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Patent citations as a tool for analysing the early stages of convergence

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ABSTRACT

The objective of this paper is to enhance understanding of the evolution of convergence. Previous research has shown that the technological interfaces between distinct industries are one of the major sources of new radical cross-industry innovations. The study creates novel patent analysis methods to analyze technological convergence and provide tools for anticipating the early stages of convergence. Our case study is based historically on two very distinct industries of the paper and electronics companies as a test environment to evaluate the importance of emerging business sectors and technological convergence as a source of industry transformation. Patent data include citations to previous patents and to the non-patent literature. These citations open up the possibility of tracing technological trajectories of the industries. Patent data was collected from the 84 main players operating in the radio-frequency identification value chain. The test environment of selected patent data base is only used to use, develop and illustrate the patent analysis tools for researching convergence of industries. Patent citation indicators, like citations made and received to patents and non-patent literature, pioneering innovations and technology cycle time are used to evaluate importance of this technology based industry transformation. Overall results from the study are that the citation analysis method shed light of the future technology competitive arena. Further research is needed to understand more deeply the relations and interaction between different stages in the convergence or fusion process.

1. Introduction

The phenomenon of convergence can be regarded as a special form of technological change where inventions emerge at the intersection of established and clearly defined industry boundaries. The phenomenon means that something started to happen between the both worlds, rather than within each of them [1]. Bonnet and Yip [2] argue that technology innovation and convergence are the two fundamental disruptive factors and the most relevant for strategy formulation today. So far, the phenomenon has been mainly analysed in the information and communication technologies (ICT) where convergence offers one of the most complex environments for strategy formulation [3,2]

Previous research [4–6,1] has shown that the technological interfaces between different industries are one of the major sources of new radical cross-industry innovations. This has been shown also in that the classical use of technology roadmapping, like dealing with all aspects of integrating technological issues into business decision making [7–9], has been widening to new ways of promoting technology convergence in technology roadmapping process [10]. Typically the new frontiers of industry and technology tend to be built on the converging paths of previously discrete technologies, such as MEMS (Micro-Electro Mechanical Systems, the convergence of mechanical devices and semiconductor manufacturing technology), bio-informatics (computer science and biotechnology) and mechatronics (mechanics and numeral control technology based on computing). Roadmapping have been identified as a helpful tool for different technologies to converge and create new business models [10]. In the light of

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		Substitution processes	Complementary integration
Assets	Convergence of technologies	Technology substitution	Technology integration
	Convergence of products	Product substitution	Product integration
Activities	Convergence of • Marketing • Sales • Distribution • Etc.	Activity substitution	Activity integration

Fig. 1. Types of technology, product or industry convergence [16].

high strategic importance and challenges in convergence predictions there seems to be clear demand to better understand its meaning in the transformation of industries. On the industry level this has been seen as an increasing need to anticipate change, which will help organizations to address strategies needed in the future.

In the literature convergence has been widely used but rarely properly defined term. Confusion in the concepts and definitions has complicated the theoretical and empirical analysis of this widely used, but rarely properly defined term. Definitions and taxonomies are important because the meaning of convergence usually depends on the author and the implications of different types of convergence are very different. Many of the definitions of convergence are based on the idea of blurring industry boundaries and growing overlaps in technologies and services. The emerging new industry segment will either replace the former segments or will complement them at their intersection [11,12]. Curran et al. [13] further distinguish the difference between the process of convergence and fusion, which have been so far mainly used interchangeably. In their classification "convergence describes a process, where objects move or stretch further from their prior and discrete spots, to a new and common place" and "fusion describes a process, where objects begin to merge with each other in the very same place of at least one of the objects" [13]. In other words convergence means that distinct industries are merging in a new field providing opportunities for new inventions for distinct industry sectors. In fusing industries (e.g. camera and mobile phone industry) the new segment will at least partly substitute prior business segments. However, as both the substitution and complementary effects unfold in parallel and are often interlinked, it can be in practice very challenging to predict the overall effect of convergence [14]. All in all, convergence across technologies, product markets or industries may be substitution-based (horizontal convergence) or integration-based (complementary convergence). The key strategic impact of convergence is that it drives companies with traditionally distinct and stable business models to the same territory. Both forms of convergence may refer to core assets (e.g. patents, know-how, products), or to core activities (e.g. purchasing, operations, distribution, marketing) [15]. Following the framework, we can distinguish between six different categories of convergence (Fig. 1).

