a useful economic model to this day, although S. Golub and Ch. Hsieh (2000) indicate that, "despite its large educational usefulness, in recent decades the model has been ignored in the professional literature," mainly because of its initially adopted assumptions. They indicated the 1960s, when the model was extensively used in economic studies (Stern, 1962; Balassa, 1963, 1965). Since the beginning of the 21st century, a renaissance of empirical research on comparative advantages has been observed (Eaton, Kortum, 2002; Kerr, 2009; Chor, 2010; Levchenko, Zhang, 2012).

The index first proposed by Balassa (1965) – the index of revealed comparative advantage (RCA) – was widely used (along with its further modifications). According to Balassa, this index discloses a comparative advantage – if the share of exports of the *j*-th sector in the *i*-th country in the total exports of the country is higher than the share of this sector in the global structure of exports, it is indirect evidence of a comparative advantage in terms of the products of the *j*-th sector in this country with respect to a specific group of countries. It should be noted that the changes in the index result not only from differences in productivity but also in changes caused by the policy of export stimulation, so care should be exercised in interpreting the results. Costinot et al. (2012) and, further, Leromain, Orefice (2013) emphasize the importance of differences in access and use of technology as determinants of diversification in patterns of trade. They have also drawn attention to such factors as geographical distance, colonial trade/legacy, language, etc. as other important determinants in measuring comparative advantages.

This study uses the concept of comparative advantage, giving it a slightly different meaning and interpretation. Balassa's RCA index is used to measure the potential sources of advantage; i.e., those technological resources not fully disclosed and used in the national context. These resources are the hard-to-quantify results of the activities of human capital in the form of new scientific and technical knowledge that, analyzed from a technological perspective, allow us to determine the potentials of national economies (R&D competences, continuity in the development of a specific field of technology, and the ability to network) or the lack thereof.

3. Research design

The concepts of sectors and areas of technological development describe different aspects of the production process. They should be analyzed separately.

The classifications of technologies and areas of technological development have been created and developed by many institutions. While creating technological taxonomies is not an impossible task (although it naturally raises substantive disputes), the measurement itself of this process is a major challenge in the process of scientific knowledge. This is particularly difficult from the macroeconomic perspective. Starting with the general assumption that the description of a new technical solution is part of the process of technological development, concordance tables are created that link sectoral classifications to the International Patent Classification (*IPC)* – a hierarchical system for classifying inventions. An important contribution in creating the concordance tables was introduced by Schmoch (2008), whose table became the basis for creating the concordance table of the World Intellectual Property Organization. This has been used in achieving the research objectives in this article. The appendix shows the classification of the areas of technological development using the schema.

Creating technological fields using the IPC schema should be assessed as a valuable way of addressing the problems in measuring the direction and dynamics of changes in technological developments in each layer of an economic analysis. The defects in patent metadata are compensated for by the possibility of working with full collections, often reaching hundreds of thousands of items (when they are considered for national economies).

Using the idea of group indexes for Balassa's relative sizes (1963, 1965), which are used in international comparisons by Eaton, Kortum (2002); Nesta, Patel (2005); Kerr (2009); Chor (2010); Levchenko, Zhang (2012); below, these are given the following meaning:

$$RPTA_{ik} = \left(\frac{P_{ik}}{\Sigma_k P_{ik}} \right) / \left(\frac{\Sigma_i P_{ik}}{\Sigma_{ik} P_{ik}} \right)$$

where:

$RPTA_{ik}$ – the relative potential technological advantages of the i-th country using the concordance table (see appendix) connecting the areas of technology and international patent classification, we can give the following meanings for the individual parameters:

P_{ik} – the number of technical solutions of the i-th country in the area of the k-th technology,

$\Sigma_k P_{ik}$ – the total number of technical solutions of the i-th country in all of the technological areas considered,

$\Sigma_i P_{ik}$ – the total number of technical solutions within the k-th technology of all of the i-th countries studied,

$\Sigma_{ik} P_{ik}$ – the total number of technical innovations in all technology areas of all of the countries studied (each within the defined analytical groups).

The index value belongs to set RPTA $\in$ (0, $+\infty$). A value above unity indicates the relative technological advantage within the surveyed population (e.g., the specific set of European countries). A value below unity indicates a relatively weak competitive position in a particular field of technology against others. When we perform the simple modifications of (RPTA – 1)/(RPTA + 1) = RPTA*, then RPTA* $\in$ [-1 ; +1]. RPTA is the result of two factors: the dynamics of the relative partial sizes and the changes in the structure of these factors.

While seeking patent protection, the entity chooses the procedure based on which of the proceedings will take place. These procedures can be divided into national, regional, and international. The procedure of European patent application was selected to implement and achieve the defined research goal.

The collection of patent metadata for the countries covered by the research was extracted directly from the patent information database of the European Patent Office in June 2015. The total number of patents granted during the accepted research period for the selected countries is 686,052.

