Technological Forecasting & Social Change 77 (2010) 385–395

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Anticipating converging industries using publicly available data

Clive-Steven Curran [a,*], Stefanie Bröring [b], Jens Leker [a]

[a] University of Münster, Institute of Business Administration at the Department of Chemistry and Pharmacy, Leonardo-Campus 1, 48149 Münster, Germany
[b] University of Applied Sciences Osnabrück, Oldenburger Landstr. 24, 49090 Osnabrück, Germany and Wageningen University, Hollandseweg 1, 6706 KN Wageningen, Netherlands

ARTICLE INFO

Article history:
Received 21 January 2009
Received in revised form 1 September 2009
Accepted 5 October 2009

Keywords:
Converging industries
Patent analysis
Nutraceuticals and Functional Foods
Cosmeceuticals
Phytosterols
Chemical industry
Bibliometrics

ABSTRACT

Industry convergence, described as the blurring of boundaries between industries, plays an increasingly pivotal role in shaping markets and industries. Traditionally, this phenomenon has been discussed in respect to telecommunications, information technologies and electronics, but more recently also the chemical and its related industries find themselves affected by a larger convergence process. With the primary example of phytosterols in the two converging industries of Cosmeceuticals and of Nutraceuticals and Functional Foods, we analyze 7455 scientific and patent references in respect to first indicators for signs of convergence. Furthermore, we present and discuss a multiple indicator concept for monitoring convergence in an R&D-intensive field on the basis of publicly available data.

1. Introduction

Industry convergence, which has been observed in various industries, plays an increasingly pivotal role in shaping markets and industry segments. In industries such as telecommunications, information technologies and electronics, formerly distinct sector boundaries have already largely faded [1,2]. More recently, this phenomenon can also be found in the chemical industry that has already exhausted to a high degree classical levers for reducing costs and improving efficiency [3]. The world of blurring industry boundaries and more and more cross-scientific research [4–6] enables the chemical sector to utilize the often tremendous technological developments in its neighboring disciplines (e.g. physics or biotechnology) or at the outposts of the chemical industry (e.g. electronics or agriculture). A general trend towards cosmetics and foods with health benefitting characteristics has led to the production of Cosmeceuticals (a combination of cosmetics and pharmaceuticals) as well as Nutraceuticals and Functional Foods (NFF: a combination of nutrition and pharmaceuticals) [7].

But while these new industry segments present a plethora of opportunities for new fields of business and economic growth, they are often also quite challenging as firms have to employ knowledge and technologies not within their traditional framework of expertise. When they cannot anymore rely on just their core businesses, they will frequently lack the knowledge and experiences necessary to cope with the risks and uncertainties of the new field. Naturally, in most cases of convergence sourcing the essential knowledge and experiences from beyond their own factory gate is necessary and key to successful innovation management.

On that account, anticipating convergence would enable firms to form strategic alliances or acquire new technologies already at an early stage and to prepare for the challenges and pitfalls of the new segment in advance. A timely reaction to challenges posed by these external events may be decisive to find the best possible partner [8]. Thus the question remains: how to foresee or

* Corresponding author. Tel.: +49 251 8331820; fax: +49 251 8331818.
E-mail address: curran@uni-muenster.de (C.-S. Curran).

0040-1625/$ – see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.techfore.2009.10.002

at least detect fading industry boundaries at the earliest possible moment? And how to distinguish mere utilization of a common technology platform or a merging market from cases of real industry convergence?

Patents are generally regarded as precursors of technological developments. Long before the general public is seeing new developments, scientists and companies are trying to secure their inventions through filing of patent applications. While a patent is mainly intended for specialists and hence describes the technological aspects of the invention in great detail, especially its relation to other patents and publications can make it valuable also for non-specialists trying to identify general trends.

In this paper we introduce the idea of a comprehensive approach towards anticipating industry convergence, based on publicly available data. We want to develop a set of indicators suitable for monitoring occurrences of convergence. To the best of our knowledge, ideas of multiple indicators based on scientific and patent literature have so far not been applied in the area of convergence anticipation. With an example from the chemical industry we finally aim at presenting a first proof of principle for our concept.

The remainder of this paper is structured as follows. In the next section we will characterize the principle of industry convergence. Furthermore, we will discuss triggers for this significant change in industry structure, leading to a concept for the anticipation of convergence. Based on the analysis of publications[1] on phytosterols we will test indicators for the converging industries of Cosmeceuticals and NFF, finalized by a discussion of first results, the developed model and promising future research strands.

2. Characterizing industry convergence

2.1. Convergence over time

Convergence describes the concept of at least two discernable items moving toward union or the merging of distinct technologies, devices or industries into a unified whole. It is used as well in mathematics, natural and social sciences as in computing and economic sciences. In management literature convergence can be found in several different contexts. While some authors use it to describe "the addition of disparate new functionalities to existing base products" [9], others concentrate on technological convergence as the use of a technology from one industry area within a new area [10].

Within this paper we will use the term for the description of a blurring of boundaries between two or more industries, thus called *industry convergence* [7,11] or also *industry fusion* [6]. While the terms have been used interchangeably in most cases, we argue that there is a clear difference between them. In line with the definition of the terms, convergence describes the "moving of items" towards a common point. In contrast, fusion addresses the blurring of boundaries in the very same place of the objects. Although both incidents are of equal interest to us, we will be using the term convergence to increase clarity. This industry convergence includes at least the technological and the product-market level [2] and is marked by converging value propositions, technologies and markets [11] of formerly distinct industry segments. Then a new industry segment is formed [12] which will either replace the former segments or will complement them at their intersection, i.e. leading to the formation of either a substitutive $(1+1=1)$ new inter-industry segment or to a complementary $(1+1=3)$ one [7].

We base our concept of anticipating convergence upon the assumption of an idealized time series of events, with industry convergence evolving when scientific disciplines, technologies and markets have converged (Fig. 1). Starting with scientific disciplines that begin to use more and more research results of one another, a scientific convergence will be initiated by cross-disciplinary citations and eventually develop further into closer research collaborations. After the distance between basic science areas has been decreasing for some time, applied science and technology development should follow [13,14], leading to technology convergence. Then, new product-market combinations will emerge leading to market convergence and, once firms have begun to merge with each other, the process will be finalized by industry convergence. Being aware that this is a considerably simplified and idealized process, we argue that full industry convergence will only take place when technologies *and* markets converge.[2] Additionally, we deem this process model useful to discuss different means for anticipating and (later in the time series) realizing occurrences of convergence.