Patent citations are a core methodology in the study of intersectoral flows of knowledge and knowledge diffusion [17,18]. This paper uses patent and citations to patents and non-patent literature data to illustrate overlapping technology areas and trajectory changes with the emergence of convergence and new science-based technologies. Patent citation analysis is used to evaluate both the spill-over effects between industries and importance of the technology-based transformation. Particular emphasis is given to validation of patent analysis methods as a tool for technology and innovation policy. This paper has two mains objectives: (1) to provide insights into use of patent data in technology forecasting and research, and (2) to provide conceptual lens to analyse the early stages of convergence via patent analysis methods. The paper uses patent citation data of the paper and electronics companies as a test environment to evaluate the importance of technological interfaces as a source of new radical innovations and industry transformation. Patent data was collected from the 84 main players operating in the radio-frequency identification (RFID) value chain. The test environment of selected patent data base is only used to use, develop and illustrate the patent analysis tools for researching convergence of industries.

The paper is structured as follows: Section 2 outlines background to the phenomenon of convergence and stages of convergence. Section 3 presents the use of patent analysis methods for analysing the early stages of convergence. Section 4 illustrates main empirical findings and finally the study is concluded in Section 5.

2. Stages of convergence

The evolutionary phases of the convergence process [19] have led to a discussion on the stage model of inter-industry innovations. Hacklin [1] identify, describe and formalize four different stages of the convergence process: (1) knowledge convergence, (2) technological convergence, (3) applicational convergence, and (4) industrial convergence. Even though the relationships between science, technology, and industry are very complicated, the stages provide a starting point from which to understand how science and technology, the technology and industry, and further science, technology, and industry are related to each other in convergent industry environments.

2.1. Knowledge and science convergence

The evolutionary phases of convergence are idealised in series of events starting with scientific disciplines, where distinct disciplines are beginning to cite each other and eventually develop further toward closer research collaboration [19]. One can regard the process of convergence as being ignited by "the erosion of boundaries that define and isolate industry-specific knowledge" [20] thereby decreasing the cognitive distance between previously distinct knowledge bases. Hence, trajectories of knowledge bases come closer, and spill-over effects give rise to innovative activities. According to [19] such erosion of knowledge boundaries does not take place, but rather through longer term developments of the industries. This is likely to be based on the awareness of combining the own internal knowledge base with an external one in order to create something novel. Hence, the trajectories of knowledge bases come closer and spill-over effects give rise to innovative activities. Hacklin [1] defines stage of science convergence: "Knowledge convergence denotes the emergence of serendipitous co-evolutionary spill-over between previously unassociated and distinct knowledge bases, giving rise to the erosion of established boundaries that isolate industry-specific knowledge."

Potential indicators for the convergence in science areas are co-authorships and co-citations in scientific articles, journal topics [13] and citations to non-patent literature (NPL) in patent documents. Many indicators of the scientific development or technological development focus on either scientific or technological activity. The interdependencies and interactions between science and technology have been measured in many studies with the use different empirical indicators. Mayer [21] found three basic approaches to study science-technology interaction – industrial scientific research publications, university patenting and non-patent literature (NPL) citations. The most straightforward use of an indicator at the company level is the average number of science references cited on the front page of the company's patents. Strong science linkages indicate that a company is building its technology on advances in science ("closeness to science"). High-technology companies tend to have more science linkages than their competitors and science linkages have been found to be predictive of a company's stock market performance [22]. If the NPL citations sources are scientific, they provide the opportunity to systematically examine relationships between science and technological development [23] and possible changes in science trajectories.

