PharmaNutrition 4 (2016) 29–37

Contents lists available at ScienceDirect

PharmaNutrition

journal homepage: www.elsevier.com/locate/phanu

Crossing industrial boundaries at the pharma-nutrition interface in probiotics: A life cycle perspective

Sabine Bornkessel[a,*], Stefanie Bröring[b], S.W.F. (Onno) Omta[c]

[a] University of Applied Sciences, Oldenburger Landstr. 62, 49090 Osnabrück, Germany
[b] University of Bonn, Meckenheimer Allee 174, 53115 Bonn, Germany
[c] Wageningen University, P.O. Box 8130, 6700 EW, Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 20 October 2015
Received in revised form 21 October 2015
Accepted 21 October 2015
Available online 1 December 2015

Keywords:
Converging industries
Cross-industry innovation
Life cycle concept
Functional ingredient
Probiotics

ABSTRACT

The aim of this paper is to advance the research on innovation at the pharma-nutrition interface by analysing the three steps of science, technology and market convergence in the area of probiotics using a life cycle perspective. Results from a bibliometric analysis drawing upon 8245 scientific publications, 2082 patents and 1357 news reports focussing on product launch announcements from 1990 up to 2009 indicate that the proposed curve shapes of the life cycles in the theory based framework can be transferred to the case of probiotics. There is a time shift considering the life cycles showing the same activities of the industrial sectors at different moments of time. The food sector dominates the field of probiotics by driving science, technology and market convergence showing earlier activities in scientific publications, patents as well as product launches, while presenting a higher clockspeed between the different life cycle phases. While the food sector dominates product launches for food products containing probiotics, the pharmaceutical sector dominates the product launches of the supplement market. In addition, a clear trend towards industry convergence can be identified by the growing number of cross-industry activities.

1. Introduction

For almost 40 years, the idea of converging industries has fascinated researchers and practitioners alike. First studies can be observed in the late 1970s with the initial identification of convergence in the area of the computing and telecommunication systems [1]. Subsequently, with the growing interest in this research field numerous studies exist which focus on the overlapping segments triggering the emergence of a new industry field of information and communication technology (ICT) [e.g. 2–5]. Another but less well understood example of convergence is the nutraceuticals and functional food sector which emerges at the interface between the food and the pharmaceutical industry [6]. This industry segment comprises products delivering nutritional as well as health value. The converging segments of food and pharma are characterised by cross-industry activities [7] resulting in rapid market changes.

These rapid market changes in converging industries can be analysed by means of life cycle concepts [e.g. 8,9] as in general life cycles are defined as *"a progression through a series of differing stages of development"* [10]. Considering the distinct concepts of life cycles, these focus on various objects like products, technologies, organisations or industries [8]. Although there are some attempts to relate specific concepts like the patent life cycle [11] to converging industries [12,13], the literature on applying life cycle concepts to measure convergence processes is rather scarce in general and, yet, has not seen a wide application on the setting of pharma-nutrition convergence. Furthermore, the literature regarding the evaluation of converging industries addresses mainly the front end of the process including science and technology convergence. These studies focus on the anticipation of convergence processes convergence [see for instance 14]. Hence, literature regarding the assessment of market convergence is rather limited, particularly in the emerging area at the borderline of foods and drugs.

Related to this particular case, a growing number of different functional ingredients has become available on the food market especially within the last decade [15]. Accordingly, the food ingredient category of *probiotics* presents a rather young group beside the more classical functional ingredients like vitamins and minerals. Food products containing probiotics are of a high relevance for the rapidly changing food market and the related

* Corresponding author.
E-mail addresses: s.bornkessel@hs-osnabrueck.de (S. Bornkessel), s.broering@ilr.uni-bonn.de (S. Bröring), onno.omta@wur.nl (S.W.F. (Onno) Omta).

http://dx.doi.org/10.1016/j.phanu.2015.10.002
2213-4344/

innovations [16]. From a market perspective, dairy products enriched with probiotics are one of the most successful functional foods on the market, especially looking at the rise of the new category of daily-dose drinks in small bottles [17]. Probiotics are defined as *"live microorganisms, as they are consumed in adequate numbers confer[ring] a health benefit on the host"* [18]. Probiotics belong to a group of functional ingredients that may improve gut health and boost the immune system [19].

In this context, the overall aim of the paper is to analyse cross-industry activities in convergence at the interface of the food and pharmaceutical sector using the example of probiotics. In doing so, the first three steps of science, technology and market convergence are analysed from a life cycle perspective—especially including the evaluation of market convergence as the consecutive step following science and technology convergence. Based on bibliometric data sets including scientific publications, patents as well as news reports, life cycle indicators are applied to the process of industry convergence. As the existent literature on the application of the life cycle concept to convergence processes encompassing cross-industry activities is rather scarce, we follow an exploratory approach leading to a research framework to assess science, technology as well as market convergence.

2.The life cycle concept in convergence processes

2.1. Cross-industry activities in convergence processes

Industry convergence has been presented in the extant literature by using various definitions. These definitions share the common idea, which is summarised by the Organisation for Economic Co-operation and Development (OECD) as follows *"the blurring of technical and regulatory boundaries between sectors of the economy"* [20]. This implies that formerly distinct industrial areas start to produce similar products in an emerging field of new approaches like for example, the telecom industry and camera technology sector developing the new segment of camera phones [21] or the segment of nutraceuticals on the interface of the pharmaceutical and food sector leading to borderline products like probiotic yoghurts [22].

Moreover, dimensions of industry convergence are discussed as a process rather than a steady state [e.g.,12,14,21,22]. One approach is the description of the consecutive steps: science, technology, market and industry as an idealised time series of events leading to a complete convergence of two hitherto distinct industrial sectors. The initial step implies that distinct scientific disciplines begin to cite each other in interaction with first collaborations of scientific disciplines. The decreasing distance between applied sciences and technology development is defined as the second step. The subsequently new product-market combinations indicate market convergence. The final step of industry convergence incorporates fusion of firms or industry segments [14,21]. Thereby, with an increasing level of diversification during convergence processes companies perform best when they are more integrated in different knowledge resources [23] which could be resembled by cross-industry activities of companies from distinct industrial backgrounds.