2.2. Triggers and forms of convergence

The degree to which such a course of events will happen in reality is largely dependent on the triggers and drivers behind a trend of convergence. These triggers naturally include scientific findings and technological developments leading to the pure ability of an organization to think of a product or process that could be made. Furthermore, changes in customer demands (with customers ranging from other organizations to individuals at the end of the value chain) or even in political regulations and industry standards can be at least equally important factors. Hence, Pennings and Puranam [1] discern between supply side-driven convergence and demand-side convergence (also called input-side and output-side [7]). This concept of input-side and output-side bears analogy to the discussion about technology push or market pull as drivers for innovation by Mowery and Rosenberg [15] or Howells [16]. While technological developments enable firms to supply the market with new or enhanced products, changes in customer structures and behavior may lead to demand-driven output-side convergence. Reasons for a decisive change on the demand-side include a growing interest in

[1] Publications at large would entail all kinds of e.g. scientific literature, patent literature, general media coverage and information on the internet. Deviating from this holistic approach, we will throughout this paper speak of publications when referring to patent literature and scientific publications, if not stated otherwise.

[2] For an overview of the discussion about market convergence happening before, after or without technology convergence see e.g. [7].

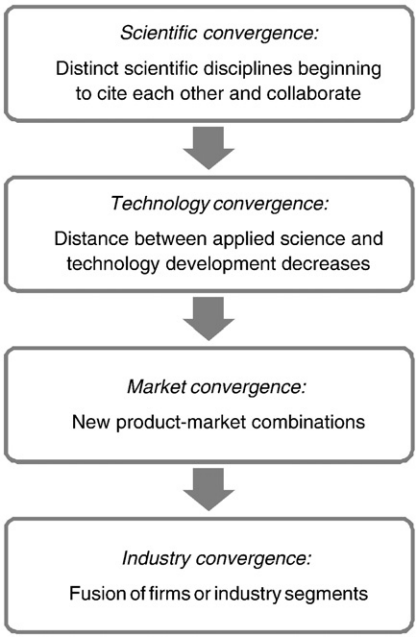

Fig. 1. Idealized time series of convergence events.

satisfying multiple needs with one transaction as well as socio-demographic developments [1][3]. Country regulations, which are quite in the middle between input- and output-side, can have significant impacts as well. Alone the question whether a product is viewed as a food ingredient, a dietary supplement or a drug might change the commercial viability of a compound completely. In contrast to normal food ingredients, compounds with strong pharmacological effects have to undergo a far more thorough investigation by the appropriate authorities. Such a drug approval process is not only time consuming and costly (normally well exceeding EUR 500 million per drug) but also has a very uncertain outcome. And as Hauschildt and Salomo [17] have argued that it takes technology push and market demand for successful innovations, full industry convergence will probably only occur where input- and output-side convergence takes place. Where this leads to total substitution of previous industry sectors, innovation seems to be imperative to keep up with trends of convergence [7].

3. A concept for monitoring convergence

3.1. Employing patent analysis

Due to the high time-sensitivity of innovation processes, it is particularly important for firms to realize at the earliest possible moment that convergence might be affecting them. Our concept puts special emphasis on using quantitative and easily accessible data. While qualitative data like expert interviews and case studies are of special importance in understanding developments and getting a "feeling" for new developments [18,19], it often proves difficult and time-consuming to find the right sources at the right time. With a plethora of new developments around, time is a resource most firms do not have to spare. Hence, using publicly available data, which is already aggregated to some extent, certainly should have its place. When considering which kinds and sources of information could be employed it has to be borne in mind that in the light of converging industries scientific articles[4] and patent publications[5] will begin to cite publications of all of the other areas involved in convergence. Additionally, they will be indexed with additional or different subject areas and keywords. Also, most disciplines or technological fields are using individual terminology, which the other fields will be increasingly using. And finally, the more sporadic cross-disciplinary collaboration begins to turn into normality with regular collaborations, alliances and networks, the more we will see co-authorship with people or organizations from all converging fields.

[3] These encompass developments such as growing customer bases in thus far developing countries, relatively free and global trade or a "homogenization of customer segments due to changing demographics" [2].

[4] When speaking of scientific articles or publications, we inherently include not only scientific journal articles, but also reviews, reports etc. where applicable.

[5] Patent publications encompass all of the available patent literature, i.e. not only granted patents but also published patent applications. Not all patent applications lead to granted patents (either the applicant does not pursue patenting any more or even withdraws his application, or the patent authorities do not grant a valid patent due to legal constraints), but still represent a valid proxy for R&D activities. Furthermore, due to the complex legal obligations and necessary steps granted patents will only be published several years after their initial filing. Thus we will include patent applications in our analysis. In order to increase legibility of our paper we will use patents as a synonym for both applications and granted patents throughout the paper.

The aforementioned kinds of publications have a decisive practical advantage over other forms of publication — scientific contributions as well as patent literature are already structured to a certain degree. Due to requirements of publishers and patent offices these items of information entail clear identification of e.g. authors or applicants, references and fields of science or technology. Furthermore, extensive databases have gathered comprehensive collections of patents and scientific articles, added information e.g. on subject area and keywords and made them full-text searchable. Thus, identifying patterns at "the touch of a button" becomes possible, appealing to practitioners and academics alike [20].

The question whether publications can really be a reliable source for an anticipation of occurrences of convergence has been discussed by several authors. Without going into too great detail on the dispute for or against the use of patent data, we want to shortly present some of the key elements of this longstanding discussion.

Pennings and Puranam [1] argue that based on a validity assumption for classification schemes like the IPC (International Patent Classification) or the SIC (Standard Industrial Classification) codes, convergence can be found in patent data through growing overlap among SIC codes or IPCs and through an increase in patent citations between different classes. Patent analysis has been employed in the context of technology-driven convergence of electronics, computers and telecommunication [2,7,21] as patents are often regarded as outcome indicators for organizations' R&D activities [10,20,22].

Fai and von Tunzelmann [10] use the University of Reading database[6] for their study of patterns of possible technological convergence at a broadly defined industry sector level. Through their analysis of patenting behavior they find that patterns of technological convergence can be identified when looking at changes within one technological field across all industry sectors. On the other hand they also report a high degree of path-dependency with industrial sectors remaining to engage most heavily in patent activities within their core technological field.