2.2. Technological convergence

The technological interfaces between different industries are one of major source of new cross-industry innovations. Hacklin [1] argues that as knowledge bases eventually translate into technologies, this phenomenon, in turn, does not necessarily represent the result of any conscious managerial action, but can in many cases be regarded as a rather autonomous process, which takes place beyond the firm level. It is as a consequence of the coming-together of underlying trajectories that new opportunities emerge, allowing firms to cross-fertilize throughout the technological intersection, and making technologies pervade new products. As the underlying trajectories converge, the involved technologies intersect in a way that a common technological knowledge base emerges, allowing opportunities for higher performance through diversification into new areas of within the underlying industries. [24,19] Innovations at this stage are at least partly based on a technological intersection, where coming together of technologies has created a tangible potential for the creation of new applications. Hacklin [1] defines the stage of technological convergence as "Technological convergence denotes the transition of knowledge convergence into a potential for technological innovation, allowing inter-industry knowledge spill-overs to facilitate new technological combinations."

Potential measures for technology convergence are co-inventions, growing overlaps and co- classification in Standard Industrial Classification (SIC) and International Patent Classification (IPC) codes, and knowledge spill-overs found in patent citations. Patent data have been mainly used as an indicator of technology convergence, as patents are the easiest way to monitor convergence – implying that the considered industries have a significant propensity to protect new technological developments by patents [13]. This study provides new insights into the analysis of technological convergence by utilizing patent citation data in the analysis.

The interdependencies and interaction between technology markets and product markets have been under wide discussion because of the fundamental difference between them and it has been widely recognized that changes in technological leadership need not necessarily result in changes in market leadership [25]. In order to evaluate analytically the competitive and complementary effects of technological convergence one challenging methodological problem is with the interaction of technology (patents) and product markets [26].

2.3. Applicational and industrial convergence

Once opportunity for the creation of new applications arises, the trajectory of technological change now becomes dependent of the industry's ability to build upon the technological intersection. According to Hacklin et al. [19] this step of technological integration does not only result in the convergence of new applications, products or services, but on a more generic level, leads to service or applicational convergence, as new, higher level forms of providing value for the customer and differentiation towards competitors emerge [19]. Hacklin [1] define the stage "Applicational convergence denotes the transition of technological convergence into opportunities for new value creation in such a way, that it with respect to the majority of metrics outperforms the sum of the original parts."

As emerging applications evolve they increasingly infringe the original value-creating territories of underlying sectors or industries and might lead to a collision of business models, as the development gradually removes the sectoral boundaries

Table 1
Measures for monitoring the stages of convergence (adapted from [13]).

Convergence in	Main sources	Measures	Possible data sources
Science areas	Scientific articles	- (Co)Authorships in scientific articles - (Co)Citations - Journal topics - NPL citations	- SCI//SCOPUS - SciFinder - PATSTAT (NPL)
Technology development	Patents	- Co-Invention (Assignees) - SIC and IPC co-classification - Knowledge spill-overs (patent citation data)	- Patent offices - SciFinder - PATSTAT
Product applications	Press releases	- Product launches - Customer trends	- Company data - Expert interviews
Industry segments	General firm and industry information	- Product portfolios - Strategic alliances - Mergers and acquisitions	- Company data - Factiva - Newspaper archives

between the involved industry segments [1,13]. In terms of competition, this paradigm shift changes the rules of the industry. In the "substitutive paradigm" the new industry segment will replace the former segments leading to the competitive convergence. In the "cooperative paradigm" a new market emerges which requires the combination of resources and competencies from previously separate industries (e.g. through strategic alliances or other forms of collaboration) leading to complementary convergence [11]. In the "coopetitive paradigm" convergence may also imply a need to collaborate and compete at the same time. Hacklin et al. [19] provide example of mobile handset manufacturers and software manufacturers which in their origins can be regarded as highly unrelated, one can today observe direct competitive collision as the industry convergence is bringing along the battle for mobile handset software platforms. Such a collision of previously established business models resulting within converging industries might be able observe in alliances and M&A activity reaching beyond previously established industry boundaries [24]. According to Hacklin [1] "Industrial convergence denotes the transition of applicational convergence into the shift of industry boundaries in such a way, that firms from previously distinct industries through the emergence of common applications suddenly become competitors." Hacklin [1] is mainly concerned with the substitution type of convergence. However, the complementary or integration type of convergence provides opportunities for inter-industry collaboration. In addition, the forces driving the knowledge and technological convergence are usually not the same as the forces driving the convergence of product markets and industries; for example, there could be fierce competition in technologies, whereas in the later stages there are more incentives to cooperation.