The years of 2000–2014 are accepted as the research period. The following two considerations were crucial in choosing the research period: first, the availability and completeness of patent data in the EPO mode; and second, the period of 15 years is long enough to capture the processes of technological accumulation.

4. Results

Using the ratio of the absolute measure of dispersion – the standard deviation (σ) and the mean value (μ) – we obtain the classic coefficient of variation (V_i), which determines the degree of diversification of the technological specialization in the time and space studied. The higher the dispersion, the narrower the technological specialization of the country. Low values of this characteristic can be interpreted as a relatively equally spread technological competence throughout the population of the considered areas of technological development. In examining the abovementioned relationship from a technological perspective, we can identify the relative technological advantage of a country and give an indication of its diversity within the group. A higher variability index value indicates an emerging technological specialization; a lower weakly exploited area, or one exploited by all countries within a similar range and with similar search results. The group subjected to analysis are the European countries before EU expansion in 2004 (hereafter referred to below as the EU15).

Table 1

RPTA within EU15 (2000–2014)

Fields of technology (see: appendix)	Austria	Belgium	Germany	Denmark	Spain	Finland	France	Great Britain	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Sweden	V_i (%)
1	0.97	0.51	1.16	0.53	1.00	0.61	1.17	0.66	0.25	0.88	0.87	0.58	0.48	0.00	0.52	46.9
2	0.90	1.00	0.93	2.18	0.78	1.19	1.13	1.36	1.39	1.07	0.46	0.86	0.82	0.43	0.77	40.1
3	0.25	0.32	0.72	0.42	0.57	4.56	1.19	1.46	0.70	0.67	0.41	0.14	0.46	0.00	2.40	118.4
4	0.17	0.21	0.58	0.22	0.78	5.15	1.13	1.64	0.20	1.82	0.32	0.00	0.41	0.30	3.52	128.1
5	0.32	0.29	0.87	0.62	0.23	2.22	1.34	1.27	0.00	0.15	0.37	0.00	0.48	0.00	1.95	102.0
6	0.39	0.53	0.79	0.48	0.26	1.64	1.52	1.70	0.54	1.73	0.28	0.14	0.50	0.00	1.27	75.5
7	0.66	0.64	0.73	0.75	2.55	2.21	1.37	1.19	0.00	9.59	0.61	0.00	1.65	0.00	1.19	147.4
8	0.56	0.69	1.18	0.15	0.14	0.25	1.35	0.91	0.00	0.25	0.32	0.00	0.48	0.00	0.59	89.6
9	0.59	0.60	0.90	0.70	0.31	0.59	1.31	1.58	0.26	1.52	0.54	0.00	1.14	0.41	0.73	59.8
10	0.72	0.72	1.10	0.68	0.40	0.89	1.04	1.10	0.39	1.02	0.55	1.97	0.69	1.06	0.81	42.4
11	1.17	1.35	0.70	2.36	0.97	1.63	0.78	2.29	2.60	1.07	0.43	0.50	1.24	4.01	1.31	62.0
12	0.83	0.36	1.11	0.55	1.53	0.68	0.99	0.93	0.83	2.26	0.77	0.64	0.72	0.85	0.80	47.6
13	0.74	0.99	0.81	2.23	0.99	0.66	0.91	1.24	2.15	3.12	1.04	0.21	0.94	1.38	2.35	57.8
14	0.39	0.73	0.86	1.18	1.15	0.33	1.38	1.64	0.89	0.70	0.75	0.15	0.43	2.90	0.63	69.5
15	0.85	1.32	0.59	5.31	1.74	0.84	0.93	2.26	0.88	1.92	0.54	0.00	1.70	2.03	0.81	82.9
16	0.73	0.92	0.55	2.86	1.83	0.60	0.91	2.44	2.86	2.51	1.18	0.00	0.78	1.99	1.40	61.6
17	0.59	1.72	1.26	0.23	0.26	0.81	0.77	0.74	0.46	0.37	0.94	0.00	1.41	0.70	0.25	66.1
18	0.90	2.58	0.56	4.65	2.16	1.61	1.03	1.29	4.33	1.94	1.32	0.00	3.65	0.61	0.77	74.7
19	0.40	0.50	1.12	0.90	0.75	0.54	0.65	1.87	0.40	0.88	0.52	0.00	0.50	0.00	0.35	70.8

Table 1 cont.