On the limitation side it has been argued, that patent analysis does not take into account structural differences in the propensity to patent of individual organizations or even whole countries and does thus not necessarily reflect the true extent of their R&D activities [23]. Substantial differences in patenting behavior cannot only be found when comparing industries or technology areas, but are also caused by different types of inventions (product inventions appear to be more likely to be patented than process inventions) [7,20,24]. Additionally, patents were originally invented as a kind of a trade-off, where the applicant will be granted a limited time of "monopoly" in exchange for disclosure of his invention and thus adding to the body of knowledge of the whole society. Hence, in many cases firms will choose to rather not engage in this trade-off, especially when they assume that their new knowledge will remain exclusive to them longer than the possible patent life-span. These limitations have to be taken into consideration when monitoring convergence building on patent analysis. Otherwise, emerging patterns could remain hidden in general industry differences.

Although these arguments may all hold true to some extent, patent analysis is extensively used in scientific research and commercial applications and is constantly being called upon. This is especially the case when e.g. dealing with knowledge transfer, strategic management questions, technological foresight or the performance of different organizations or countries [8,20,22,24–31]. Patents represent easily accessible, highly structured and — due to their commercial importance and legal constraints — very carefully compiled means of information. An additional reason for this popularity of patent analyses lies in the fact that probably more than 80% of the world's technological knowledge is to be found in patents [4]. Finally, Schmookler [32] has put it rather to the point: "We have a choice of using patent statistics cautiously and learning what we can from them, or not using them and learning nothing about what they alone can teach us." Hence, we will employ patent and scientific publication analysis and in contrast to prior studies develop a more comprehensive indicator set employing standard databases.

3.2. Developing a monitoring concept

Identifying full-scale convergence is based on three aspects. Firstly, monitoring scientific articles will reflect trends of scientific convergences or the convergence of technological knowledge bases [4]. Secondly, patent analysis will result in an overview of how far technological areas and firms from different industry segments are already interwoven at any given point in time. Thirdly, additional analysis of collaboration projects [33], press releases or general business media can be employed [34,35] for a thorough assessment of complete industry convergences compared to just technological or market-side convergences. The use of multiple indicators has been demanded for some time, as the large amount of studies on firms' innovative performances has thus far not led to the one single and broadly accepted indicator or at least a universal set of indicators [24]. We want to measure the distances between scientific fields/industries for all three stages of convergence. In a setting of convergence the distance will gradually decrease until a substitutive or additional area of convergence is formed (see Fig. 2). In our illustrative example A and B are converging whereas A and C and even more so B and C are still clearly distinguishable.

The areas of A, B and C entail the publications in the respective areas (industry sector or scientific field, depending on whether they are patents or scientific articles). The distances are calculated by combining different factors which have been employed in R&D evaluation and management for a long time, such as the results of (co-)citation [36–38], co-authorship [39,40], co-applicant and co-word analyses [41]. Additional proxies to be used are classifications regarding keywords, subject area, journal topics and IPCs or SIC codes. These different pieces of information on certain aspects of convergence can then be combined to generate a useful and more comprehensive picture [23,29,42–44]. Albeit it has been argued that a lesser amount of factors would be sufficient to draw a reliable picture we choose to gather more input variables. As we will not only take into account traditional high-technology industries like the pharmaceutical or the chemical industry but also firms from the fast moving consumer goods sector

[6] This patent database was compiled by Prof. John Cantwell, based on all patents registered at the USPTO between 1890 and 1995 and grouping 399 technological classes into five broad technological fields while compiling four broad industrial groupings from 875 companies or affiliates [10].

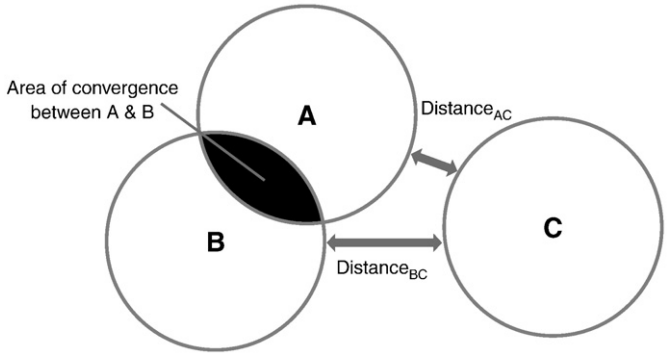

Fig. 2. Measuring convergence through the distance between scientific fields or industry sectors A, B and C.

and agricultural companies, we expect to see differences in patenting and publication behavior independent of industry convergence trends. Thus accessing multiple data sources [45] should enlarge the clarity, significance and reliability of the produced picture. The analysis of scientific publications next to patents will also reduce the danger to oversee patterns because of differences in the propensity to patent (as discussed in Section 3.1).

As we want to create a monitoring concept that can act as an early warning system we have to take into consideration that many signals will be rather weak at the beginning [46]. Thus it might well be that e.g. co-authorship analysis will not show significant changes at an early stage in converging industries but citation and co-citation analyses may already yield first indicators for a change in the technological environment. We will employ longitudinal analyses where possible, so as to not only asses a status quo but really see a change over time and thus monitor the *process* of convergence [47]. A distance can be measured on the basis of different indicators at different points in time. When comparing these individual values, a consistent development towards convergence can be differentiated from distracting but random changes in the calculated distances.

Furthermore, it is important to draw the information from comprehensive databases that are not only providing it content driven but also in a way that makes statistical evaluation possible. For instance, the SciFinder Scholar^{TM} software used for the compilation of results in Section 4.2 normally presents citations to a set of publications only once per set, even when several articles or patents will cite the same reference, thus making citation analysis useless if not performed on a single item basis. Each database has particular strengths and drawbacks, which can be minimized when using a combination of them.

3.3. Identifying indicators for convergence

In a final concept, the employment of indicators will have to be a compromise between an absolutely comprehensive collection of possible indicators (as reasoned above) and a reduction to the absolutely necessary number. The time, effort and money (e.g. due to database charges) an investigator can spend on the assessment of the degree of convergence is especially limited in managerial practice. Thus it is our aim to test a wider array of indicators and then assess their suitability. Their collection should be based on standard data sources and software wherever possible.

We want to measure occurrences of convergence on each of the stages of our idealized time series of events. But we believe the early stages to be most important, since anticipating convergence as early as possible would enable firms to prepare in time for the necessary changes.

Measuring a distance in converging scientific disciplines can be grounded on two aspects. If two disciplines begin to merge or to form a common sub-segment, we would expect collaboration to intensify and each area to work more with results from the other area. Collaboration could be assessed on the basis of co-authorships of articles or on precise information on collaborative projects, changing researcher affiliations and broadened research agendas. Whilst information on each of the items is available, the only one that can be easily and comprehensively accessed is co-authorship. As this information is incorporated in all of the databases, it is well structured and controlled by database providers.