As convergence processes are based on the activity of different industrial sectors, cross-industry activities occur during this merging process [7]. Cross-industry innovation is based on knowledge, technologies, and partners with a high cognitive distance which remains a current research field on innovation management [24], as the resulting radical innovations are of a high relevance for companies [25]. The need for the different competences of the different industrial sectors might lead to competence gaps of the involved firms [26]. Furthermore, the stretch of resources to serve the adjacent industry, resp. emerging inter-industry segment might result in competence gaps [26] since innovation barriers are industry-specific [27]. Companies' strategic actions to close the arisen competence gaps encompass the internalisation of external assets for instance through the acquisition of companies or strategic alliances [28,29]. Thus, the competence base of hitherto distinct industry sectors starts to become alike.

The research setting of this study of probiotics belongs to the functional food sector, as a new inter-industry segment between the food and pharmaceutical sector. The research and development investments of the European food industry is much lower than in other sectors [30] as for example in the pharmaceutical sector. The pharmaceutical sector is characterised as a research-intensive sector [31]. This leads to strong competences in research and development for the pharmaceutical sector whereas the food sector is more consumer market-oriented [22]. In other words, the core competences of one sector will appear as competence gaps of the other sector while the research and market areas of these two sectors converge. Although external collaborations along the value chain seems to be underdeveloped in the food sector [32], collaborations in the emerging area of functional foods will become increasingly important due to the growing market interest.

The subsequent theoretical perspective to analyse cross-industry activities in convergence processes is based on the life cycle concept, which originated in biology and is adapted in marketing research [9,33]. The steps are commonly defined as introduction, growth, maturity and decline [8,9]. One possibility to categorise the different approaches is the framework delivered by Höft [for a detailed description see 8]. This categorisation is based on the different objects of life cycles: products, technologies, organisations and industries. Thereby, the technology life cycle respectively the industry life cycle are both concepts, which aggregate the underlying life cycles of products respectively organisations on a higher abstraction level [8,34]. Furthermore, specialised concepts focussing on one certain area of life cycle concepts are described in literature. For instance, the patent life cycle introduced by Ernst based on the s-curve concepts of technologies is one approach to measure the life cycles of technologies [11]. As a further example, the product generation life cycle extends the product life cycle perspective incorporating the sum of the product life cycles of the associated products which are connected to one product generation [35,36].

In literature, technology life cycles are often combined with an analysis of patent data leading to a patent life cycle [11,37]. The patent life cycle can be divided into the three phases of *emergence* showing a slight increase in the amount of patent applications, followed by a *consolidation* phase leading to a high increase in patent applications during the *market penetration* of a technology [11]. In derogation from the traditional life cycle concept, the patent life cycle considers a consolidation phase between the emergence (introduction) and market penetration (growth). This consolidation phase describes the reorientation of research efforts based on first market experiences of the new technology [11].

Patent analyses are used for the depiction of technology life cycles [37] as well as for the description of ongoing processes in the context of converging industries, especially to scrutinise technology convergence [see for instance,38–40]. Therefore, the usage of patent data as a measurement tool for technology life cycles, which in turn are used to describe converging industries, presents a current research field [41]. Especially for industrial sectors arisen at the interface of pharma and nutrition like the medical nutrition sector, the consideration of patent data is of importance due to the protection of intellectual property [42]. In addition, (industry) life cycle concepts hardly consider the dynamics of relationships between actors from different industries [43]. However, these

cross-industry relationships are of great importance in the context of ongoing convergence processes as they could be used to close the arisen competence gaps.

The life cycle concept might be one approach to reflect the rapid market changes in the emerging sector at the pharma-nutrition interface, thus an ongoing convergence process which leads to cross-industry activities. Against this backdrop, the first research question is:

RQ1 To what extent can cross-industry activities at the pharma-nutrition interface be depicted in life cycles?

2.2. Life cycle patterns in convergence processes

As described above, the idealized time series of convergence events encompass the four steps of science, technology, market and industry convergence [see for instance,14]. The technology life cycle indicators introduced by Watts and Porter may be used to operationalise the measurement of convergence processes in general based on the technology life cycle approach [44,45]. Relating the idealized time series of convergence events to these life cycle indicators, firstly, the step of science convergence corresponds to the fundamental research measured by scientific publications. Secondly, the level of technology in convergence processes resembles the life cycle indicator of applied research and development measured by patent data. Thirdly, the market convergence where new product-market combinations arise is equivalent to the application in life cycle indicators, which can be reflected by news reports on product launches.

Relating the two described concepts of life cycle indicators and the patent life cycle, the idealized curve shape of the patent life cycle might be extended to the application of the other life cycle indicators. That means scientific publications are used to measure science convergence and news reports on product launches to measure market convergence while identifying the occurrence of new product—market combinations drawn from different industrial backgrounds.

In summary, the convergence process might be assessed employing life cycles applied to each convergence level (scientific publications for science convergence, patents for technology convergence and reported product launches for market convergence). The curve shapes might appear in form of the patent life cycle. Thereby, a time lag is postulated between the occurrence of scientific publications and patents according to the described consecutive steps of convergence processes [see for instance 12]. Furthermore, following the time series of events another time lag between technology and market convergence might be postulated (Ref. Fig. 1).

Furthermore, relating this concept to the convergence process, we strive to consider the different industrial sectors involved as well as their cross-industry activities. Therefore, these idealized curves can be shown for each publication type separated for the distinct industrial sectors as well as for the cross-industry activities resembled by the joint activity of different industrial backgrounds. The curve shapes of the diverse industrial backgrounds might have maxima at different moments in time. These different curves might not occur simultaneously. Cross-industry activities might result from the earlier activities of distinct industrial backgrounds. Therefore, the occurrence of the cross-industry activities may take place at a later stage. In addition, the speed in development might differ between the different industrial sectors due to the distance to the emerging field and therefore the difficulties of closing the arisen competence gaps. Moreover, the clockspeed of an industry is commonly defined as the speed of the product life cycle which differs between industrial sectors [46,47] and is driven by the new product development [47]. While the general concept states a difference between the clockspeed of industrial sectors due to the length of the product life cycles [46,48], the clockspeed of convergence can be measured by length of the time lags between science, technological and market life cycle as the inception of the next phase in convergence is reached when the next life cycle starts. The question arises how the involved industrial sectors differ in their clockspeed within the science, technology and market convergence. Based on the discussion about difference in curve shapes, thus life cycle patterns, this leads to the second research question:

RQ2 What life cycle patterns can be identified in the convergence processes at the pharma-nutrition interface?

2.3. Research framework

Against this theoretical background, the study at hand aims to analyse life cycle patterns in the research setting of pharma-nutrition. Accordingly, the evaluation of the first three steps in the idealized time series of convergence events is based on the assessment framework of life cycle indicators identifying differences in life cycle patterns of scientific publications, patents and reported product launches. Furthermore, we distinguish between the convergence process of the involved industrial sectors while showing the science, technology and market life cycle for each involved sector as well as for cross-industry activities. In addition, the reported product launches are scrutinized considering the market outlet of the launched products (Ref. Fig. 2).