Fields of technology (see: appendix)	Austria	Belgium	Germany	Denmark	Spain	Finland	France	Great Britain	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Sweden	V_i (%)
20	2.77	2.92	0.99	0.77	0.86	0.91	1.11	0.68	0.87	0.30	0.80	11.08	0.66	0.67	1.05	147.0
21	0.99	1.87	1.18	0.47	0.72	0.92	0.80	0.78	0.84	0.69	0.90	0.87	0.75	0.43	0.89	36.8
22	0.00	0.00	0.93	0.46	0.34	0.56	2.22	0.60	10.83	0.00	0.62	0.00	0.00	0.00	0.68	230.4
23	0.93	1.30	1.05	1.01	0.83	1.07	0.97	0.89	0.58	1.09	0.99	0.82	1.16	1.98	0.83	29.1
24	1.16	1.64	1.04	1.12	0.79	1.30	1.03	0.79	2.33	0.78	0.76	2.21	1.16	0.80	1.03	40.1
25	1.00	0.74	0.93	0.87	1.60	1.53	0.76	0.74	0.40	0.84	2.09	0.94	1.72	0.75	0.92	42.1
26	1.70	0.81	1.18	0.47	0.83	0.68	0.61	0.58	2.08	0.36	1.40	1.03	0.55	1.17	1.35	48.0
27	0.89	0.64	1.22	0.94	0.45	0.45	0.94	0.69	1.21	0.25	0.85	1.73	0.31	1.09	0.79	45.5
28	1.01	3.30	1.12	0.49	0.65	2.89	0.54	0.76	0.56	0.12	1.22	0.22	0.90	0.87	0.92	83.1
29	1.11	1.45	0.95	1.14	1.06	0.85	0.92	0.67	1.25	1.28	1.33	0.84	3.41	1.67	0.76	51.0
30	2.00	0.89	1.06	1.29	1.26	1.15	0.81	0.48	1.75	0.80	1.38	4.08	1.17	0.90	1.09	61.0
31	0.91	0.30	1.24	0.60	0.69	0.38	0.89	0.65	0.58	0.23	0.93	1.41	0.88	0.38	0.69	45.2
32	0.88	0.36	1.19	0.21	1.00	0.29	1.21	0.51	0.47	0.34	0.82	0.60	0.74	0.46	0.74	46.9
33	1.90	1.06	0.89	1.05	1.94	0.36	1.01	0.85	0.73	1.51	1.86	1.24	1.07	1.57	0.81	38.2
34	1.15	1.32	0.88	0.42	1.69	0.37	1.26	0.89	1.19	0.70	2.03	0.00	0.77	1.31	0.53	53.2
35	2.25	2.18	0.97	1.20	1.64	0.82	0.88	0.85	1.67	1.27	1.19	1.98	1.24	1.63	0.86	34.3
RPTA >1	11	14	15	13	13	13	18	15	13	16	11	9	13	13	12	
V_i (%)	61.8	72.7	21.4	100.8	59.6	91.4	29.1	47.1	141.2	127.6	51.6	198.1	74.0	96.1	60.9	

Source: own study

Table 1 shows the cumulative RPTA values from the period of 2000–2014 obtained using the patent metadata set of the European Patent Office (EPO) and the technology concordance table (see appendix). From Table 1, the following findings can be concluded for the EU15 group:

1) the RPTA index value above unity indicates a potential technological advantage within the surveyed population (EU-15); considering this criterion, the following leaders should be indicated (i.e., the countries with the highest number of potentially competing technologies); these are France (with 18 potential relative technology advantages)[1], Ireland[2] (16), Germany[3], United Kingdom[4] (15), and further Belgium, Denmark, Spain, Finland, Greece, Portugal, the Netherlands (13), and then Sweden (12), Austria, Italy (11), and Luxembourg (9);
2) the highest technological concentration is observed in microstructural and nanotechnology technologies (attention here to Greece and France); it is also relatively high in terms of management IT systems (Ireland), plastics and metallurgy (Luxembourg, Belgium, Austria), and digital communications and telecommunications (in both cases, the decisive leader is Finland);
3) the most exploited fields of technological development simultaneously in all of the countries surveyed are chemical engineering, civil engineering, and processing and surface-coating technologies;
4) the biggest European economies (Germany, France, United Kingdom) have a relatively balanced development in all 35 analyzed technological fields;
5) in the case of small economies within the EU15 study group (Luxembourg, Greece, and Ireland), the greatest relative technological specialization can be observed.

Table 2 contains the groups of quartile technological development fields (potential advantages) at three time points during the period studied (i.e., 2000, 2008, and 2014). The first quartile group includes the countries with the highest number of technological fields in which they have the potential technology advantages; the last (fourth) quartile group includes countries with the lowest values of the characteristic.

[1] If we take into account the proximity and increased tolerance in a range of [0.9:1.10] in the case of four fields of technology, a moderately successful advance should be noted in the 18 chosen fields of technology (i.e., the value of the indicator is slightly greater than 1) and omission in the case of 7 fields of technology (i.e., the value of the indicator is slightly lower than 1).
[2] Moderate success in advance – in the case of four fields of technology, and without omissions.
[3] Moderate success in advance – in the case of four fields of technology, and apart from six fields.
[4] Moderate success in advance – in the case of one technological field, and apart from two fields.

