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TENDENCIES IN RESEARCH ON INNOVATION IN LOW-TECHNOLOGY SECTORS

The aim of the article is to identify and analyse the main tendencies in and subject matter of research on innovation in low-technology sectors. The data analysed come from the Scopus database covering 1977–2015. The author concentrates on the dynamics of the numbers of such research articles, the major academic fields applied in this research, together with the industrial sectors, countries and topics studied. With respect to temporal dynamics, it is clear that the overall trend is growth, with more and more articles being published on innovation in low-tech sectors. These studies are concentrated mainly within four academic areas: business, management and accounting; economics, econometrics and finance; social sciences; engineering. As far as industrial sectors are concerned, the food industry is the most common subject of interest. The United States and Great Britain can be clearly identified as the countries most often studied. The main topics discussed concern technical issues related to new products, interactions between industry and research centres, together with aspects of innovation by managers and enterprises.

Keywords: *innovations, low-tech sectors, research tendencies*

1. Introduction

Innovations in various industrial sectors are often discussed in research. Exploring the Scopus database for research on innovations in high-tech and low-tech sectors, a research gap has been identified in the latter. According to Scopus [„high-tech”] or [“high-technology”] and [innovation]; [low-tech] or [“low-technology”] and [innovation]) the initial periods of research on innovations in low-tech and high-tech enterprises show a similar pattern, with often only one article being published in a year, and many years

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in which there were no such publications. Research on innovations in high-tech industries began to appear first, the first article recorded by Scopus comes from 1969, while innovation in low-tech sectors appears in 1977, 8 years later. In the following years, the evolution in both streams is similar. The numbers of articles published in particular years are similar (low), although the number of articles on low-tech sectors shows a clear lag in comparison to the number of those on high-tech sectors. For example, the number of articles published on innovation in high-tech sectors reached 10 articles per year in 1982, whereas in the case of low-tech sectors, such a number was achieved 20 years later, in 2002. In addition to this time lag, one significant difference is that, as early as 2006, the number of articles on innovations in high-tech sectors reached more than 100 and 2 years later, in 2008, more than 200 and these figures are constantly growing. On the other hand, in the case of articles about innovations in low-tech sectors, there have never been more than 31. This underrepresentation of research on innovations in low-tech sectors led to formulating the aim of this analysis: to identify and analyse the main tendencies and subject matter in research on innovation in low-technology sectors; together with further exploration and more detailed analysis of this area. A set of five research questions has been formulated:

- RQ1. How has the dynamics of innovations in low-tech sectors been developing over the years?
- RQ2. What academic disciplines are the most common in research on innovations in low-tech sectors?
- RQ3. Which industrial sectors appear most often in research on innovations in low-tech sectors?
- RQ4. Which countries are most often the subject of research on innovations in low-tech sectors?
- RQ5. What aspects of innovations in low-tech sectors receive the greatest attention from the academic and research community?

2. Research procedure

It is appropriate to use bibliometric analyses to answer these research questions (the main advantages and disadvantages of bibliometric analyses are presented in Table 1). Bibliometrics, introduced by Pritchard, is a collection of research techniques that can be used for analysing publications [17, 22]. Klincewicz divides bibliometrics into evaluative (for the evaluation of research centres or researchers) and descriptive (for analysing trends in research, the identification of relevant researchers or research centres) [16]. The following analysis will use a descriptive approach. Bibliographic data concerning

publications are the primary type of data used in bibliometric analysis: these data include abstracts and information on the authors, research centres, sources, etc. These data are aggregated in global bibliographic databases [20].

Table 1. Basic advantages and disadvantages of bibliometric analyses

Advantages	Disadvantages
The analyses are based on quantitative and reliable data which are not easy to falsify or distort	Omission of some relevant elements, e.g., relevant Polish-language publications are not recorded in English-language bibliometric databases
Bibliometric analyses are based on measurable results in the form of articles published in different contexts. Such analyses are therefore based on a stable foundation rather than on difficult to verify opinions of expert groups	Underrepresentation of, e.g., academic monographs published by reputable national and foreign publishing houses
Bibliometric analyses are carried out on a wide range of global data sets, the research material is rich and at the same time objectivised	Dominance of the English language and thus research publications in other languages are underrepresented (non-English speaking researchers usually publish more often in their own languages)

Source: [32] based on [16, 18, 20].