3. Methods and measurement

3.1. Scientific publications and patent documents

The present study analyses 8245 scientific publications as well as 2082 patent documents published worldwide considering the functional ingredient probiotics. The search term used is *"probiotic*"*. Thereby, for both document types duplicate entries as well as non-company entries are excluded. Furthermore, this study

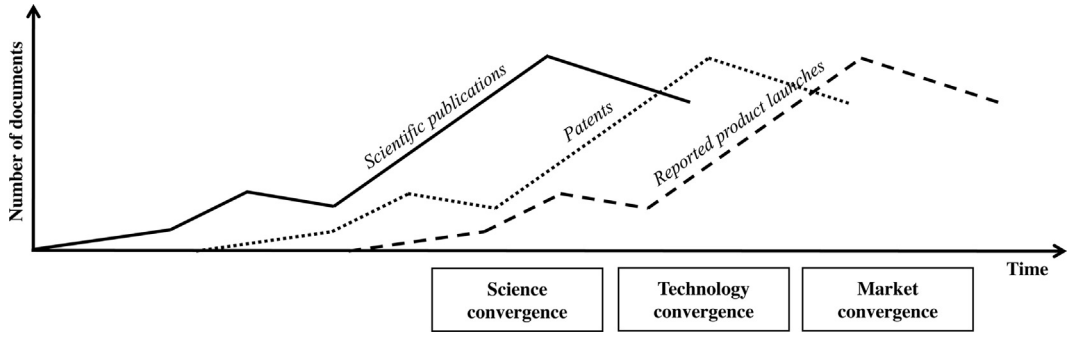

Fig. 1. Life cycles measuring the convergence process.

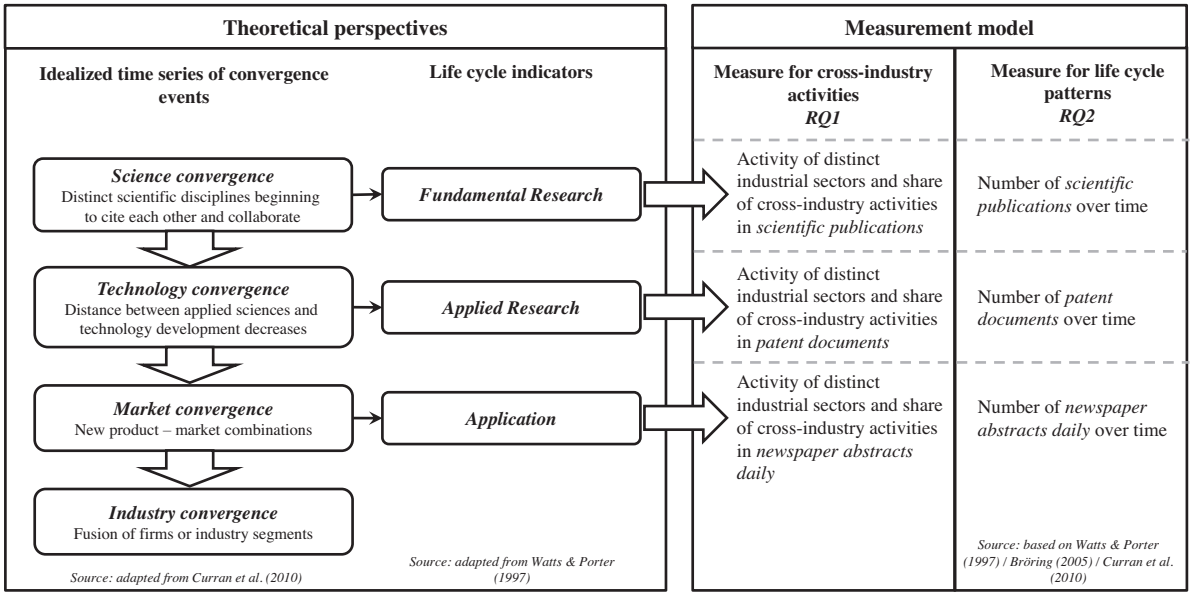

Fig. 2. Research framework.

concentrates on industry convergence, thus the industrial perspective. The top 50 organisations are included leading to 629 considered scientific publications and 527 considered patents. We evaluate a 20-year period between 1990 and 2009. Hence, the essential steps of the convergence process in probiotics are covered [see for instance 7]. As the study at hand entails the application of the life cycle concept to the convergence process encompassing the steps of science, technology and market convergence, the necessary period is enclosed. The Thomson Innovation software tool is used. This software tool is a platform that facilitates analysis of intellectual property, scientific literature and business data [49]. It draws upon the DWPI (Derwent World Patents Index), a database, which categorises patent documents using a classification system for all technologies. Standard Industrial Classification (SIC) codes [50] are used to analyse the industrial background of the patent filing companies. We focus on the four industrial segments on the subject of the analysis of scientific publications and patents: pharmaceutics, chemistry, personal care and food. Furthermore, collaborative activities of different industrial sectors in one scientific publication/patent/reported product launch are defined as cross-industry activities.

3.2. News reports including new product announcements

To identify launches of products containing probiotics, we follow a quantitative approach using the database Nexis to screen the news reports using a time frame reaching from 1990 to 2009 (Ref. to scientific publications and patent documents using the same time frame). The used search term is "probiotic*" to screen news reports with the following setting: *All News, all languages*. This data source encompasses all full-text and selected abstract news sources regardless of the language [51]. Furthermore, we limit the news reports to the predefined category of "*new products*". Therefore, we focus on the new product announcements in the area of probiotics. As all news reports are included, different target groups are addressed by the different news resources, for instance newspapers