Table 2

Quartile groups of fields of technological development during period of 2000–2014 (EU15)

Quartile group	Years		
	2000	2008	2014
First	Germany, France, United Kingdom, Sweden	France, UK, Germany, Spain	France, Germany, Spain, UK
Second	Belgium, Denmark, Spain, Finland	Sweden, Denmark, Italy, Belgium	Ireland, Belgium, Portugal, Italy
Third	Ireland, Italy, the Netherlands, Austria	Ireland, the Netherlands, Finland, Greece	The Netherlands, Finland, Denmark, Austria
Fourth	Luxembourg, Greece, Portugal	Luxembourg, Austria, Portugal	Sweden, Greece, Luxembourg

Source: own study

From Table 2, the following general findings can be concluded: (1) at the three time points investigated, the first quartile group included France, the UK, and Germany; (2) Luxembourg was consistently placed in the last quartile group; (3) in the case of the other countries, there is a relatively high volatility of places occupied in the quartile ranking.

An analysis of the correlation using Spearman's rank correlation coefficient among the EU15 during years t and $t - 1$ shows a fading correlation during the period analyzed (Fig. 1):

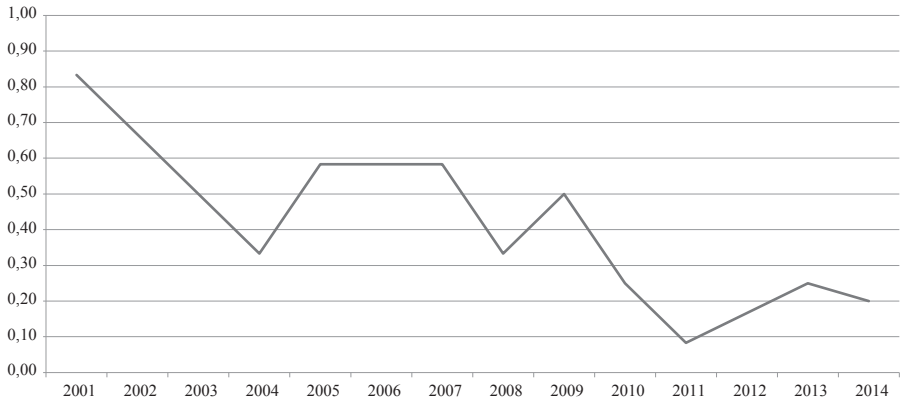

Fig. 1. Values of Spearman rank correlation coefficient among EU15 countries

Source: own study

Further, using (a) the coefficient of variation based on the standard deviation (i.e., the quotient of standard deviation and the unweighted arithmetic mean – V_S), (b) the coefficient of variation based on the average deviation (i.e., the ratio of the average deviation to the unweighted arithmetic mean – V_d), (c) the coefficient of variation based on the deviation quartile (i.e., the ratio of quartile deviation and median – V_Q), and considering that the coefficients of variation used (V_S, V_d, V_Q) are a mapping of σ-convergence of the issue under examination, it cannot be said that the countries in the EU15 group have clearly assimilated to the extent of their number of developed fields of technology (see Fig. 2).

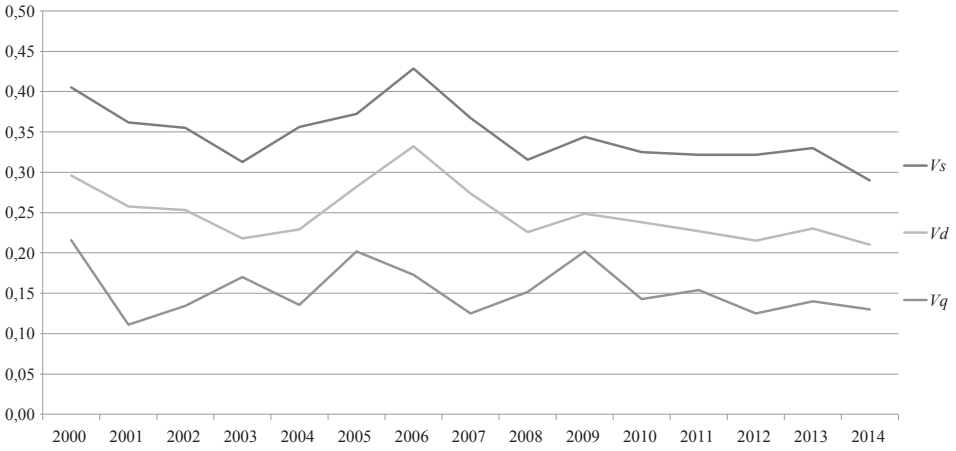

Fig. 2. Coefficients of variation in developed technological fields during period of 2000–2014

Source: own study

The variation in the number of developed fields of technology is generally determined by the size of the economy. For smaller economies, an important role is played by foreign capital, which promotes technological diversification in the country (as is the case in Ireland).