The analysis of the state of research on innovations in low-tech sectors by means of bibliometric methods is based on the following steps:

• Identification of the sources of data. Relevant bibliometric data are provided by global bibliographic databases, the broadest of which are Web of Science and Scopus (covering all scientific disciplines). These bases cover the fields of science, social sciences, humanities, medicine and art. Data are aggregated from other databases that are already strictly profiled or just have regional coverage.

• Determining the basic data set for study. Searches were carried out in both databases using a combination of words [low], [tech], [technology], the hyphen [-] and quotation marks [“”] to form a very broad search field. Based on these searches, it was determined that the largest and least contaminated collection was given by Scopus (using the search box: Article title, Abstract, Keywords, logical expression: [low-tech] or [“low-technology”] and [innovation]). This resulted in a maximal collection of 362 records in terms of quantity and cleanliness, which was then subjected to further cleaning.

• Cleaning the basic data set. Non-academic documents were eliminated (e.g., reviews, press articles, notes, editorial notes) together with those types of document that are underrepresented in the database (e.g., books, chapters in books). The remaining research articles (including conference articles) formed a collection of 310 articles. The range of publication dates was also limited. In scientific databases, records for the most recent years are supplemented over a significant period and the number of articles in these years keeps changing. Although these records include the latest academic research,

rational evaluation requires them to be excluded from the analysis, since they are incomplete and possibly affect the result of the overall analysis. They are not representative of a given year and cannot be reliably compared with previous ones. Therefore, the year 2016 was excluded from the dataset and the range of the remaining publication dates covers the period from 1977 (when the first article appeared in Scopus) to 2015 (the most recent year that contains stable data, i.e. data which do not change significantly over time). The data collected in this way are composed of 292 articles.

3. Analysis of dynamics in time

When analysing the data set within the scope of RQ1, it turned out that the overall trend is growth, but not rapid growth. The size of the data set for the 39-year period analysed is small, and as a consequence, the number of years in which such publications appeared is not large either. The largest upward trend has been seen in the last decade. Since 2007, there have never been fewer than 10 articles per year, while more than 20 articles have been recorded in every year since 2009. This trend seems to be stable and the largest number of such articles appeared in the final year, 2015, when 31 articles were recorded.

On the other hand, there are many years in the period studied when no such articles appeared. There are 10 such years within the span of 39 years, which constitutes 25.64% of the entire period. This is a very high percentage. In addition, there are 11 years with very few articles of this kind (1–3 articles per year), which accounts for 28.21% of the total period. Hence, in more than half of the years of the study period (22 years – 56.41%) at most 3 articles of this kind were published.

It appears that innovations in low-tech sectors have not attracted much interest as a research topic. Until 2007, the dynamics of growth in the numbers of publications was very slow and interrupted by periods in which no such articles appeared. However, in the last decade, this situation has changed and a continuous upward trend can been observed. A negative growth rate was only observed in two years (2010 and 2013). These rates were –4,17% and –3,70%, respectively. In absolute terms, in both cases these changes correspond to 1 article less than in the previous year. The average absolute annual growth rate since 2007 is 2.5 articles, while the average relative growth rate is 18.77% per annum. This period of the fastest growth in research on innovations in the low-tech sectors (2007–2015) has resulted in 211 articles, which constitute 72.26% of all the articles in the period analysed. It can be clearly stated that, quantitatively, this has been the most significant period in the development of an area of exploratory research, and there is no indication that this positive trend has changed or slowed down. The temporal dynamics of research on innovations in low-tech sectors is presented in Fig. 1.