Potential measures for product market and industrial convergence are changes in product portfolios, customer trends, strategic alliances, and mergers and acquisitions. The evolutionary stages of convergence has lead to a discussion on the stage-model of inter-industry innovations and Curran et al. [13] present some potential measures for monitoring the stages of convergence (Table 1).

Although such a linear mode is criticized it provide basis for analysing convergence as evolutionary process. Scientific, technological, and industrial knowledge differ greatly in the characteristics of their creation, and clarifying the linkage between them is not easy because the properties of knowledge generated in each stage are very different. In case of emerging technologies, where little or no historical data available, use of science and patent indicators have been used on forecasting and foresight studies [27–29]. Daim et al. [30] demonstrate that there is a strong correlation between research funding and different research outputs. In their study the time lag between funding and patents issued is evident from the patent trend analysis and bibliometric analysis. In case of nanoscope the patent time lag was found to be approximately 5–6 years, for journal article it was approximately 2–3 years and conference presentations happened right after the funding [30]. The evolutionary stages provide a starting point to understand the complicated phenomenon and relations between science, technology, and industry evolution. Patent analysis is used mostly to evaluate the technology dominated emergence of convergence, but also science-based convergence has been evaluated as the citations to non-patent literature have been analysed. All in all, patent data have been used in some studies in analysing technological trajectories [31–34] and technological trajectories in converging industry environments [35,36].

3. Patent citations in converging industry environments

3.1. Prior art search

Patents are legal documents where citations are much more carefully selected than citations in journal papers. This is to some extent due to patent examiners, who identify the citations that are relevant for the examination of a patent [37]. The main objective of the search process is to discover the relevant prior art for determining whether the invention meets the novelty and inventive step requirements for patentability. The prior art search is important for citation analysis because citation analysis use references to patent and non-patent literature derived from the search report. There are, of course, many fundamental differences between the patent systems and so indicators are not directly comparable. One of the most striking differences is that in the EPO system the initial prior art search is carried out by a searcher at the European Patent Office. In the U.S. system the patent applicant and his attorney are required to present to the patent examiner a complete list of relevant prior art for inclusion on the patent front page. At the EPO no such requirements exists [37]. In addition that the difference in interpretation between examiner and applicant citations can be significant [38], the European search report should include only the most important documents [39]. Alcacer and Gittelman [38] found that examiners are responsible for 63% citations of U.S. patent data. Inasmuch as examiners simultaneously classify patents and search for prior art within classes, it is plausible that they match citing and cited patents on technology class to a greater than inventors indicating more within-class technology citations than if only inventor citations were used [38].

Michel and Bettels [40] state that ".. according to the EPO philosophy a good search report contains all the technical relevant information within a minimum number of citations." Applicants to USPTO are legally required to include a full list of prior art known which can be filtered and supplemented by the examiner. Michel and Bettels [40] report that US patents cite about three times as many patent references and three and a half times as many non-patent references compared with European patents. At Japan and South Korea there is tendency to patent more incremental inventions as a corporate researcher there is required to deliver one to two inventions per month leads to a smaller but more numerous patent applications [41]. The differences in patent law and practices leads to the question of how to interpret highly aggregated statistical regularities and citation patterns in a worldwide database. One natural solution is to use homogenous patent data coming from a single patent office or single set of patent office's [37].

3.2. Patent citation indicators in convergent environments

Among other important virtues of patent citations an ability to trace spillovers and to create indicators of the significance of individual patents has allowed patent citations to be used to trace the technological trajectories [42,43]. Previous research has used information on citations made about the extent of knowledge spillovers between regions, industries, firms and science-technology interaction [44–45] and citations received by patents are considered to reflect the patent's technological significance, the applicability and the ability of the inventors to benefit from their inventions, namely, their appropriability [46,47].