The above analysis is further enriched by a cluster analysis (Everitt et al. 2011; Kaufman, Rousseeuw 2005).

On the basis of these calculations, dendrograms for each technological process pair within groups of countries were created. These represent the division into clusters (groups) of countries resulting from the Euclidean distances between the standardized values of attributes and the arithmetic average distance between the clusters.

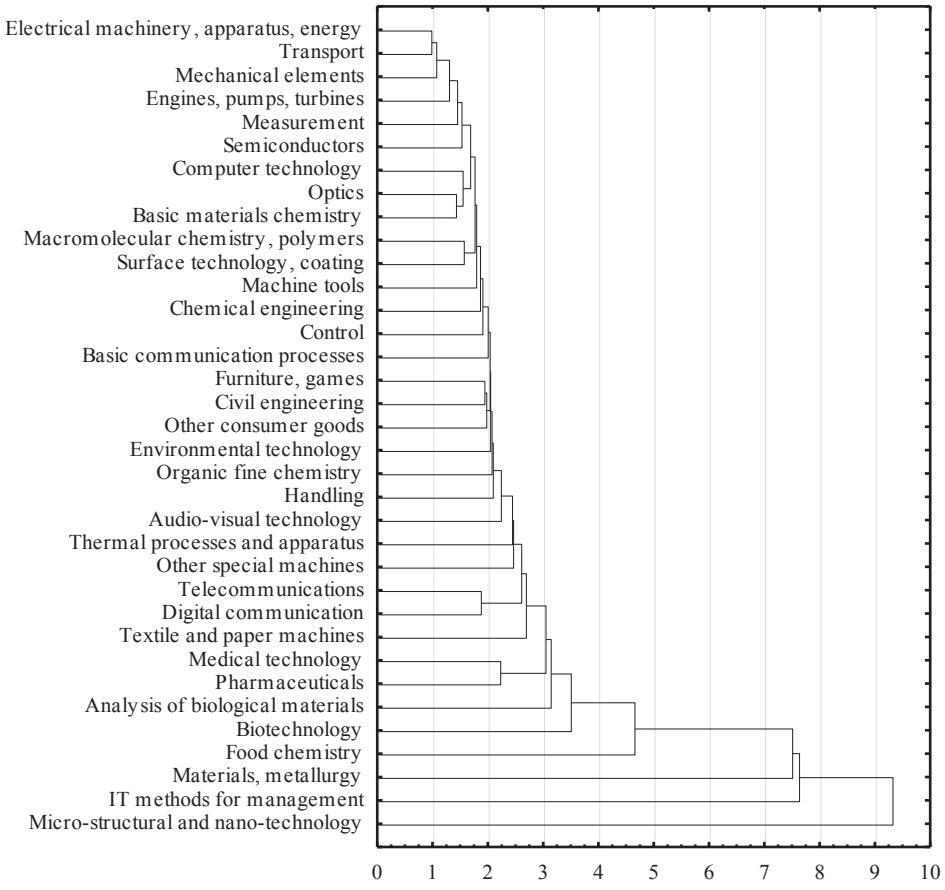

Fig. 3. Dendrogram of technological clusters in EU15

Source: own study

In order to isolate the clusters of the potential technology advantages that were most similar to each other, a critical distance of 4 was taken into account.

Reading Figure 3 leads to the deletion of a *de facto* two-part structure of technological groups in the EU15 (for which the degree of linking among the countries in terms of the various technologies is greatest): the first (covering 31 technological fields) developed relatively evenly; the second (distinctly different from the first) includes the following technologies in the field: food chemistry, materials and metallurgy, IT methods for management, and microstructural technology and nanotechnology.

5. Conclusions

Innovation research does not provide direct knowledge of technological accumulation and technological changes. Patent information provides greater opportunities in this field. It goes deeper into those processes compared to other alternative methodological approaches. Its main advantage is the high flexibility of aggregation and disaggregation of the processes analyzed. This allows for the identification of a strategy for the directions of future development. Patent information and innovation surveys provide the most important knowledge on the trends and dynamics of technological change at the micro-, meso-, and macro-economic levels.

The analysis of the potential comparative technological advantages in two groups of countries with distinctly different levels of development using a single methodological approach for achieving the purpose of this study enables us to derive the following general conclusions:

1) the level of development determines the number of developed specializations; the largest economies are characterized by the greatest diversity of potential technological advantages, and the smallest economies are characterized by the highest specialization;
2) a quartile analysis shows high stability among the technology leaders during the period analyzed and high variability within the second and third groups, which is further confirmed by the course of the coefficient of variation based on the quartile deviation;
3) in the areas of microstructural technology and nanotechnology, the largest concentration is observed;
4) relatively evenly exploited fields of technological development in the EU15 are chemical engineering, civil engineering, and processing and surface-coating technologies.