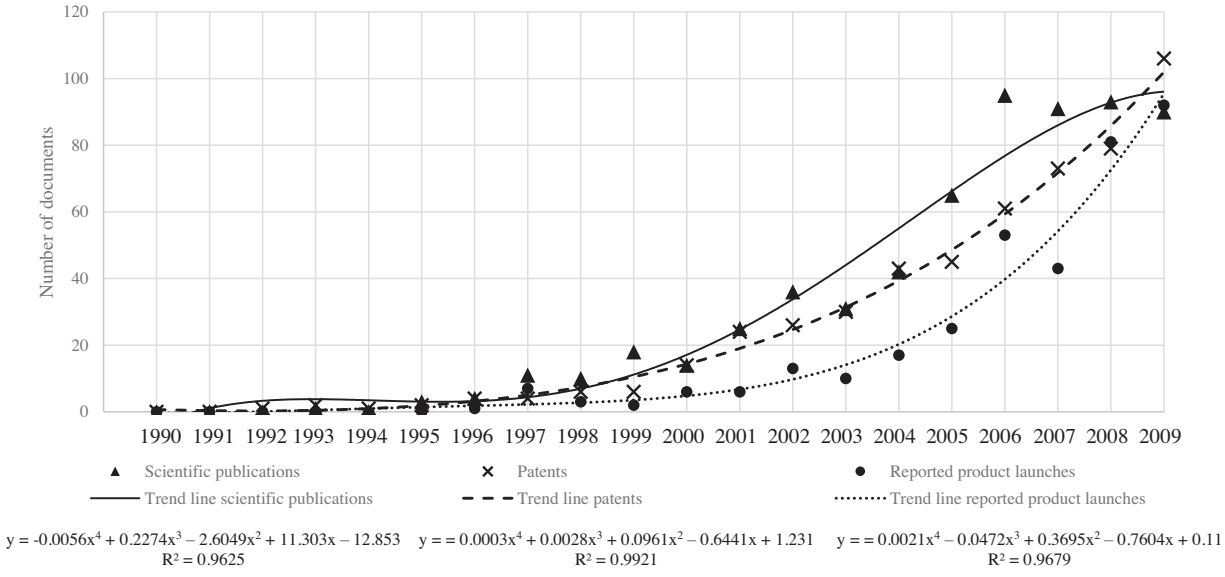

Fig. 3. Comparison of the life cycles of scientific publications, patent documents and reported product launches.

aimed at consumers and business journals aimed at scientific as well as industrial experts in this field. To identify the real product launches, each news report is screened to exclude the non-relevant announcements like for instance market reports. In addition, double announcements of one product launch are eliminated leading to 359 reported product launches. Furthermore, the industrial background of the launching company is determined based on SIC codes. Based on each reported product launch, the product category used as market outlet is determined. The categorisation is as follows: food, dietary supplements (OTC[1]) and other.

The timely development of scientific publications, patent documents and reported product launches in general as well as for each involved industrial sector is depicted. Based on the idealized curve shape of the patent life cycle, a function with two maximal and one minimal turning point is expected. Hence, a polynomial function of 4th degree is used to calculate the trend line for each life cycle in Excel 2013. In addition, the local and global maxima as well as minima are calculated based on curve sketching to determine the life cycle phases.

4. Results

4.1. Life cycle patterns in science, technology and market

Generally, an increase in the number of scientific publications, patent documents as well as news reports focussing on product launches in the research field of probiotics can be observed (Ref. Fig. 3). By means of the above presented idealised time series of convergence processes, firstly, distinct scientific disciplines show R&D output in the field of probiotics indicated by the activity in publishing scientific articles. Secondly, the distance between applied sciences and technology development decreases shown by the increase of activity in patenting. Thirdly, the news reports on the launches of probiotic products illustrate market convergence with an increasing amount of reported product launches. High R^2 show an appropriate goodness of fit.

In case of scientific publications, a global maximum is identified immediately after 2009 indicating the introduction and growth phase leading up to 2010 where maturity will be reached. As the trend line for scientific publications shows a local minimum between 1995 and 1996, at this point the emergence of science life cycle in probiotics can be shown indicated by the consecutive increase. Examining the trend line for patent documents, a global minimum between 1991 and 1992 can be shown indicating a still ongoing increasing trend for patent documents in which maturity cannot be yet defined. In the context of the life cycle concept, the growth phase continues. Like in patent documents, the trend line of reported product launches shows a global minimum (1990/1991) indicating an ongoing growth phase.

By applying the life cycle concept to the three levels of convergence (science, technology and market), different patterns emerge. First of all, our findings confirm the time lag initially identified by Curran et al. [14] between science and technology convergence. Moreover, we extend the notion of the consecutive