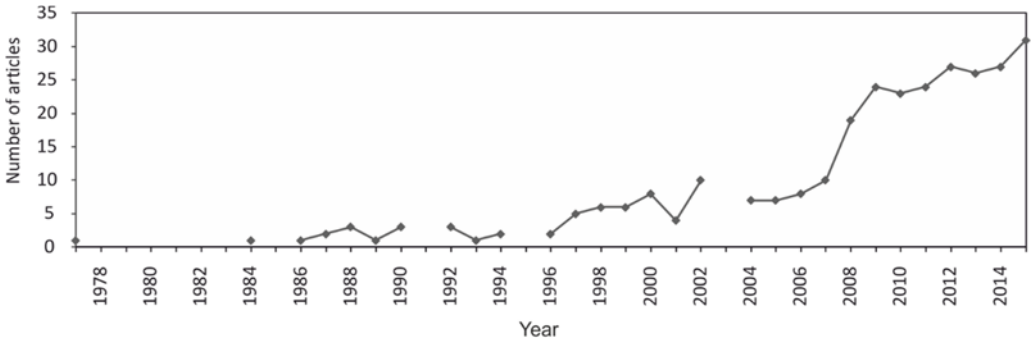

Fig. 1. Dynamics of the number of research articles on innovations in low-tech sectors in the years 1977–2015 according to data from Scopus

It can be seen that growth in the amount of research on the examined area is slow. This is probably due to the specifics of low-tech sectors, which are largely traditional and the frequency of innovations that raise the interest of researchers is low. In spite of its slowness, the upward trend is evident and seems to be stable. By no means is there stagnation or a decrease in research interest in innovations in low-tech sectors.

4. Analysis of disciplines

When looking for an answer to RQ2, it turns out that according to the taxonomy of academic areas built into the Scopus database, the articles were classified in 24 different areas of which 4 academic areas proved to be dominant.

Table 2. Research on innovations in low-tech sectors in various fields of academia in the years 1977–2015 according to the Scopus database

No.	Field	No. of articles	Percentage
1	Business, management and accounting	129	44.18
2	Economics, econometrics and finance	78	26.71
3	Social sciences	62	21.23
4	Engineering	54	18.49
5	Medicine	27	9.25
6	Computer science	23	7.88
7	Decision theory	19	6.51
8	Agricultural and biological sciences	15	5.14
9	Environmental sciences	15	5.14
10	Materials science	8	2.74

In the discipline taxonomy built into the Scopus database, one article can be classified into several areas, 100% in the Percentage column is based on the number of articles in the dataset: 292. These percentages sum to more than 100% due to single articles being ascribed to more than one field of academia.

These areas include business, management and accounting; economics, econometrics and finance; social studies and engineering (see Table 2). No other area obtained a two-digit result for the percentage of observations in the dataset. It turns out that innovations in the low-tech sectors are of most interest to researchers in management, business and economics, as well as in social sciences, understood in a broad sense. The relatively low position of engineering (considering that this is research on innovation) can probably be explained by the nature of traditional sectors, which have limited potential for technical development. This means that there is little scope for research on such a subject to be published in reputable scientific journals from the point of view of engineering.

5. Analysis of industrial sectors

The following classification of economic activities and industrial sectors considered to be low-tech [8, 14], was taken into account in the search for an answer to RQ3:

- food,
- beverages,
- tobacco,
- textiles,
- clothing,
- leather products,
- wood products (cork, straw, plating),
- paper products,
- printing,
- furniture.