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Appendix 1

WIPO technology concordance table links for International Patent Classification (IPC).

No.	Fields of technology	IPC codes
1	Electrical machinery, apparatus, energy	F21H; F21K; F21L; F21S; F21V; F21W; F21Y; H01B; H01C; H01F; H01G; H01H; H01J; H01K; H01M; H01R; H01T; H02B; H02G; H02H; H02J; H02K; H02M; H02N; H02P; H05B; H05C; H05F; H99Z
2	Audio-visual technology	G09F; G09G; G11B; H04N3; H04N5; H04N7; H04N9; H04N11; H04N13; H04N15; H04N17; H04N101; H04R; H04S; H05K
3	Telecommunications	G08C; H01P; H01Q; H04B; H04H; H04J; H04K; H04M; H04N1; H04Q
4	Digital communication	H04L; H04N21; H04W
5	Basic communication processes	H03B; H03C; H03D; H03F; H03G; H03H; H03J; H03K; H03L; H03M
6	Computer technology	G06C; G06D; G06E; G06F; G06G; G06J; G06K; G06M; G06N; G06T; G10L; G11C
7	IT methods for management	G06Q
8	Semiconductors	H01L
9	Optics	G02B; G02C; G02F; G03B; G03C; G03D; G03F; G03G; G03H; H01S

10	Measurement	G01B; G01C; G01D; G01F; G01G; G01H; G01J; G01K; G01L; G01M; G01N1; G01N3; G01N5; G01N7; G01N9; G01N11; G01N13; G01N15; G01N17; G01N19; G01N21; G01N22; G01N23; G01N24; G01N25; G01N27; G01N29; G01N30; G01N31; G01N35; G01N37; G01P; G01Q; G01R; G01S; G01V; G01W; G04B; G04C; G04D; G04F; G04G; G04R; G12B; G99Z
11	Analysis of biological materials	G01N33
12	Control	G05B; G05D; G05F; G07B; G07C; G07D; G07F; G07G; G08B; G08G; G09B; G09C; G09D
13	Medical technology	A61B; A61C; A61D; A61F; A61G; A61H; A61J; A61L; A61M; A61N; H05G
14	Organic fine chemistry	A61K8; A61Q; C07B; C07C; C07D; C07F; C07H; C07J; C40B
15	Biotechnology	C07G; C07K; C12M; C12N; C12P; C12Q; C12R; C12S
16	Pharmaceuticals	A61K6; A61K9; A61K31; A61K33; A61K35; A61K36; A61K38; A61K39; A61K41; A61K45; A61K47; A61K48 A61K49; A61K50; A61K51; A61K101; A61K103; A61K125; A61K127; A61K129; A61K131; A61K133; A61K135; A61P
17	Macromolecular chemistry, polymers	C08B; C08C; C08F; C08G; C08H; C08K; C08L
18	Food chemistry	A01H; A21D; A23B; A23C; A23D; A23F; A23G; A23J; A23K; A23L; C12C; C12F; C12G; C12H; C12J; C13B10; C13B20; C13B30; C13B35; C13B40; C13B50; C13B99; C13D; C13F; C13J; C13K
19	Basic materials chemistry	A01N; A01P; C05B; C05C; C05D; C05F; C05G; C06B; C06C; C06D; C06F; C09B; C09C; C09D; C09F; C09G; C09H; C09J; C09K; C10B; C10C; C10F; C10G; C10H; C10J; C10K; C10L; C10M; C10N; C11B; C11C; C11D; C99Z
20	Materials, metallurgy	B22C; B22D; B22F; C01B; C01C; C01D; C01F; C01G; C03C; C04B; C21B; C21C; C21D; C22B; C22C; C22F
21	Surface technology, coating	B05C; B05D; B32B; C23C; C23D; C23F; C23G; C25B; C25C; C25D; C25F; C30B