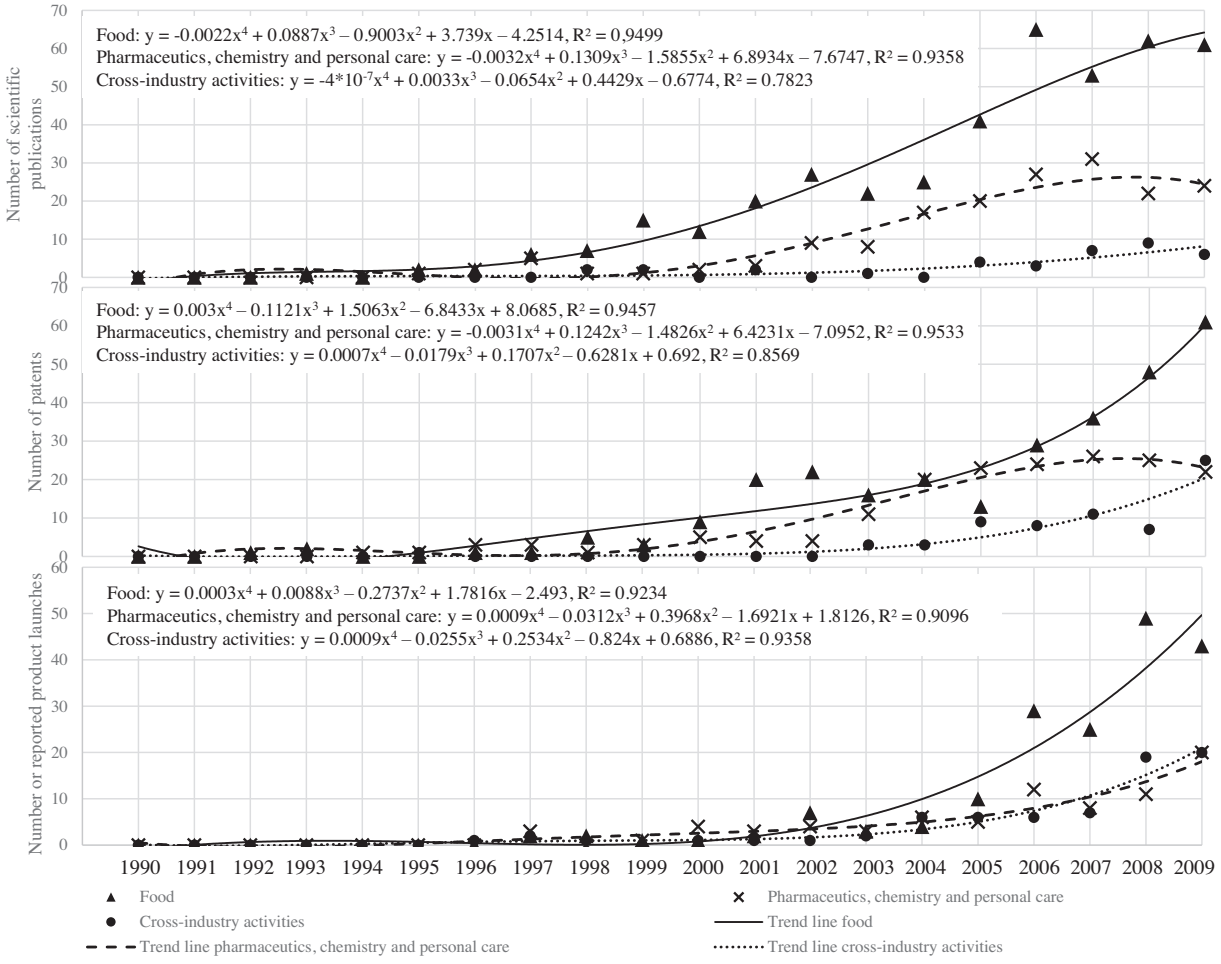

Fig. 4. Number of scientific publications, patent documents and reported product launches according to the industrial background of the publishing companies.

steps to the level of market convergence also showing a time lag between technology and market convergence.

4.2. Science, technology and market life cycle of the distinct industrial backgrounds showing cross-industry activities

Relating the life cycle concept to converging industries, the comparative consideration of the sectors involved for each step (science, technology and market convergence resembled by scientific publications, patents and news reports focussing on product launches) is important to identify time lags as well as differences in the clockspeed of the involved industrial sectors. In the area of probiotics, the active industrial backgrounds are the food, the pharmaceutical, the personal care and the chemical sector. The number of documents published by the food sector outnumbers those from the other sectors. Due to the dominance of this sector, for the subsequent analysis we use the categories as follows: food sector, summary of pharmaceutical, chemical and personal care sector as well as cross-industry activities (Ref. Fig. 4). The high number of scientific publications by collaborations indicating cross-industry activities shows the interest of distinct industry sectors in the area of probiotics and therefore might constitute an indication of ongoing convergence processes. Again, high R^2 show an appropriate goodness of fit.

In summary, there is a shift over time regarding the life cycles showing the same activities of companies of distinct industrial sectors at different times resulting in time lags. The distance between the starting points of the activity of the different industrial backgrounds is the largest in scientific publications and the smallest in reported product launches. Overall, the food sector seems to have a higher growth rate, thus a faster diffusion pace than the other sectors, which is typical for the food sector delivering *fast moving consumer goods* (FMCG). In addition, the clockspeed – thus the time lags between the life cycles – is higher in the food sector indicating a faster adoption time.

Phase determination scientific publications

The food trend line of scientific publications will reach is global maximum in approximate 2010, thus the maturity phase will be reached. In case of pharmaceutics, chemistry and personal care, the trend line shows two local maxima and one local minimum. Firstly, the local minimum is directly at the beginning of the considered period. The first maximum is reached between 1992 and 1993 and the second in 2008. According to the patent life cycle, there might be a short consolidation phase after 1992, before reaching the second growth phase, which reaches is maximum in 2008. After 2008, there seem to be a decline phase. The trend line of cross-industry activities shows a calculated global maximum in about 4000 years, thus the science life cycle of cross-industry activities remains in the early phases and the polynomial function cannot depict the further realistic development.

Phase determination patent documents

Examining the patent trend line of the food sector, a global minimum between 1992 and 1993 can be shown indicating a still ongoing increasing trend for patent documents in which maturity cannot be yet defined. Like in scientific publications, the trend line of the pharmaceutical, chemical and personal care sector shows two local maxima and one local minimum. Whereas the local minimum is immediately at the beginning of the considered period, the first local maximum is between 1992 and 1993 and the second between 2007 and 2008, thus one year earlier than in scientific publications. Related to the patent life cycle, there might be a short consolidation phase after 1993, which is terminated by the consecutive increase indicating the growth phase. In case of cross-industry activities, there can be identified one global minimum between 1992 and 1993 indicating a still ongoing increasing trend for patent documents.

Phase determination reported product launches

Regarding the considered time frame, the trend line of the reported product launches of the food sector shows one local minimum and one local maximum. The local maximum is already reached between 1993 and 1994 whereas the local minimum follows 5 years later between 1998 and 1999. The local minimum might indicate the consolidation phase referring to the patent life cycle concept having between the emergence and the growth phase of the life cycle a decline. In case of pharmaceutics, chemistry and personal care, there can be identified one global minimum directly at the beginning of the considered period indicating a still ongoing increasing trend of product launch announcements in which maturity cannot be yet defined. The same holds true for the trend line of cross-industry activities.

4.3. Market outlet

The reported product launches are analysed regarding their market outlet, therefore the product categories are as follows: *functional foods, dietary supplements (OTC)* and *other*. Firstly, *functional foods* summarises all applications in food products like fortification in yoghurt drinks. Secondly, the category *dietary supplements (OTC)* encompasses all products in a drug-like appearance which are sold “over the counter” without a prescription in pharmacies, drugstores or supermarkets. These products are sold for instance as pills, powder or gels [52]. Thirdly, the category *other* summarizes the remaining application areas such as feed, drugs, cosmetics or speciality products like gardening products.

The industrial sectors show different levels of activity in the aforementioned product categories (Ref. Table 1). Overall, the food sector as well as the cross-industry activities concentrate on functional food products whereas the pharmaceutical sector

Table 1
Activity of industrial sectors in different product categories.[a]

Industrial background	Functional foods	Supplements (OTC)	Other	Total
Food	161	6	11	178
	48.6%	1.8%	3.3%	53.8%
Pharmaceutics, chemistry and personal care	12	55	13	80
	3.6%	16.6%	3.9%	24.2%
Cross-industry	55	13	5	73
	16.6%	3.9%	1.5%	22.1%
Total	228	74	29	331
	68.9%	22.4%	8.8%	100%

[a] Numbers indicate the counted reported product launches for each category.

concentrates on OTC supplements. As depicted in Fig. 4, the cross-industry activities occur mainly from 2008 whereas the food sector reports already a high number of product launches three years earlier in 2005. This time lag might be because competence gaps of single companies are closed by collaborations resulting in later product launches. Overall, functional food products dominate the product launches containing probiotics as main market outlet of the food sector. Functional food products are first in the probiotics market followed by product launches of dietary supplements, which increases over time. Thus, according to the general time lag between the food and pharmaceutical sector in product launches, this can be also shown for the market outlet with firstly functional food products and secondly OTC products launched. Therefore, the clear dominance of functional food products is apparent. Examples of supplements launched by the food sector are for instance probiotic drops, which are sold in pharmacies. Exemplary functional food products launched by the pharmaceutical sector are for instance chewing for children.