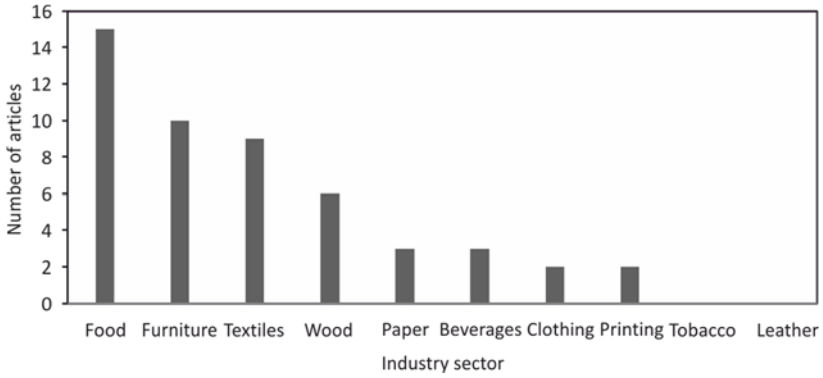

Fig. 2. Number of articles ascribed to each low-tech sector

The articles from the analysed dataset were assigned to the appropriate industrial sector using a specially constructed thesaurus that identified an article as corresponding to a particular sector. This thesaurus filtered words and phrases from abstracts, titles and keywords from the entire analysed collection, totalling 10 021 different expressions. Such research most commonly relates to the food sector, followed by furniture and textiles. On the other hand, there is no research on the tobacco or leather sectors in the context of innovation. The wood, paper, beverage, clothing and printing sectors are also weakly represented. The summary presented in Fig. 2 shows only the interest of researchers in innovation within specific industrial sectors, indicating which of the low-tech sectors appear most often in research, but unfortunately this cannot be used as a basis for determining which one of these sectors is most innovative. The amount of research published on a sector (high or low) does not prejudge the degree of innovation of a sector but may vary due to, for example, the difficulty of obtaining data and information, or due to the policy for protecting intellectual property applied by industrial organizations. It is also worth noting that all 3 articles attributed to the beverage sector were also attributed to the food sector, reflecting the fact that these two sectors are often linked food and beverages.

6. Regional analysis

When analysing the dataset in order to answer RQ4, it turned out that in the entire dataset 51 countries were recorded. Taking into account two measures: of quantity (the number of articles) and quality/level of interest (number of citations), the countries considered were those appearing in the top ten of either of the rankings based on these two measures, which gave a total of 11 countries. It turned out that, in this case, quantity and quality go hand in hand, since these two classifications overlap to very high degree. There were only two exceptions. China was classified in the top 5 according to the number of articles, but in terms of the number of citations dropped to the low position of 24th. This means that, despite the hard work of Chinese researchers, they failed to publish high quality research that gains the attention of the academic/research community. On the contrary, the opposite was recorded for Austria, which was the subject of only 3 articles, but these articles gained a lot of attention from the academic and research community obtaining a total of 228 citations, which gave Austria 9th place in the classification based on citations.

The United States and Great Britain, the two countries ranked 1st and 2nd in both classifications, published very good, well-received research. Good positions (in the top 10 in each of the two classifications) were also achieved by the Netherlands, Italy, Spain

and Germany. One might also be surprised by the result of Brazil, the subject of 9 articles, which gave it 10th place in the classification based on the number of articles, but the number of citations of these papers is virtually the same as the number of citations of the 40 articles from the United Kingdom. A detailed overview of the most important countries in terms of quantity of publications and number of citations is presented in Table 3 and the positions in the two classifications (based on the number of articles and the aggregate citation index) is presented in Fig. 3.

Table 3. Countries with the largest number of published articles and citations

No.	Country	No. of articles	Total number of citations	No. of citations per article
1	USA	59	804	13.63
2	Great Britain	40	587	14.68
3	Spain	30	296	9.87
4	Italy	20	246	12.30
5	China	19	25	1.32
6	The Netherlands	16	348	21.75
7	Canada	14	292	20.86
8	Denmark	13	171	13.15
9	Germany	11	575	52.27
10	Brazil	9	578	64.22
11	Austria	3	228	76.00