No.	Fields of technology	IPC codes
22	Micro-structural and nano-technology	B81B; B81C; B82B; B82Y
23	Chemical engineering	B01B; B01D1; B01D3; B01D5; B01D7; B01D8; B01D9; B01D11; B01D12; B01D15; B01D17; B01D19; B01D21; B01D24; B01D25; B01D27; B01D29; B01D33; B01D35; B01D36; B01D37; B01D39; B01D41; B01D43; B01D57; B01D59; B01D61; B01D63; B01D65; B01D67; B01D69; B01D71; B01F; B01J; B01L; B02C; B03B; B03C; B03D; B04B; B04C; B05B; B06B; B07B; B07C; B08B; C14C; D06B; D06C; D06L; F25J; F26B; H05H
24	Environmental technology	A62C; B01D45; B01D46; B01D47; B01D49; B01D50; B01D51; B01D52; B01D53; B09B; B09C; B65F; C02F; E01F8; F01N; F23G; F23J; G01T
25	Handling	B25J; B65B; B65C; B65D; B65G; B65H; B66B; B66C; B66D; B66F; B67B; B67C; B67D
26	Machine tools	A62D; B21B; B21C; B21D; B21F; B21G; B21H; B21J; B21K; B21L; B23B; B23C; B23D; B23F; B23G; B23H; B23K; B23P; B23Q; B24B; B24C; B24D; B25B; B25C; B25D; B25F; B25G; B25H; B26B; B26D; B26F; B27B; B27C; B27D; B27F; B27G; B27H; B27J; B27K; B27L; B27M; B27N
27	Engines, pumps, turbines	F01B; F01C; F01D; F01K; F01L; F01M; F01P; F02B; F02C; F02D; F02F; F02G; F02K; F02M; F02N; F02P; F03B; F03C; F03D; F03G; F03H; F04B; F04C; F04D; F04F; F23R; F99Z; G21B; G21C; G21D; G21F; G21G; G21H; G21J; G21K
28	Textile and paper machines	A41H; A43D; A46D; B31B; B31C; B31D; B31F; B41B; B41C; B41D; B41F; B41G; B41J; B41K; B41L; B41M; B41N; C14B; D01B; D01C; D01D; D01F; D01G; D01H; D02G; D02H; D02J; D03C; D03D; D03J; D04B; D04C; D04G; D04H; D05B; D05C; D06G; D06H; D06J; D06M; D06P; D06Q; D21B; D21C; D21D; D21F; D21G; D21H; D21J; D99Z

29	Other special machines	A01B; A01C; A01D; A01F; A01G; A01J; A01K; A01L; A01M; A21B; A21C; A22B; A22C; A23N; A23P; B02B; B28B; B28C; B28D; B29B; B29C; B29D; B29K; B29L; B99Z; C03B; C08J; C12L; C13B5; C13B15; C13B25; C13B45; C13C; C13G; C13H; F41A; F41B; F41C; F41F;;F41G; F41H; F41J; F42B; F42C; F42D
30	Thermal processes and apparatus	F22B; F22D; F22G; F23B; F23C; F23D; F23H; F23K; F23L; F23M; F23N; F23Q; F24B; F24C; F24D; F24F; F24H; F24J; F25B; F25C; F27B; F27D; F28B; F28C; F28D; F28F; F28G
31	Mechanical elements	F15B; F15C; F15D; F16B; F16C; F16D; F16F; F16G; F16H; F16J; F16K; F16L; F16M; F16N; F16P;;F16S; F16T; F17B; F17C; F17D; G05G
32	Transport	B60B; B60C; B60D; B60F; B60G; B60H; B60J; B60K; B60L; B60M; B60N; B60P; B60Q; B60R; B60S; B60T; B60V; B60W; B61B; B61C; B61D; B61F; B61G; B61H; B61J; B61K; B61L; B62B; B62C; B62D; B62H; B62J; B62K; B62L; B62M; B63B; B63C; B63G; B63H; B63J; B64B; B64C; B64D; B64F; B64G
33	Furniture, games	A47B; A47C; A47D; A47F; A47G; A47H; A47J; A47K; A47L; A63B; A63C; A63D; A63F; A63G; A63H; A63J; A63K
34	Other consumer goods	A24B; A24C; A24D; A24F; A41B; A41C; A41D; A41F; A41G; A42B; A42C; A43B; A43C; A44B; A44C; A45B; A45C; A45D; A45F; A46B; A62B; A99Z; B42B; B42C; B42D; B42F; B43K; B43L; B43M; B44B; B44C; B44D; B44F; B68B; B68C; B68F; B68G; D04D; D06F; D06N; D07B; F25D; G10B; G10C; G10D; G10F; G10G; G10H
35	Civil engineering	E01B; E01C; E01D; E01F1; E01F3; E01F5; E01F7; E01F9; E01F11; E01F13; E01F15; E01H; E02B; E02C; E02D; E02F; E03B; E03C; E03D; E03F; E04B; E04C; E04D; E04F; E04G; E04H; E05B; E05C; E05D; E05F; E05G; E06B; E06C; E21B; E21C; E21D; E21F; E99Z

Summaries

Mariola Dźwigoł-Barosz: **Prerequisites for successful succession in family company according to its successor** ▪ Managerial Economics 2018, vol. 19, No. 2

JEL Classification: M12, L00

Keywords: *succession, family businesses*

The aim of this paper was to indicate prerequisites for successful succession in a family company from the successor's point of view. The author presented the methods used to assess the conditions of the succession process with the use of observations and an individual semi-structured interview. Particular emphasis was placed on the influence of being brought-up in an entrepreneurial family on the further development of the successor's professional career. Special consideration was given to finding out why a successor chose a particular area of education and what the parents' influence on was shaping his/her entrepreneurial attitudes. The author underlined the role of emotional intelligence, as the latter is a part of the successor's competencies. In this field, the author defined the competencies that are of crucial importance for the given process. The author enumerated factors affecting the succession process to the greatest extent, and the key role of the senior member in ensuring the continuity of the family company was also shown. Furthermore, the paper indicated the course of the succession process in the family business, as the former should be a comprehensive, long-term, and meticulously planned process in which (apart from the formal requirements and competencies) one should take into consideration family values, rules of the behavior and traditions of the company.