Patent data include references to non-patent literature opening up the possibility to study spill-overs in technologies and scientific fields between distinct industrial sectors. Patents and scientific literature can often be regarded as complements: patents focus on how to make inventions work, whereas scientific articles focus on the scientific contribution and research findings. Patent indicators can give insight into process of knowledge transfer from science to technology. The citations to non-patent literature have been used in evaluating the proximate linkages between scientific research and technological innovation. This means that patents are considered a representation of technology, while papers and citations to them are viewed as representations of science. Science linkage indicators are based on counts of references to the non-patent literature considered as scientific and the data can offer a proxy measure for the industrial relevance of research. There is some recognition that non-patent references are useful for investigating the interplay between science and technology [48,49,41]. Given the current understanding of these non-patent literature citations, they should not be reflecting directly scientific sources, but rather considered a general indicator of interaction between science and technology [41]. The science linkage indicators have become an increasingly important policy in times where even basic research needs to document its value for industry.

This study uses patent citations to non-patent literature (NPL) in order to evaluate potential science-based convergence between distinct industries. Previously, the average amount of citations made to the scientific literature in a patent produced in a particular sector has been used as a proxy of the science intensity of R&D activities in the sector. We are utilizing citations to scientific sources in providing a view of the stage of new industry segment in the intersection of paper and electronics industries. Non-patent literature (NPL) references consist not only of scientific articles, but include a mixed set of other types of publications: conference proceedings, books, and many other non-scientific sources such as disclosure bulletins, abstract services, and so forth. In practice, patent applications which have a closer link to traditional fields of science, for example, chemistry and physics are more frequently confronted with non-patent literature [41]. According to OECD [50] references to non-scientific documents such as "patent abstracts" and commercial online patent database services should be removed for the purposes of analysis of science linkage in patents. Karvonen and Kässi [51] divided NPL citations into scientific and technology-related categories (Table 2).

In the taxonomy of reference types (Table 2), in a most narrow sense only journal references refer to the actual scientific journal literature and covered by the Science Citation Index (SCI) could be considered scientific. However, other serial journal literature, conference proceedings, and books can be considered "science at large." On the other side, industry and patent-related

Table 2
Taxonomy of NPL reference types (adapted from [23]).

Category	Sub-category	Description
Science "at large"	SCI-covered journals	References to scientific publications published in serial journal literature covered by The Science Citation Index (SCI).
	Not SCI-covered journals	References to scientific publications published in serial journal literature but NOT covered by the SCI.
	Conference proceedings	Proceedings from conferences and workshops.
	Books (reference books, databases)	All books (including encyclopaedias, handbooks).
Technology "at large"	Industry/company related documents	Technical Disclosure journals and bulletins; Company journals: Catalogues, Brochures; Technical reports.
	Patent related documents	Patent abstracts; abstract services, search reports.

Table 3
Patent citation indicators for convergence analysis.

Category	Sub-category	
Non-patent literature citations (exploration)	Within scientific discipline	
	Beyond scientific discipline	
Backward citations (exploration)	Self-citations	Within technological domain
		Beyond technological domain
	External citations	Within technological domain
		Beyond technological domain
Forward citations (exploration)	Self-citations	Within technological domain
		Beyond technological domain
	External citations	Within technological domain
		Beyond technological domain
Pioneering innovations	Within technological domain	Beyond technological domain
Technology cycle time	Rate of technological innovation	
	Firms absorptive capacity	
2nd order citations ('breakthrough innovations')	Within technological domain	Beyond technological domain

documents can be seen as "technology at large." [23] One indicator of interdisciplinary development is the percentage of citations outside one's own industry discipline (Table 3).