When research is becoming mutually interesting, authors will begin to cite journals and scholars from the other area and use (key-)words that used to be part of the other area. Thus both citation analysis and co-citation analysis, based on individual authors where possible and on journal topics or keywords where necessary, should be employed. Analyzing co-words would theoretically be one of the best means, but this could only work if disciplines use a set of precisely discernable words, that could be undoubtedly allocated. Hence this approach does not appear to be easily generalizable.

In patents, which would be most important for the assessment of technological convergence, co-citation analysis is a two-edged sword. On the one hand patents and the accompanying reports of the patent examiners are of high relevance to the patent presented. But on the other hand not all patent data entails useful citation data, and the amount of citation tends to be rather scarce. Thus additional proxies to be included are assignee data (in most cases this will be the funding company, which can be allocated to certain areas on the basis of e.g. SIC codes) and IPC codes that should be clustered into broader technological fields. For patents the same holds true as for scientific articles when it comes to (co-)word analyses. Thus we will exclude this proxy from our indicator set, for the time being. Market convergence appears to be the most difficult to assess on the basis of automated and large

scale monitoring concepts. It would be identifiable through an overview of actual products or services in the market, or more generally by identifying general customer trends. For a proof of concept this could be done by individually collecting data on companies' product portfolios (especially the introduction of new products in possibly converging areas) and through expert interviews, but in managerial practice this would probably remain a weakness. Once markets begin to converge, companies' strategic actions would already be mostly too late. Data on strategic alliances, on shifts in product portfolios and on mergers and acquisitions should be employed to judge on the degree of complete industry convergence.

4. Phytosterols — an example of industry convergence

4.1. Phytosterols and their use in Nutraceuticals and Cosmeceuticals

For our illustrative analysis we chose the example of phytosterols. With many applications in the areas of NFF and Cosmeceuticals, this term's use is pretty much restricted to the natural sciences and thus proves to be easily identifiable in publications.

Phytosterols (or plant sterols) are a subclass of the chemical steroid group. Their structure is very similar to the well known sterol "cholesterol". The class of phytosterols can be subdivided into plant sterols and stanols and consists of about 250 different molecules, with β-sitosterol, campesterol and stigmasterol being the most common ones. As the name indicates, they are found in plants with the highest concentrations found in corn, sunflower or safflower oil [48]. Because of the high structure analogy to cholesterol it competes with the absorption of dietary cholesterol in the intestines and thus leads to lower blood concentrations of LDL[7]-cholesterol. Bearing in mind that high concentrations of LDL-cholesterol are a risk factor for cardiovascular diseases [7] such as near term coronary heart disease (CHD), several studies have undertaken research on possible uses in primary and secondary prevention of CHD [48,49]. Phytosterols could also help patients suffering from chronically high concentrations of LDL-cholesterol due to one of the most frequent monogenic hereditary disorders, the familial hypercholesterolemia [49] or help in cancer prevention [50].

Besides their possible applications in pharmaceuticals and foods, phytosterols are also commonly topically applied in cosmetics, e.g. as hair care agents, moisturizers, skin barrier strengtheners or in treating cellulite as well as in deodorizing preparations [51–54].

Due to their broad applications in foods and cosmetics, phytosterols can work well as an example of two recent developments of industry convergence — the emerging sectors of Nutraceuticals and Functional Foods and of Cosmeceuticals. The NFF sector has been emerging since the early 1990s at the intersection of the pharmaceutical and food industry sectors [5,7,55], starting in Japan, which is still a very strong market for NFF [56]. The NFF sector is marked by input-side convergence as well as output-side convergence. Food technology competencies are converging with LDL-cholesterol lowering technologies. Regulations regarding pharmaceutical products are increasingly transferred also to food products with enhanced characteristics. And finally, customers are seeking to purchase foods with added health-benefits in an attempt of one-stop shopping [7]. Thus firms do not only need knowledge and technological skills formerly unimportant to them, but also find themselves competing with one another in one unified market of nutrition and disease prevention [57].

A similar setting can be found in the sector of Cosmeceuticals, a term coined by Klingman in the 1970s [58]. It is reported to be the fastest growing segment of the "natural personal care industry" with cosmetic-pharmaceutical hybrids aiming at enhancing both "beauty" and health [59]. While health benefits appear to be more disputed than for most products in the NFF sector,[8] some experts are calling for a harmonized regulation through bodies like the FDA (Food and Drug Administration, USA) [59]. The broader the health claims marketed with the Cosmeceuticals, the more likely they will have to undergo scrutiny by drug administration bodies, leading to a convergence of regulations and standards.

4.2. Indications of convergence

For our analysis we used SciFinder Scholar™ to analyze the 29 million patent and journal article references from more than 10 000 scientific journals and 57 patent authorities. Entering *phytosterols*, *plant sterols* and their derivatives as search terms and afterwards removing duplicate entries resulted in 7455 references ranging from 1897 to 2008. These consisted of 6212 scientific references and 1243 references to patents. An analysis of the filing organization for these patents yielded in 654 organizations, including countries, research institutions and companies. Excluding all non-companies from the 50 organizations with the highest numbers of patents and including their subsidiaries led to 451 remaining patents, filed by 27 firms.

With these patents we conducted our further analysis. Firstly, we assigned the firms to four categories as follows:

- *Personal Care*, nine firms who are selling or conducting R&D on phytosterols applied in Cosmeceuticals.
- *Food & Agriculture*, nine companies who are either active in agricultural processing or selling food and food ingredients under their brand names.
- *Pharmaceuticals*, the smallest group, consisting of four firms specialized in developing and marketing drugs in a highly regulated industry sector.
- *Chemicals*, six companies producing phytosterols and selling it in the B2B market.

[7] LDL = low density lipoprotein.

[8] See e.g. Crompton [58] who also cites Dr. Nicholas Perricone, founder of NV Perricone MD Cosmeceuticals, opposing accusations of Cosmeceuticals' low credibility: "Cosmeceuticals are science-based rather than marketing-driven, giving the customer results and value for their investment."

Table 1
Patenting by industry sector and subject areas.

Subject area concerning	Industry sectors of sample				Share of subject area across all industry sectors of sample	Share of subject area in total [a] sample
	Personal Care	Food & Agriculture	Pharmaceuticals	Chemicals		
Personal Care	87%	8%	19%	33%	45%	29%
Food & Agriculture	1%	71%	16%	33%	30%	31%
Pharmaceuticals	9%	7%	43%	16%	14%	25%
None of other three	3%	14%	22%	18%	11%	15%
Number of patents	184	152	58	57	451	1101

[a] For easier analysis we truncated off the patents containing no information on subject area or from subject areas representing less than 1% of all patent publications, leading to a sample representing 88.6% of all patents.