5. Discussion and conclusion

Assessing convergence processes at the pharma-nutrition interface from a life cycle perspective, the consecutive phases can be measured by life cycle indicators drawing upon the analysis of scientific publications, patents and reported product launches. Yet, a shift over time can be seen considering the life cycles showing the same activities of companies of distinct industrial sectors at different times resulting in time lags. The earlier activity of the food sector might be due to a closer distance of the new emerging area to this industrial sector as most products are launched in the functional food category. Furthermore, the diffusion time of industrial sectors might differ due to their distance to the new emerging field.

Cross-industry activities depicted in life cycles at the pharma-nutrition interface (RQ1)

As the activity of different industrial backgrounds, e.g., the pharmaceutical and chemical sector, increases over the considered period indicated by the increase of submitted scientific publications as well as filed patents resulting in reported product launches, signs of an ongoing convergence process in probiotics are evident. Especially the huge increase of patents filed through cross-industry activities in the later years confirms this phenomenon. In addition, these cross-industry activities support the definition of this emerging area to be a complementary convergence process [53] as the industrial backgrounds focussing on the new segment of for example probiotics enriched yoghurt drinks while the traditional areas of food products (yoghurt) and pharmaceutical products (drug containing probiotics) remain. Furthermore, the higher number of alliances across industries might lead to a higher degree of research specialization [54] resulting in new borderline products.

Cross-industry innovation based on knowledge, technologies, and partners with different competences [24] can be shown in converging industries as these processes are based on different industrial sectors leading to cross-industry innovation characterized by borderline products. In the case of probiotics, there is a clear difference between industrial sectors in the first increase of scientific publications and patents (Ref. Fig. 4). Nevertheless, the increase in reported product launches occurs almost at the same time. The increase of cross-industry activities might be due to differences in research & development resulting in a simultaneous product launch based on cross-industry alliances or joint ventures. The arisen competence gaps due to the distance of the involved sectors in basic research might be closed by cross-industry activities. Although the pharmaceutical industry relies on intellectual property rights [31], in case of probiotics the food sector outnumbers the patents of the pharmaceutical sector. The dominance of the food sector in the reported product launches might be due to the innovation approach of the introduction of a relatively high amount of different products in a short time span [30]. These cross-industry activities start after activity of the food sector. Furthermore, an increasing degree of convergence through science, technology and market convergence can be linked to the growing number of cross-industry activities.

Although the earlier development steps are characterised by activities from distinct industrial backgrounds, the main market outlet for probiotics is in the form of functional food products. This might be due to the dominating food sector. Based on that main functional food market outlet, one reason for the increasing cross-industry activities might be that for instance the pharmaceutical sector requires the marketing strengths of the food sector to launch a functional food product successfully. This product category as such shows a convergence of the food and pharmaceutical sector as those products deliver a health benefit beyond the nutritional value. Therefore, the evaluation of these borderline products might be used as a measurement tool for market convergence as market convergence describes the new product—market combinations.

Life cycle patterns at the pharma-nutrition interface (RQ2)

The application of the patent life cycle to the different levels of convergence delivers one approach to scrutinise the different phases of convergence in the case of pharma and nutrition. Especially the evaluation of market convergence measured by the number of reported product launches provides one possibility to consider this area that has been neglected in the recent literature [see for instance 14]. However, the sole consideration of the overall amount of news reports might not be enough to analyse market convergence as the same topic can be repeated in several news reports for example published by different journals or newspapers. Therefore, the analysis conducted in the study at hand of the therein reported product launches could provide an approach to evaluate the arising product-market combinations during market convergence. In addition, borderline products present market convergence as such, as they integrate different competences of the involved industrial sectors. Therefore, the further analysis of the market outlet considering potentially arising new product categories could describe market convergence. The dominance of the food sector in probiotics is confirmed as functional food products are the main category of launched products.

Extending the patent life cycle to the three levels of convergence (Ref. Fig. 1), the different phases of the life cycles do not seem to be as static as in the theoretical approaches. The consolidation phase, which is hypothesised in the patent life cycle to occur between the emergence and growth phase, does not seem to be found in every case. In the respective literature, the consolidation phase for patents encompasses the reorientation of R&D efforts based on the first experiences with new technology in the market [11]. This reorientation process could also be shown for the science life cycle of the pharmaceutical, chemical and personal care sector as after the first description of a scientific issue, e.g. the detection of a certain probiotic strain, further research might take a new focus. As the consolidation phase cannot be shown universally, the curve could be adapted in the form of showing firstly a slight increase (introduction phase) directly followed by an increase with a steep incline (growth phase). This non-static performance of the life

[1] OTC, over the counter. This includes all non-prescribed products, which are sold in pharmacies, drugstores and supermarkets.

cycle might be due to two reasons discussed in literature: firstly, lack of or weak opportunities for process innovations which lead to significant scale advantages and secondly, major product innovations may disrupt existing (product) life cycles and shape new life cycles [55]. Detecting new life cycles might enable companies to observe new trends.

Focussing on the phases of convergence processes, in the literature these are described to be consecutive. Therefore, there might be a time lag between each step [Ref. 14]. In case of probiotics, a time lag is confirmed between science and technology as well as between technology and market convergence. Beyond the interpretation of a time lag, the identification of the first phases and their occurrence might deliver assumptions about anticipating ongoing convergence processes, which confirms recent literature about the anticipation of convergence processes by evaluating science and technology convergence [12,14,56]. As the step of market convergence is already reached in probiotics, future studies could concentrate on the following step of industry convergence evaluating fusion of firms or industry segments.

As regards the clockspeed of industries, this concept seems useful to explore the convergence phases. The food sector dominates the field of probiotics by driving science, technology and market convergence showing earlier activity in scientific publications, patents as well as product launches while having a higher clockspeed of the life cycle phases. In the probiotics case emerging at the pharma-nutrition interface, the categorisation of the pharmaceutical industry as a high-value research-intensive sector is supported which launched products linked to the science base [31].