The meaning for the industry structures and economic value of each type of citation may be different. Self-citations would suggest that the firm has a strong competitive position in that particular technology. Citations to patents of others are closer to the pure notion of spillovers. Typically a more appropriable technology does not transmit readily through external spillovers [47]. In our framework both self-citations and external citations can be classified within or beyond industry citations leading altogether to the four different kinds of citations: (1) self citations within the industry, (2) self citations beyond the industry, (3) external citations within the industry, and (4) external citations beyond the industry (Fig. 2) which are close to Rosenkopf and Nerkar [52] typology of local search (within firm and within technological boundaries), internal boundary-spanning search (within firm and beyond technological boundary-spanning), external-boundary spanning search (beyond firm and within technological boundaries), and radical (or distant) search (beyond firm and beyond technological boundary-spanning).

Making a distinction between the types of citations and looking into both backward and forward citations may shed light on the future competitive area. Self-citations within the industry (technological domain) describe that of "local search" – also referred to as exploitation – generates mainly incremental innovations concentrated in existing technological domains. Self-citations typically indicate a strong competitive position in the particular technology and the firms are in a position to internalise the knowledge created by their own development. Local search indicate mainly capability development in own technological fields. Rosenkopf and Nerkar [52] argue that moving beyond local search requires exploration span some boundary, organisational or technological. Self-citations beyond the industry (technological domain) span the technological domain. This internal-boundary spanning search means capability diversification to the new fields. External citations within the industry span organisational domain, i.e. external-boundary spanning meaning intensifying competition within the industry. External citations beyond the industry (or technological domain), i.e. radical search spans both boundaries, meaning diversification to the new fields (see [27]). The literature of evolutionary economics assume that innovations are history dependent, i.e. organizations often search for new capabilities in areas that allow them to build on their established technological base. The central assumption in evolutionary theory is that of "local search", where firm R&D activity is closely related to its previous R&D activity [53]. Local search also has a downside as by focusing on familiar combinations can preclude the inventor from investigating more distant—and potentially more useful—possibilities; as inventors continue to work with a particular set of components, they may exhaust the set of useful combinations. In radical search spanning both boundaries new technological combinations engineers carry over an exploration process or distant search [53,54]. Convergence between distinct industries leads increasing citations made (exploration) outside industry boundaries (Table 2) and to the potential emergence of new converging industry segment (exploitation).

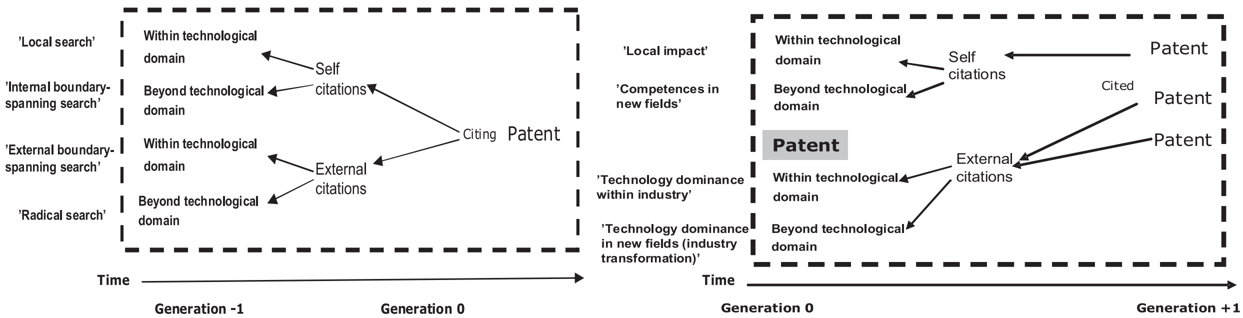

Fig. 2. Types of patent citations for evaluating knowledge spill-overs and technology competences.

In addition one possibility is also to look at inventions without prior art as a potential pioneering (or potential radical inventions) innovation approach. The patents with no references to previous patents (no prior art), but with many received citations, are called pioneering innovations (Fig. 3). The pioneering innovations can be considered as real breakthrough innovations in the industry.