Izabela Jonek-Kowalska: **Exposure of Polish enterprises to risk within business cycle** ▪ Managerial Economics 2018, vol. 19, No. 2

JEL Classification: M21, M10, E32

Keywords: *economic risk, risk assessment, Polish enterprises, business cycle*

In economies with relatively short free-market traditions, enterprises are highly exposed to general economic risk, including fluctuations in the business cycle, which may result in the limitation of their development opportunities and discourage them from undertaking business activity. Having regard to the aforementioned circumstances, the main goal of this article is to assess the exposure of Polish enterprises to the risk related to changes in the economic situation. To achieve the goal set in such a manner, the first part of the article covers the grounds for the undertaken research along with an overview of the literature concerning the presented issues. In the second part of the article, the results of the risk assessment and the relationships of its level to the course of the business cycle in Poland during the years of 2000 to 2015 are shown. In the process of risk measurement, the statistical measures of variability and dynamics indices regarding the financial results of Polish enterprises are used. Whereas, in the course of determining the changes in the business cycle, the author makes use of the changes in the level of the Gross Domestic Product (GDP).

Łukasz Kuźmiński, Arkadiusz Halama: **Odra River in Lower Silesia: probabilistic analysis of flood risk dynamics as part of sustainable development of water management** ▪ Managerial Economics 2018, vol. 19, No. 2

JEL Classification: C02, C3, Q01, Q25, R14

Keywords: *flood risk, flow, sustainable development, water management, extreme value distributions, Gumbel distribution*

One of most common natural catastrophes in Poland are undoubtedly floods. Climatic change contributes to more and more often and violent occurrences of the maximum flow in rivers, which increases flood damage. Inadequate land management and the unjustified belief in the effectiveness of technical flood control measures can also contribute to flood damage. The development of water management (including flood protection) should be carried out in a sustainable way by integrating social, environmental, and economic objectives. In flood protection, those measures that are least invasive to the natural environment should be used first; in particular, non-technical flood protection methods (e.g., flood risk assessment and management, and the proper definition and management of flood plains). One of the bases for the sustainable development of water management is the preparation of models that can help us calculate the likelihood of maximum flow and to identify areas that are at risk of flooding. On this basis, the proper spatial policy and prevention of flood effects will be possible. This article presents the probabilistic analysis carried out on the flood risk dynamics for a selected area of the Odra River basin. The authors based their risk dynamic assessment on the results from the distributions of the maximum values for a selected hydrological characteristic – the flow rate. Based on the daily flow data from the years of 1994–2013 collected at a hydrological station on the Odra River in Malczyce, the 30-day flow maxima were set individually for four 5-year periods. Then, a probabilistic model of the maximum flow was developed based on these peaks for each 5-year period. The resulting models were used to estimate flood risks and for analyzing the dynamics for the studied area.

Małgorzata Wachowska: **Cluster as place of efficient diffusion of knowledge. Experiences of Lower Silesia** ▪ Managerial Economics 2018, vol. 19, No. 2

JEL Classification: O30, D62, D85, R10

Keywords: *knowledge flows, clusters, patent cooperation, patent citations, Poland*

Due to the fact that clusters should implement the idea of an open innovation model, the paper focuses on the role of Lower Silesian clusters in promoting knowledge flow between enterprises and other network participants, which are measured by the numbers of joint inventions and patent citations. On the basis of the analysis of national and international patent applications, it has been found that few inventions of enterprises are created in cooperation with other cluster members as well as that enterprises refer to the knowledge of other cluster members in their patent descriptions to a limited extent, which in general does not support the thesis that cluster membership contributes to the intensification of knowledge-diffusion processes.

Rafał Wisła: **Patterns of technological accumulation in European Union countries** ▪ Managerial Economics 2018, vol. 19, No. 2

JEL Classification: O33, O34

Keywords: *technological advantage, technology concordance table, ranking of technological advantages*

This paper discusses the issue of the patterns of technological accumulation in selected European Union countries. Using the WIPO Technology Concordance Table and the index of relative comparative advantage (Balassa's Revealed Comparative Advantage), it seeks to answer the question about the directions and dynamics of technological change in selected EU countries. The main objectives of the research are the identification of relative technological advantages in individual countries and an assessment of the diversification of comparative technological advantages. The principal findings of the analysis are (1) technological advantages (and competences) are relatively stable over time, and (2) technology leaders rarely change.

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