Table 2
Scientific publications by industry sector and subject areas.

Subject area concerning	Industry sectors of sample				Share of subject area across all industry sectors of sample	Share of subject area in total sample
	Personal Care	Food & Agriculture	Pharmaceuticals	Chemicals		
Personal Care	40%	0%	0%	11%	6%	1%
Food & Agriculture	27%	77%	25%	67%	66%	31%
Pharmaceuticals	7%	3%	13%	0%	4%	12%
None of other three	27%	20%	63%	22%	24%	55%
Number of publications	15	79	8	9	111	4364

Note: Due to rounding, shares do not necessarily add up to exactly 100%.

Secondly, the 451 patents were organized according to these four industry groups. Thirdly, they were analyzed in regard to subject areas. Subject areas are assigned content based by CAS (the division of the American Chemical Society responsible for SciFinder®). We structured subject areas into four disjunctive groups, with the first three representing the core businesses of the industry sectors Personal Care, Food & Agriculture, Pharmaceuticals and the last one including all the remaining subject areas. This resulted in the figures depicted in Table 1.

Not surprisingly are most industry sectors filing their patents in the subject areas closely related with their core businesses. But while Personal Care (87%), Food & Agriculture (71%) and Pharmaceuticals (only 43%, but still the largest share of the four areas) show only little to medium activity in the additional areas, the firms in the Chemicals group file two thirds of their patents regarding Personal Care and Food & Agriculture (33% each). The last third is about evenly shared between Pharmaceuticals and the Rest. The total shares of patents in the four subject groups do also resemble the total share of patents of the corresponding industry sectors within the range of a few percentage points (e.g. the firms from the Personal Care sector account for 184 of 451 = 41% of all patents and the subject area Personal Care accounts for 45% of all patents in all of the different sectors). When looking at the patent documents of all organizations,[9] this picture changes to some degree. Overall, only 29% of the patents are from the subject area Personal Care, 31% from Food & Agriculture, 25% from Pharmaceuticals and 15% from the Rest.

We also analyzed the scientific publications in respect to the subject area and specifically to our firm sample as submitting organizations. Of the total 6212 documents, 4364 (70.3%) were assigned to a subject area which was identifiable and represented at least 1% of all publications. Of those, 111 were submitted by the firms of our sample (see Table 2). Again, when comparing the figures to those in the sample of all submitting organizations, we found that the Personal Care and the Food & Agriculture areas are accounting for larger shares within our sample than within publications from all organizations (6% to 1% and 66% to 31%, respectively).

We further analyzed the growth of scientific publications and patents in the last ten years in respect to subject areas (Fig. 3a and b). Looking at the 4364 scientific articles there is a strong increase over all sections within the last decade. While publications on Food & Agriculture have started on a rather low level they have gained the strongest momentum (to be seen in the formula for the respective linear fits), followed by the unassigned and the pharmaceutical ones. Personal Care does not only show very few publications but also virtually no tendency to change this. With regard to patents both Food & Agriculture and Personal Care patents show the same acceleration in patent behavior, followed by Pharmaceuticals and Rest. Interestingly, the graph for Pharmaceuticals shows a nearly identical slope for the publication and the patent graphs.

In this case nearly all of the curves share a common direction (i.e. the later the year, the higher the number of scientific publications/patents), with varying steepness. To reduce the complexity of such information to one number, that can be combined with other numbers to one distance measure, we calculated the *weighted average year (WAY)* of scientific publications and patents in each of the industry sectors and subject areas. With this weighted average year we got a measure for the age of an average document from the respective sector or area, enabling us to assess a part of the process of convergence. It is based on the number of documents per year (thus weighted) multiplied by the respective year and divided by the total number of documents. The employed formula is as follows:

$$WAY(p,s) = [\sum_i (n_i(p,s)^* y_i(p,s))] / [N(p,s)]$$

[9] See footnote in Table 1.

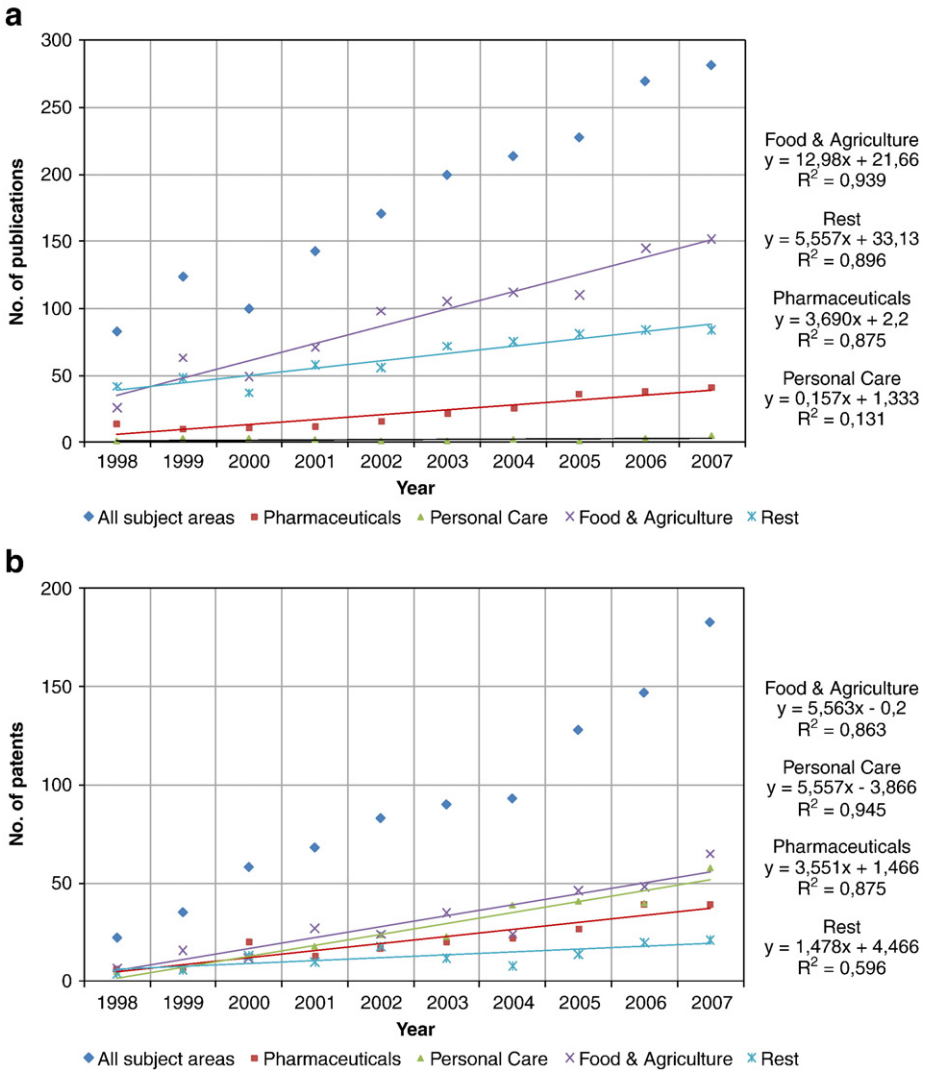

Fig. 3. a) Number of scientific publications by subject area for 1998–2007. b) Number of patents by subject area for 1998–2007.