Technology cycle (TCT) time measures the rate of technological innovation and how quickly firms are absorbing new technologies. The TCT is defined "as the median age of the patents cited on the front page of a patent document" [55]. When the TCT was long, the technology was older, and when the TCT was short, the developed technology was younger. Typically emerging technologies have short cycle times, four years or less, whereas more mature technologies can display TCT that averages 15 years or more [56]. TCT uses the rate of substitution in relation to technological progress with the shorter cycle times reflecting faster substitution (fast progress) and longer cycle times reflecting slower substitutions (slow progress). Long TCT's could indicate the cumulativeness of innovative activities implying that the knowledge base that forms the foundation of the technology is large. Short TCT indicate that something new has been added to the knowledge base [55]. The areas of convergence can be articulated to be characterized by most rapid growth and innovation and based on that so we could anticipate shorter TCT values in converging environments. In addition Bierly and Chakrabarti [57] have found that TCT is significantly faster for firms that predominantly generate new knowledge internally and slower for firms that rely on external sources of new knowledge.

3.3. Data and method

In order to identify a firm's technological domains, the observed International Patent Classification (IPC) technologies in the firm's patent records were identified and classified into technology fields representing the firm's major business domains. Patent application in each field indicates an accumulation of knowledge and advancement in the technological trajectory [33]. IPC codes are a hierarchical way of assigning the category to which every patent belongs. In a first step relevant technical areas which are prone to be influenced by the changing business environment will be identified. In a second step patents and citations in the technical areas between the industry players are analysed more deeply based on the findings from the first step. Our attempt to identify patent classes which are substitutes or complements is an important first step in an assessment of the overlapping technology areas. In order to evaluate the competitive and complementary effects one challenging methodological problem is with the interaction of patents and product markets. The patent literature does not contain a reliable method to map patents to products markets. A complementary practical problem emerges as patents are classified into technology fields using the International Patent Classification (IPC) codes, whereas firms are often assigned to industry classifications according to their principal line of business. Any attempt to link between patents and product markets must assign patents in IPC classes to industry classes. Attempts to do this exist but these disregard the problems in linking product markets and patent classes which noted above. Regardless of the challenges related to associating technologies and industries, IPC classifications based concordances have become more popular for associating patents with industry-based categories [58,59]. In using these descriptive measures we assume that patents which are used as complements (or substitutes) within the same technology fields will also reference the same prior art more often than patents which are independent. The measure can be misleading if different patents are related in a technological sense but used independently in the product market [25]. We will compute many of these indicators on an annual basis in order to analyse and to compare their development over time. For most of the indicators we will use the application filing date of a patent as the reference year for the indicators.

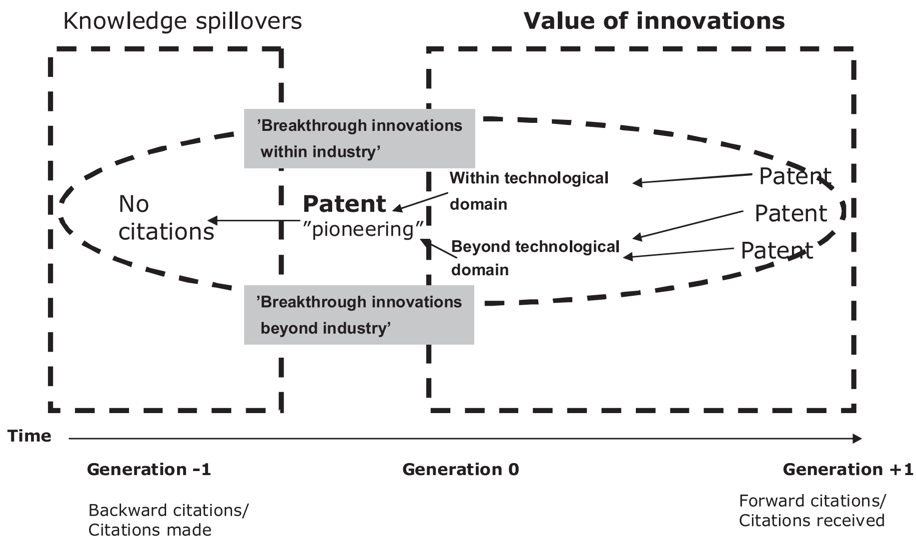

Fig. 3. The pioneering innovations.