6. Concluding remarks

In this paper we extent the evaluation of the consecutive convergence steps to market convergence. This allows us to deliver a framework to determine the driving sector(s) in each convergence step by the dominance of the amount of documents in the different periods. Furthermore, the pace of reaching the different convergence phases of distinct industrial sectors (clockspeed) is another indicator for the dominance of certain industrial sectors. The cross-industry activities measured by the number of collaborative documents help to identify ongoing convergence processes. More specifically, this allows us to analyse the competitive environment, especially through depicting the cross-industry relationship between single companies. From an academic perspective, this study delivers a research framework to analyse converging processes including the specific market convergence steps. In addition, the consideration of cross-industry activities from a life cycle perspective provides a dynamic view over time to analyse current developments as well as to gain first insights in the anticipation of future developments. While the theoretical contribution evolves around the explanation of convergence characteristics in science, technology and market focussing on cross-industry activities, practical contributions lie in the transferability of the employed methodology to other areas of (potential) convergence and their easy applicability. Managerial implications arise from the great strategic importance of converging industries, enabling firms to identify processes at an early stage and prepare for changes in demand structures, technological shifts, and future competitors.

However, the sole consideration of bibliometric data is not adequate to describe and explain the dynamics in convergence processes. Therefore, events like changes in regulations should also be considered as determinants of life cycles as distinct regulations show differences in their impact on the innovation performance [57]. Especially, the ongoing discussion about the possible health effect of probiotics led by the European Food Safety Authority might have an influence on life cycle patterns. Furthermore, as we focus on product launch announcements, we only consider those launches, which are published in news reports. The real number of product launches might be higher than the ones considered in this study. The determination of the phases should be adapted to each single case as the definition is dependent of the total amount of documents. Further studies could derive a general framework of assessing the different phases. In part, the coefficients of determination are rather low which could be due to the identification of the phases' length. Further studies might concentrate on shorter periods to identify the trends in-depth.

When discussing the value of bibliometric analysis including scientific publications, patents and news reports in terms of converging industries, one generally needs to take into account that these documents deliver a useful information source as they contain detailed information and are quite readily available although the period of 18 months between application and publication must be considered. This information also includes the industrial background of the active company. That is one reason for the usefulness of bibliometric analysis in the case of converging industries. Bibliometric analysis delivers a nearly holistic view on co-operations between different companies but the complexity of collaborations cannot be shown in these data sets. Therefore, further research could concentrate on a more qualitative approach of analysing collaborations in terms of convergence processes. Currently, although the study at hand covers the three steps of science, technology and market convergence, the convergence process in the area of probiotics is still ongoing; therefore, the life cycles could be further extended. Furthermore, the adaptability of the derived methodological framework might be tested in other cases to validate it.

Acknowledgements

The authors would like to thank Monique Vingerhoeds and Greer Wilson from TI Food and Nutrition for their support and for being granted access to the database, and especially Frances Fortuin and Supranee Tangnatthanakrit from Wageningen University.

References

[1] D. Farber, P. Baran, The convergence of computing and telecommunications systems, Science 195 (4283) (1977) 1166–1170.
[2] R.M. Henderson, K.B. Clark, Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms, Adm. Sci. Q. 35 (1) (1990) 9–30.
[3] M.L. Katz, Remarks on the economic implications of convergence, Ind. Corporate Change 5 (4) (1996) 1079–1095.
[4] C.K. Prahalad, Managing Discontinuities: the emerging challenges, Res. Technol. Manage. 41 (3) (1998) 14–23.
[5] S. Bröring, J. Leker, Industry convergence and its implications for the front end of innovation: a problem of absorptive capacity, Creative Innov. Manage. 16 (2) (2007) 165–175.
[6] S. Bröring, L.M. Cloutier, J. Leker, The front end of innovation in an era of industry convergence: evidence from nutraceuticals and functional foods, R&D Manage. 36 (5) (2006) 487–498.
[7] S. Bornkessel, S. Bröring, S.W.F. Omta, Analysing indicators of industry convergence in four probiotics innovation value chains, J. Chain Netw. Sci. 14 (3) (2014) 213–229.
[8] U. Höft, Lebenszykluskonzepte. Grundlage für das strategische Marketing- und Technologiemanagement, Technological Economics, E. Schmidt, Berlin, 1992, pp. 46 p. XII, 308 S.
[9] C. Herrmann, Ganzheitliches Life Cycle Management. Nachhaltigkeit und Lebenszyklusorientierung in Unternehmen, VDI, Springer, Berlin [u.a.], 2010 p. XXXII, 474 S.
[10] Farlex The Free Dictionary, 2014. Available from: http://www.thefreedictionary.com/ (accessed 22.04.14.).
[11] H. Ernst, The use of patent data for technological forecasting: the diffusion of CNC-technology in the machine tool industry, Small Bus. Econ. 9 (4) (1997) 361.