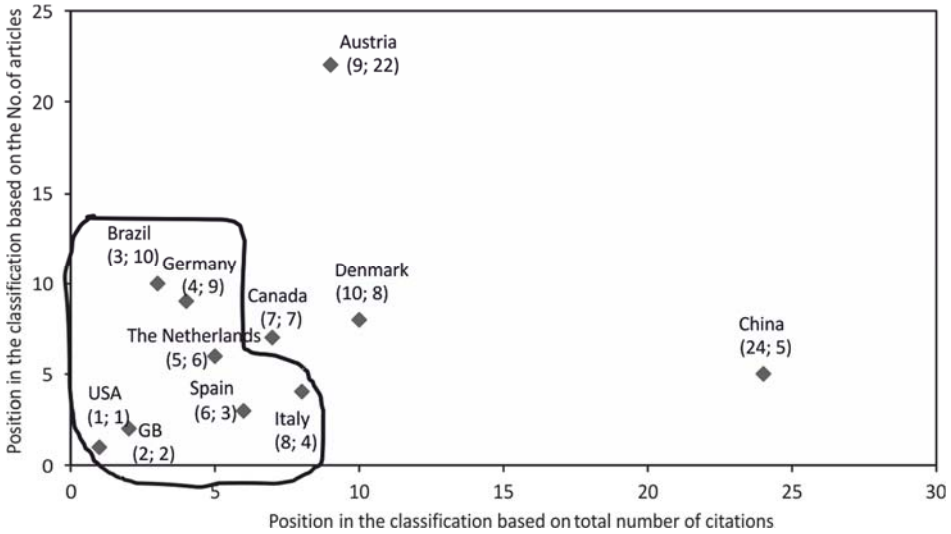

Fig. 3. Positions of the highest ranked countries in the two rankings considered

7. Analysis of research topics

When analysing the research material in order to answer RQ5, it is worth focusing on the number of citations. More than 42% of these articles (123 articles in total) were cited at most once. Those that have been cited from 50 to 99 times can be described as high impact articles. 16 such articles were found in the dataset (slightly over 5%), while 8 articles were cited at least 100 times (very high impact). This represents less than 3% of the analysed dataset. These articles have received considerable attention from the academic and research community engaged in innovation in the low-tech sector.

It is also important to look at the temporal distribution of the highest impact articles (at least 100 citations, Table 4) and high impact articles (from 50 to 99 citations – Table 5). It is noticeable that in both groups the most frequently cited papers are all relatively recent.

Table 4. Summary of the most significant research on innovations in the low-tech sector

No.	Author(s), year of publication	No. of citations	Thematic scope / comments
1	Pandey, Soccol, Michell, 2000	546	Biotechnology, fermentation processes. The research is of a technical and specialized character. Low importance for innovation management. Innovation in the low-tech sectors is only in the background and is not a subject of research.
2	Herstatt, von Hippel, 1992	284	Applying the "lead user" approach to developing new products using a low-tech case study. The study is relatively old, from the last century.
3	Schartinger, Rammer, Fischer, Fröhlich, 2002	207	Knowledge generation and sharing between industry and public research centres in Austria in the 1990s.
4	Balkin, Markman, Gomez-Mejla, 2000	198	Innovative actions of managers and the level of their salaries. The research was mainly about high-tech companies, low-tech companies formed the control sample.
5	Thornhill, 2006	192	The prevalence of innovations, their nature, impact on the performance of Canadian companies in low and high-tech sectors.
6	Ettilie, Pavlou, 2006	113	Model for developing and commercializing new products in low and high-tech automotive industry companies.
7	Bolton, Saxena-Iyer, 2009	103	Interactive services in low and high-tech companies.
8	Kirner, Kinkel, Jaeger, 2009	100	Paths and results of innovation in German low and high-tech companies.

Based on [1, 5, 7, 12, 15, 21, 26, 31].