$WAY(p,s)$ = weighted average year of patent or publication p in subject area or industry sector s; n_i = number of p,s in each year y; $N(p,s)$ = total number of p in s in all i years.

Hence the *WAY* will be the higher (a late average year of publication) the larger the share of documents is in later years when compared to earlier years. Table 3 presents the findings of this calculation for our sample. With one exception (the industry sector of Chemicals), the weighted average year of scientific articles for each of the sectors and each of the subject areas lies earlier than the weighted average year of the respective patents. Additionally, the time lag between both varies between 0.8 years (industry

Table 3
Average weighted year of scientific articles and patents, according to industry sector or subject area.

	Industry sector						Subject area				
	All	Select.	Ph	Ch	PC	F&A	All	Ph	Rest	PC	F&A
Art.	1982.3	2000.1	1996.3	2004.8	1991.1	2001.7	1988.2	1973.3	1978.1	1990.4	1993.4
Pat.	1998.2	2002.1	1999.3	2001.8	2002.7	2002.5	1999.8	1998.0	1995.0	2002.3	2001.4
Lag	15.9	2.0	3.0	−3.0	11.6	0.8	11.6	24.7	16.9	11.9	8.0

Notes: Art. = scientific articles; Pat. = patents; All = all industry sectors or subject areas, respectively; Select. = selected firms; Ph = Pharmaceuticals; Ch = Chemicals; PC = Personal Care; F&A = Food & Agriculture.

Table 4
Average weighted year of patents, according to industry sector and subject area.

Industry sector	Subject area			
	Rest	Pharmaceuticals	Personal Care	Food & Agriculture
Chemicals	1995.0	2005.4	2003.8	2004.9
Pharmaceuticals	1992.7	2000.2	2003.5	2003.2
Personal Care	1996.0	2002.7	2003.1	1989.0
Food & Agriculture	1999.7	2001.2	2000.2	2003.6

sector Food & Agriculture) and 24.7 years (subject area Pharmaceuticals). When looking deeper into the individual sectors, we found that generally patents from the "Rest" subject area were the oldest ones (see Table 4). While in the Pharmaceuticals sector patents regarding "its own" subject area were the second oldest ones, in the Personal Care and Food & Agriculture sector it was those focusing on Food & Agriculture (in the Personal Care sector even the on average oldest patents) and Personal Care, respectively.

5. Discussion

Based on the findings presented in Section 4.2, we will discuss their significance as first indicators for convergence.

In our sample the Personal Care patents are strongly overrepresented while especially Pharmaceuticals are underrepresented. Thus, as we have chosen the filing organizations for our sample by number of patent references, the Personal Care sector is apparently to a higher degree consolidated regarding intellectual property on phytosterols than the Pharmaceuticals sector. Even with the small amount of scientific publications by these firms, a similar pattern holds true. Especially the core areas of Cosmeceuticals and NFF appear to be of higher commercial than scientific importance, leading to large multinational corporations having a substantial share especially of the publications in these areas. Furthermore, we found that over 80% of patents from the Chemicals sector are in the other three areas. This is in accordance with our expectations as patents are granted on the basis of commercial applicability and as the chemicals' producers find their customers mainly in the other three groups.

Interesting results could be found in the developments over time. Personal Care does not only represent a negligible share of all publications but also exhibits no tendency to change this. Apparently it is of much greater concern to researchers in this field to have their inventions patented than to publish scientific articles on them. This is in contrast to the Food & Agriculture subject, where probably especially academic researchers have a higher interest in discussing their findings with the scientific community. Not surprisingly do pharmaceutical aspects bear an equal importance to commercial and scientific stakeholders. Finally, the Rest group is comprised mainly of subjects covering fundamental research, thus often with low application orientation needed for patentability.

We further argued that trends will emerge in scientific publications first and only later be seen in patents. Our findings shown in Table 3 can support this — with the only exception of the industry sector of Chemicals. The (weighted) average scientific article from the Chemicals' sector will be three years younger than the average patent. In contrast to the other sectors, Chemical companies will be active much less in regard to possible market applications of phytosterols. Their competencies focus mainly on topics such as methods for analysis, separation or processing of phytosterols. And many of these procedures are either not patentable or more valuable as internal "procedural" knowledge.

Strikingly, the overall time lag is eight times higher than in our set of firms (15.9 years to 2.0 years, respectively), indicating a high interest in commercialization and probably also a holding back of research results until promising findings are filed for patenting. One additional reason for the considerably higher age of the publications by organizations not within our company sample could be based on academic papers focusing on general characterizations and descriptions of phytosterols, e.g. in their natural environment of plants (as presented in Table 2, 55% of all publications are not from any of our three dedicated subject areas). Finally, the fact that in the Personal Care sector as well as in the Food & Agriculture sector the (second) oldest patents are from the other of the two subject areas might speak for a development from basic patents (subject area "Rest") over the respective other area and Pharmaceuticals to the primary subject of the industry sector itself. This would be in line with our reasoning of a trend of convergence, as this means companies have seen possible applications of "their" products in the other sector and have deemed it interesting enough to have it patented. Apparently both sectors have identified these cross-sectoral applications, pointing to a certain degree of fading boundaries.

6. Conclusion

In this paper we introduced the idea of a comprehensive approach towards anticipating industry convergence on the basis of publication data analysis. We aimed at developing a reliable concept for monitoring such phenomena of blurring industry boundaries and demonstrating its applicability with first results from the Cosmeceuticals and NFF sectors.