[12] The Anticipation of Converging Industries—A Concept Applied to Nutraceuticals and Functional Foods, in: C.-S. Curran (Ed.), Westfälische Wilhelms-Universität Münster, Münster, 2010.
[13] T.C. Weenen, et al., Patenting in the European medical nutrition industry: trends, opportunities and strategies, PharmaNutrition 1 (2013) 13–21.
[14] C.-S. Curran, S. Bröring, J. Leker, Anticipating converging industries using publicly available data, Technol. Forecast. Soc. 77 (3) (2010) 385–395.
[15] G. Ares, A. Giménez, A. Gámbaro, Does information about the source of functional ingredients influence consumer perception of functional milk desserts? J. Sci. Food Agric. 88 (12) (2008) 2061–2068.
[16] MarketsandMarkets. Global Probiotics Market. 2010.
[17] M. Saxelin, et al., Probiotic and other functional microbes: from markets to mechanisms, Curr. Opin. Biotechnol. 16 (2) (2005) 204–211.
[18] C. Stanton, et al., Market potential for probiotics, Am. J. Clin. Nutr. 73 (2001) 476–783.
[19] H. Verhagen, et al., Status of nutrition and health claims in Europe, Arch. Biochem. Biophys. 501 (1) (2010) 6–15.
[20] OECD, Telecommunications and Broadcasting: Convergence or Collision? Organisation for Economic Co-operation and Development, 1992.
[21] Management of Convergence in Innovation—Strategies and Capabilities for Value Creation Beyond Blurring Industry Boundaries, in: F. Hacklin (Ed.), Physica-Verlag, Heidelberg, 2008.
[22] S. Bröring, The front end of innovation in converging industries. The case of nutraceuticals and functional foods, Gabler Edition Wissenschaft: Betriebswirtschaftliche Studien in forschungsintensiven Industrien, Dt. Univ.-Verl., Wiesbaden, 2005 p. XX, 342S..
[23] Nasiriyar, Nesta, Dibiaggio, The moderating role of the complementary nature of technological resources in the diversification—performance relationship, Ind. Corp. Change 23 (5) (2014) 1357–1380.
[24] E. Enkel, O. Gassmann, Creative imitation: exploring the case of cross-industry innovation, R&D Manage. 40 (3) (2010) 256–270.
[25] K. Bader, How to benefit from cross-industry innovation? A best practice case, Int. J. Innov. Manage. 17 (6) (2013) 1–26.
[26] J.M. Pennings, P. Puranam, Market convergence & firm strategy: new directions for theory and research, ECIS Conference, The Future of Innovation Studies, Eindhoven, The Netherlands, 2001.
[27] T.C. Weenen, et al., Barriers to innovation in the medical nutrition industry: a quantitative key opinion leader analysis, PharmaNutrition 1 (3) (2013) 79–85.
[28] A. Gambardella, S. Torrisi, Does technological convergence imply convergence in markets? Evidence from the electronics industry, Technol. Firm 27 (5) (1998) 445–463.
[29] J.L. Bower, Not all M&As are alike–and that matters, Harv. Bus. Rev. 79 (3) (2001) 92–103.
[30] A.I.A. Costa, W.M.F. Jongen, New insights into consumer-led food product development, Trends Food Sci. Technol. 17 (8) (2006) 457–465.
[31] J. Howells, D. Gagliardi, K. Malik, The growth and management of R&D outsourcing: evidence from UK pharmaceuticals, R&D Manage. 38 (2) (2008) 205–219.
[32] J. Lindgaard Christensen, et al., Patterns and collaborators of innovation in the primary sector: a study of the Danish Agriculture, Forestry and Fishery Industry, Ind. Innovation 18 (2) (2011) 203–225.
[33] E. Faßbender-Wynands, G. Beuermann, Umweltorientierte Lebenszyklusrechnung. Instrument zur Unterstützung des Umweltkostenmanagements, Gabler-Edition Wissenschaft, Dt. Univ.-Verl., Wiesbaden, 2001 p. XXIV, 201 S.
[34] M.E. Porter, V. Brandt, Wettbewerbsstrategie. Methoden zur Analyse von Branchen und Konkurrenten. 12., aktualisierte und erw, Aufl. ed. Strategie, Campus-Verl., Frankfurt am Main [u.a.], 2013 486 S.
[35] F. Fortuin, Strategic Alignment of Innovation to Business: Balancing Exploration and Exploitation in Short and Long Life Cycle Industries, Academic Publishers, Wageningen, 2007.
[36] P.J.P. Garbade, et al., The impact of the product generation life cycle on knowledge valorization at the public private research partnership, the centre for biosystems genomics, Wageningen J. Life Sci. 67 (0) (2013) 1–10.
[37] R. Haupt, M. Kloyer, M. Lange, Patent indicators for the technology life cycle development, Res. Policy 36 (3) (2007) 387–398.
[38] M.-S. Kim, C. Kim, On a patent analysis method for technological convergence, Procedia- Sco. Behav. Sci. 40 (2012) 657–663.
[39] M.-S. Kim, C. Kim, Patent analysis for analysing technological convergence, Foresight 13 (5) (2011) 34–51.
[40] S. Jeong, J.-C. Kim, J. Choi, Technology convergence: what developmental stage are we in? Scientometrics 104 (3) (2015) 841–871.
[41] L. Gao, et al., Technology life cycle analysis method based on patent documents, Technol. Forecast. Soc. 80 (3) (2013) 398–407.
[42] T.C. Weenen, et al., A decision framework to evaluate intellectual property strategies in the medical nutrition market, PharmaNutrition 1 (2013) 65–72.
[43] M. Peltoniemi, Reviewing industry life-cycle theory: avenues for future research, Int. J. Manage. Rev. 13 (4) (2011) 349–375.
[44] R.J. Watts, A.L. Porter, Innovation forecasting, Technol. Forecast. Soc. 56 (1) (1997) 25–47.
[45] H.M. Järvenpää, S.J. Mäkinen, S. Seppänen, Patent and publishing activity sequence over a technology's life cycle, Technol. Forecast. Soc. 78 (2) (2011) 283–294.
[46] C.H. Fine, Clockspeed Winning Industry Control in the Age of Temporary Advantage, Basic Books, 1998.
[47] J.E. Carrillo, Industry clockspeed and the pace of new product development, Prod. Oper. Manage. 14 (2) (2005) 125–141.
[48] H. Mendelson, R.R. Pillai, Clockspeed and informational response: evidence from the information technology Industry, Inform. Syst. Res. 9 (4) (1998) 415–433.
[49] Thomson Reuters Intellectual Property Research and Analysis, 2011. Available from: http://www.thomsoninnovation.com/ (accessed 31.08.11.).
[50] U.S. Securities and Exchange Commission Standard Industrial Classification (SIC) Code List, 2011. Available from: http://www.sec.gov/info/edgar/siccodes.htm (accessed 31.08.11.).
[51] Nexis Nexis Wirtschaft, 2014. Available from: http://www.lexisnexis.com/de/business/ (accessed 06.11.14.).
[52] S.R. Eussen, et al., Functional foods and dietary supplements: products at the interface between pharma and nutrition, Eur. J. Pharmacol. 668 (1) (2011) 2–10.
[53] S. Bröring, L.M. Cloutier, Value-creation in new product development within converging value chains. An analysis in the functional foods and nutraceutical industry, Br. Food J. 110 (1) (2008) 76–97.
[54] W. Zidorn, M. Wagner, The effect of alliances on innovation patterns. An analysis of the biotechnology industry, Ind. Corp. Change 22 (6) (2013) 1497–1524.
[55] J.F. Christensen, Industrial evolution through complementary convergence: the case of IT security, Ind. Corp. Change 20 (1) (2013) 57–89.
[56] T.U. Daim, et al., Forecasting emerging technologies: use of bibliometrics and patent analysis, Technol. Forecast. Soc. 73 (8) (2006) 981–1012.
[57] K. Rennings, C. Rammer, The impact of regulation-driven environmental innovation on innovation success and firm performance, Ind. Innov. 18 (3) (2011) 255–284.