Table 5. Summary of high impact research on innovation in low-tech sectors

No.	Authors, year of publication	No. of citations	Thematic scope / comments
1	Tether, Tajar, 2008	98	Typology of models of innovation: product – research, process – technology, organizational cooperation. European studies.
2	Blanes, Busom, 2004	93	Effectiveness of public aid to R&D in companies from low and high-tech sectors. Spanish studies.
3	Rubera, Kirca, 2012	84	The impact of innovation on performance in companies in low and high-tech sectors.
4	Grimpe, Sofka, 2009	79	Ways of searching for and gaining knowledge in companies from low and high-tech sectors. European studies.
5	Bhattacharya, Bloch, 2004	78	Conditions for innovation in enterprises in low and high-tech sectors. Australian studies.
6	Stam, Wennberg, 2009	75	Impact of R&D on the development of new products in start-ups from low-tech sectors. Dutch research.
7	Heidenreich, 2009	71	Determinants of innovation in companies from low-tech sectors, location issues. European studies.
8	Link, 1978	71	Research on the determinants of success or failure of the commercialization of new products by companies in low and high-tech sectors. Research from the 1980s, relatively old.
9	Redding, 1999	70	Issues related to the specialization of developing countries in specific industrial sectors, both low and high tech. Research from the last century.
10	Shapiro-Ilan, Gaugler, 2002	69	Technology of the production of insecticidal nematodes. Research in the field of biotechnology and microbiology. The context for innovation in low-tech sectors lies only in the fact that in this case in-vivo production methods are classified as low-tech.
11	Hirch-Kreinsen, 2008	65	Like all of Hirch-Kreinsen's research, this also focuses on innovation in low-tech sectors. The author emphasizes their importance for employment and development.
12	Raymond, Mohnen, Palm, van der Loeff, 2010	64	Maintaining the effects of innovations within companies in low and high-tech sectors. Dutch research.
13	Costantini, Crespi, 2008	63	Testing the Porter–van der Linde hypothesis. This has no connection with the management of innovation in low-tech sectors. Low technology is only used as a background for verifying a hypothesis.
14	Guiso, 1998	62	Research on loans in high-tech companies in Italy, they were just a background issue and issues regarding credit in such companies were not analysed in detail. Research from the last century.
15	Battista, 1989	58	Innovation and diffusion of innovation in health-related technologies. The research deals with both high and low-tech solutions. The study is relatively old, from the eighties of the last century.
16	Sundbo, 1996	56	Research on the empowerment of employees in innovative processes within service enterprises and low-tech sectors. Danish study. Research from the last century.

Based on [2–4, 6, 9–11, 13, 19, 23–25, 27–30].

Only one article from before 2000 is included in the group of most cited articles (above 100 citations). Considering high impact research (50–99 citations), it is important to note that the majority of them were published in the first decade of the 21st Century (10 out of 16 articles). It turns out that the high impact research in this field is relatively new.

If one considers more closely the articles from the group of most cited papers, the one with the highest number of citations refers primarily to technical content in the field of chemistry, in particular solid state fermentation (SSF) in bioprocesses. The authors point out that traditional SSF processes are considered low-tech but, on the other hand, they have the potential to be used in high level technologies such as the production of biopharmaceuticals, enzymes, organic acids, biopeptides and biofuels [21].

Herstatt and von Hippel's research is a classic case study showing the use of the Lead user method in the development of new products in low-tech manufacturing, based on the example of the tube hinges produced at Hilti AG. Use of this method implies the shared commitment of lead users (i.e., users who have certain needs that are not currently met by the market and expect significant benefits from obtaining solutions to meet these needs) and production staff to develop new products or services. One of the authors (Herstatt) applied this method during a three-day workshop at Hilti and found that implementation of such innovation was cheaper and almost twice as fast as using other methods [12].

In turn, Schartinger, Rammer, Fischer and Fröhlich focused on the study of knowledge sharing between industry and public research centres in Austria in the 1990s (research was based on representative data). The authors identified 9 different types of knowledge sharing, analysed 46 fields of academia and 49 economic sectors. Knowledge sharing created complicated structures, not limited to a specific field of knowledge or industry, but covering different sectors and disciplines of knowledge. Such cooperation is based on innovation. It also turned out that there is no simple correlation such that the level of interaction is high between high-tech sectors and technical universities and low between low-tech sectors and the humanities. In addition, collaboration takes place in many different fields, and knowledge sharing runs through different channels, not just the citation of articles on the academic side and financial flows on the industrial side [26].

The analysis by Balkin, Markman and Gomez-Mejla dealt with the relationship between the innovative actions of company managers and the level of their salaries. The authors focused mainly on high-tech companies but the control sample was composed of 74 low-tech companies. Researchers have assumed that in such companies innovations are not as crucial to success as in high-tech companies. As a result of the analysis of the companies from the control sample, it was found that managers' innovativeness was not associated with their level of remuneration, neither were their salaries related to the results of the company [1].