Notwithstanding our encouraging first results, they should be interpreted with great caution. For a thorough analysis of the degree of convergence in the two industrial sectors many more indicators should be tested (as outlined in Sections 3.2 and 3.3),

covering all three steps of convergence — scientific, technological and market convergence. Thus far (co-)citation and co-word analyses have been given much of the credit as powerful means of analyses. Only after a comprehensive comparison of these indicators with research on e.g. co-authorship/co-applicant, patent and industry classifications, should a decision be made in respect to which indicators might be indispensable proxies and which may only have additional informational or no benefit at all. Because of the varying degree in the propensity to patent (based mainly on industry, firm and patent type specifics) further studies should give special consideration to the type of patents in different industry sectors.

Future research will not only have to show which of the discussed indicators should be used, but also whether these results are applicable to other occurrences of convergence as well. This holds especially true for those, which are not already largely recognized. The choice of search terms and the appropriate databases will play a most vital role. Finally, in order to be able to gather all the necessary data even for larger technological or scientific fields, we will have to use computer-aided data mining techniques in order to process larger amounts of the available information and to use standard statistical methods without violating obligatory minimum sizes for meaningful calculations. This is even more important, where underlying mega trends might be cloaked under massive amounts of data. A further refinement of this approach should especially include the visualization of time-dependent shifts in overlap between scientific/technological fields and industries. STN® AnaVist™, a software tool within the chemical and its related domains, could enable both the employment of visual data mining techniques and a larger emphasis on the time component. One application of this program could be the compilation of research landscapes (topographical maps clustering documents according to content and classifications) based on IPCs. If this would prove to be a reliable source for the assessment of the degree of convergence, researchers would only have to use the IPCs of interest to them to create a sample of documents for an AnaVist-based analysis. This would make any consideration of proper search terms redundant and could be done easily on a regular basis.

With recent developments in the chemical industry and exponentially growing amount of data, a closer look on industry convergence and effective tools for harvesting the world's knowledge wealth appears to be necessary and of high relevance to academics and practitioners alike. We contributed to the existing body of literature, discussing a monitoring concept for the anticipation of converging industries. Practical implications lie in the high strategic importance of building a clear margin over a firm's current and future competitors. Thus, on the basis of publicly available data, firms will be able to anticipate technology and industry convergence and prepare for new markets and new customers in advance.

Acknowledgements

The authors would like to thank the editor Fred Phillips, the two anonymous reviewers and the participants of the XIX ISPIM Conference and the R&D Management Conference 2008 for their constructive comments, leading to a substantially improved research approach and its delineation in the present paper.

References

[1] J.M. Pennings, P. Puranam, Market convergence & firm strategy: new directions for theory and research, ECIS Conference, The Future of Innovation Studies, Eindhoven, Netherlands, 2001.
[2] G. Duysters, J. Hagedoorn, Technological convergence in the IT industry: the role of strategic technology alliances and technological competencies, Int. J. Econ. Bus. 5 (1998) 355–368.
[3] B. Niedergassel, C.-S. Curran, M. Leßing, J. Leker, What drives partners in industry–academia cooperation? Int. J. Technol. Intell. Plan. 3 (2007) 331–342.
[4] O. Gassmann, M.A. Bader, Patentmanagement: Innovationen erfolgreich nutzen und schützen, Springer, Berlin, Germany 2006.
[5] S. Bröring, J. Leker, Industry convergence and its implications for the front end of innovation: a problem of absorptive capacity, Creat. Innov. Manag. 16 (2007) 165–175.
[6] P.E. Bierly, A. Chakrabarti, Dynamic knowledge strategies and industry fusion, Int. J. manuf. Technol. Manag. 3 (2001) 31–48.
[7] S. Bröring, The Front End of Innovation in Converging Industries: The Case of Nutraceuticals and Functional Foods, DUV, Wiesbaden, Germany, 2005.
[8] L.G. Zucker, M.R. Darby, J.S. Armstrong, Commercializing knowledge: university science, knowledge capture, and firm performance in biotechnology, Manage. Sci. 48 (2002) 138–153.
[9] T. Gill, Convergent products: what functionalities add more value to the base? J. Mark. 72 (2008) 46–62.
[10] F. Fai, N. von Tunzelmann, Industry-specific competencies and converging technological systems: evidence from patents, Struct. Chang. Econ. Dyn. 12 (2001) 141–170.
[11] D. Choi, L. Valikangas, Patterns of strategy innovation, Eur. Manag. J. 19 (2001) 424–429.
[12] M.L. Katz, Remarks on the economic implications of convergence, Ind. Corp. Change 5 (1996) 1079–1095.
[13] M. Meyer, Does science push technology? Patents citing scientific literature, Res. Policy 29 (2000) 409–434.
[14] F. Murray, Innovation as co-evolution of scientific and technological networks: exploring tissue engineering, Res. Policy 31 (2002) 1389–1403.
[15] D.C. Mowery, N. Rosenberg, The influence of market demand upon innovation: a critical review of some recent empirical studies, Res. Policy 8 (1979) 102–153.
[16] J. Howells, Rethinking the market–technology relationship for innovation, Res. Policy 25 (1997) 1209–1219.
[17] J. Hauschildt, S. Salomo, Innovationsmanagement, Vahlen, München, Germany, 2007.
[18] M.G. Moehrle, H. Lessing, Profiling technological competencies of companies: a case study based on the theory of inventive problem solving, Creat. Innov. Manag. 13 (2004) 231–239.
[19] H. Ernst, T. Teichert, The R and D marketing interface and single informant bias in NPD research: an illustration of a benchmarking case study, Technovation 18 (1998) 721–739.
[20] H. Ernst, Patenting strategies in the German mechanical engineering industry and their relationship to company performance, Technovation 15 (1995) 225–240.
[21] A. Gambardella, S. Torrisi, Does technological convergence imply convergence in markets? Evidence from the electronics industry, Res. Policy 27 (1998) 445–463.
[22] H. Ernst, Patentinformationen für die strategische Planung von Forschung und Entwicklung, Deutscher Universitäts Verlag, Wiesbaden, Germany, 1996.
[23] R.J. Watts, A.L. Porter, Innovation forecasting, Technol. Forecast. Soc. Change 56 (1997) 25–47.
[24] J. Hagedoorn, M. Cloodt, Measuring innovative performance: is there an advantage in using multiple indicators? Res. Policy 32 (2003) 1365–1379.