Thornhill also focused on a comparison between high-tech and low-tech companies, but from another perspective. He based his analysis on a sample of 845 Canadian industrial enterprises and his main conclusion was that innovations are more common in industrial sectors that are developing dynamically. In dynamic high-tech sectors, innovations are implemented by companies more than twice as frequently as in the case of low-tech sectors. However, it was also found that innovations have a positive impact on a company's financial results, regardless of the technological level of the sector in which a company operates. As far as low-tech companies are concerned, one more observation was noted – that innovations have the greatest impact on revenue when investments are made in high quality training. This study also showed that innovations in low-tech sectors do not need to be of a very high level of novelty to be successful on the market, contrary to dynamic high-tech sectors [31].

Ettilie and Pavlou proposed a model for the development of new products. The analyses were carried out for 72 automotive companies and concerned, among other things, the technological level: defined as high or low. It turned out that the dynamism in high-tech sectors may be an obstacle, due to constant changes in knowledge and a market's environment. High-tech companies are more likely to develop new products, but commercialization is easier in low-tech sectors, because of their greater stability and lower level of risk [7].

On the other hand, Bolton, and Saxena-Iyer researched interactive services (customer-company interactions) in both high and low tech companies. This is an unconventional approach, because it does not restrict interactive services to only high-tech companies. The analyses are based on a two-dimensional model: the degree of customer participation and technology level. The authors take into account such services as traditional trade or traditional banking, which are based on a low level of technology, but are also classified as interactive services [5].

Kirner, Kinkel, and Jaeger focused on an analysis of the paths and results of innovation in 1663 German low-tech companies compared to medium and high-tech enterprises. The authors show that high-tech companies are also active in low-tech sectors, and vice versa. It was found that low-tech companies do poorly in terms of results related to product and service innovation. However, the results of process innovation (productivity and the speed of processes) are not significantly associated with the level of technology, and sometimes are even better (in terms of quality control – fewer defects and repairs) in low-tech companies [15].

8. Conclusions

At the end of this analysis, it is worth mentioning the emerging tendencies in the analysed dataset according to the set of research questions formulated in the introduction:

• There is an upward trend over time in the amount of research on innovations in the low-tech sectors. The year-to-year increase in the number of articles is not large, but there is no basis to claim that this positive (but slow) trend will change.

• Research on innovations in low-tech sectors is concentrated mainly around four academic disciplines: business, management and accounting, economics, econometrics and finance, social sciences, engineering.

• Such research is mostly concentrated around the food, furniture and textile industries.

• The leading countries in the field of research on innovations in low-tech sectors are the United States and Great Britain. The Netherlands, Italy, Spain, Germany and Brazil should also be noted.

• The most significant research concerns, inter alia, such issues as technical research in biotechnology and microbiology; implementation of the lead user approach in developing new products, interaction between industry and research centres, managers' innovativeness and their remuneration, innovativeness of enterprises in the context of their results, the development and commercialization of new products, as well as interactive services. The most cited articles are, among other things, focused on issues such as typologies of models of innovations, the effectiveness of public aid in the context of R&D, innovations and the results of enterprises, sources of knowledge, the development of new products in start-ups from the perspective of R&D, successful and unsuccessful implementation of new products, maintaining the effects of innovations.

In further research, the analysis carried out here should be deepened. It seems reasonable to conduct comparative analysis of innovativeness in low-tech and high-tech sectors and to focus on selected industrial sectors. Although this article did not consider political issues, it seems reasonable to confront the results of analysis with policies in the field of, e.g., R&D in various countries or regions. Unfortunately, the analyses carried out in this field do not give a basis for the formulation of a set of specific recommendations in this regard.

In order to properly understand these analyses, it is necessary to identify the following important limitations:

• The analyses were conducted on a set of articles collected from the Scopus database on 11.10.2016.

• They were conducted by searching for a specific phrase using the relevant search box.

• The articles covered the period from 1977 to 2015.

• The analyses concerned academic articles (including conference articles).

Therefore, analyses carried out on other datasets, taken from other databases, covering other time periods, on data found using other phrases, using other search boxes, analyses covering other types of documents, carried out using different conditions for

including and excluding datasets and analyses defined by other sets of research questions may yield different results and lead to different interpretations.

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