[25] A. Agrawal, R. Henderson, Putting patents in context: exploring knowledge transfer from MIT, Manage. Sci. 48 (2002) 44–60.
[26] M. Gittelman, B. Kogut, Does good science lead to valuable knowledge? Biotechnology firms and the evolutionary logic of citation patterns, Manage. Sci. 49 (2003) 366–382.
[27] F. Valentin, R.L. Jensen, Reaping the fruits of science: comparing exploitations of a scientific breakthrough in European innovation systems, Econ. Syst. Res. 14 (2002) 363–388.
[28] I. Daizadeh, Using intellectual property to map the organisational evolution of firms: tracing a biotechnology company from startup to bureaucracy to a multidivisional firm, J. Commer. Biotechnol. 13 (2006) 28–36.
[29] S. Lee, S. Lee, H. Seol, Y. Park, Using patent information for designing new product and technology: keyword based technology roadmapping, R & D Manag. 38 (2008) 169–188.
[30] C. Canongia, A. Antunes, M.D.F. Pereira, Technological foresight — the use of biotechnology in the development of new drugs against breast cancer, Technovation 24 (2004) 299–309.
[31] J.C. Guan, S.Z. Liu, Comparing regional innovative capacities of PR China-based on data analysis of the national patents, Int. J. Technol. Manag. 32 (2005) 225–245.
[32] J. Schmookler, Invention and Economic Growth, Harvard University Press, Cambridge (MA), USA, 1966.
[33] J. Hagedoorn, Inter-firm R&D partnerships: an overview of major trends and patterns since 1960, Res. Policy 31 (2002) 477–492.
[34] M. Henzinger, S. Lawrence, Extracting knowledge from the World Wide Web, Proc. Natl. Acad. Sci. U. S. A. 101 (2004) 5186–5191.
[35] H. Järvenpää, S. Mäkinen, Managerial foresight and recognising value creation potential in an uncertain environment: a bibliometric study of distinguishing successful from unsuccessful technology, R&D Management Conference 2007, Risk & Uncertainty in R&D Management, Bremen, Germany, 2007.
[36] E.J. Rinia, T.N. van Leeuwen, E.E.W. Bruins, H.G. van Vuren, A.F.J. van Raan, Measuring knowledge transfer between fields of science, Scientometrics 54 (2002) 347–362.
[37] M. Meyer, U. Schäffer, M. Gmür, Transfer und Austausch von Wissen in der Accounting-Forschung: Eine Zitations- und Kozitationsanalyse englischsprachiger Accounting-Journals 1990–2004, Schmalenbachs Z. Betr.wirtsch. Forsch. 60 (2008) 153–181.
[38] A.L. Porter, D.E. Chubin, An indicator of cross-disciplinary research, Scientometrics 8 (1985) 161–176.
[39] J. Butcher, P. Jeffrey, The use of bibliometric indicators to explore industry–academia collaboration trends over time in the field of membrane use for water treatment, Technovation 25 (2005) 1273–1280.
[40] L. Ortega, K. Antell, Tracking cross-disciplinary information use by author affiliation: demonstration of a method, Coll. Res. Libr. 67 (2006) 446–462.
[41] H.F. Moed, Citation Analysis in Research Evaluation, Springer, Dordrecht, Netherlands, 2005.
[42] R.J. Watts, A.L. Porter, G. Tech, N.C. Newman, Innovation forecasting using bibliometrics, Compet. Intell. Rev. 9 (1998) 11–19.
[43] B. Yoon, R. Phaal, D. Probert, Morphology analysis for technology roadmapping: application of text mining, R & D Manag. 38 (2008) 51–68.
[44] A. Verbeek, K. Debackere, M. Luwel, E. Zimmermann, Measuring progress and evolution in science and technology — I: the multiple uses of bibliometric indicators, Int. J. Manag. Rev. 4 (2002) 179–211.
[45] K.W. Boyack, Mapping knowledge domains: characterizing PNAS, Proc. Natl. Acad. Sci. U. S. A. 101 (2004) 5192–5199.
[46] M. Makri, P.J. Lane, A search theoretic model of productivity, science and innovation, R & D Manag. 37 (2007) 303–317.
[47] D.M. Hicks, J.S. Katz, Where is science going? Sci. Technol. Human Values 21 (1996) 379–406.
[48] R.E.J. Ostlund, Phytosterols in human nutrition, Annu. Rev. Nutr. 22 (2002) 533–549.
[49] K.G. Moruisi, W. Oosthuizen, A.M. Opperman, Phytosterols/stanols lower cholesterol concentrations in familial hypercholesterolemic subjects: a systematic review with meta-analysis, J. Am. Coll. Nutr. 25 (2006) 41–48.
[50] National Cancer Institute, Phytosterol, 2008 Retrieved April 18, 2008, from http://www.cancer.gov/Templates/db_alpha.aspx?CdrID=44485.
[51] Y. Ichiji, Arista Lifescience Corporation, Japan, Cosmetics containing sulfated phytosterols, 2004, JP Patent 2004250402.
[52] R. Wachter, H. Tesmann, A. Behler, K.-H. Maurer, Deodorizing Preparations, 1998, WO Patent 98/17241.
[53] H. Meyer, Cosmetic preparation for topical application, used for treating cellulite, 2001, WO Patent 01/87257 A1.
[54] W. Eisfeld, P. Busch, U. Issberner, P. Biehl, Haarpflegemittel mit natürlichen Ölen, 2002, DE Patent 10126448 A1.
[55] 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 Manag. 36 (2006) 487–498.
[56] M. Cole, When food meets medicine, Int. Rev. (June/July 1991) 15–17.
[57] W.J. Donnelly, M.A. Fenelon, L. Giblin, C. Stanton, Obesity. The food research agenda, Int. J. Dairy Technol. 61 (2008) 11–15.
[58] S. Crompton, Hype or beautiful science? Times Online, Times Newspaper Ltd., London, 2007 Retrieved April 18, 2008, http://women.timesonline.co.uk/tol/life_and_style/women/body_and_soul/article2645139.ece?print=yes&randnum=1208519464093.
[59] H. Dureja, D. Kaushik, M. Gupta, V. Kumar, V. Lather, Cosmeceuticals: an emerging concept, Indian J. Pharmacol. 37 (2005) 155–159.

Clive-Steven Curran graduated from the University of Münster with a Diploma in Biotechnology, including a research stay at the Hamburg University of Technology. Currently, he works as a research assistant, focusing on the use of Visual Data Mining and patent analysis to anticipate converging industries — with a special consideration of the characteristics of the chemical and related industries.

Stefanie Bröring holds a PhD from the University of Münster. After gaining practical experience in the life science sector and management consulting, she recently has been appointed as Professor for Food Chain & Innovation Management at the University of Applied Sciences in Osnabrück. Her research focuses on innovation management in converging industries.

Jens Leker is a Professor of Business Administration at the Department of Chemistry and Pharmacy at the University of Münster. He obtained his PhD in Business Management from the University of Kiel. His institute's interdisciplinary approach combines business management research with natural sciences in order to get a deeper understanding of R&D processes.