Information on patenting was drawn from the publicly available EPO Worldwide Patent Statistical Database, also known as PATSTAT. The database covers data from over 80 countries including over 70 million records (63 million patent applications and 7 million granted patents). In the study we consider patent applications allowing an analysis of more recent data, knowing that several years typically elapse between the filing and the granting of a patent. Patent applications are classified by applicant, inventor, priority dates, application date and technological classes [60]. The PATSTAT database resolve issues over patent family members and allows us to identification of claimed priority permitting us to distinguish between multiple applications for the same inventions in several patent offices. The structure makes citation analysis more reliable since it allows for the identification of the original priority application of any cited patent. However, our analysis is based wholly on patent applications and their citations this have to be taken account when interpreting the results. The citations data of patents and non-patent literature have been used to get an idea of the stage of new industry segment emergence in the context of the paper and electronics companies as a test environment. Patent data was collected from the 84 main players operating in the RFID value chain. The test environment of selected patent data base is only used to use, develop and illustrate the patent analysis tools for researching convergence of industries.

4. Empirical illustration

We introduced some of the empirical results on applicability of patent citation data related to our test environment in earlier papers [61–62] and in this paper we are focusing on experiences of methods which we have used in our studies. Our test environment the RFID and printed functionality sector provides an interesting area to study emerging business sectors as there is both convergence process (totally new business segments for distinct industries) and elements of fusion of technologies (substituting conventional electronics and paper products). The definition of converging (or fusing) technologies implies that overlaps between technologies are a precondition for the phenomenon, and therefore the procedure for identification of technological overlaps and technical areas, in which possible convergence (or fusion) are most likely to occur, is an important step in our analysis.

In the analysis there were altogether 84 firms which were characterised into four different clusters under the following headings: upstream focused players ($n = 26$), vertically integrated players ($n = 23$), downstream players ($n = 17$) and paper and printing ($n = 18$) companies. In the empirical part we analysed each cluster patents and their citations in years 1978–2006. The analysed firms had altogether 464,225 patent applications in the period. For the patents there were on average 4.2 references to patents and 1.1 references to non-patent literature. The firms had made altogether 1,942,254 citations of previous patents and 515,815 citations to non-patent literature. The results of the analysis reveal great differences in the “science intensity” between the different industry sectors. Table 4 shows that the downstream electronics and vertically integrated electronics players have on average made most of the backward citations both to patents (“technology intensity”) and to non-patent literature (“science intensity”). Paper and printing firms have made an average of only 2.14 citation references to their previous patents 0.12 citations to the non-patent literature [52].

The patent data analysis is used to identify overlapping technology areas and potential trajectory changes with the emergence of convergence and new science-based technologies. The results of our empirical test environment indicate that the paper and printing companies patent increasingly in electronics technologies, suggesting that the industries are becoming more technologically convergent [62].

4.1. Non-patent literature citations

When analysing more deeply the paper and printing firms 9,597 citations made to non-patent literature (NPL) we can see that they are rather evenly to “scientific at large” (51.4%) and “technology at large” (48.6%) categories. In our dataset citation to NPL was very low in the early 1980s and started then to grow quite rapidly, and the figures presenting relative distribution between different types of citations is presented from 1987 to 2006.

When looking all the “scientific at large” citations we can see that most of citations are to the scientific journals covered by the Science Citation Index (SCI) (43.1%), which in the narrowest sense could be considered as the only really scientific references. The other “scientific at large” references are formed by not SCI covered journals (31.3%), conference papers (14.4%), and books (11.4%). In our analysis we divided the citations made to different NPL sources to the traditional paper industry related sources of

Table 4
Descriptives of the players' patent and citations data.

1978–2006	Upstream electronics ($n = 26$)	Downstream electronics ($n = 17$)	Integrated electronics ($n = 23$)	Paper and printing ($n = 18$)	SUM
Patent applications	124,184	43,518	218,560	77,963	464,225
Patent citations	417,118	247,786	1,110,719	166,631	1,942,254
“Technology intensity”	3.35	5.69	5.08	2.14	4.18
NPL citations	62,809	85,257	348,569	9,597	515,815
“Science intensity”	0.51	1.96	1.59	0.12	1.11

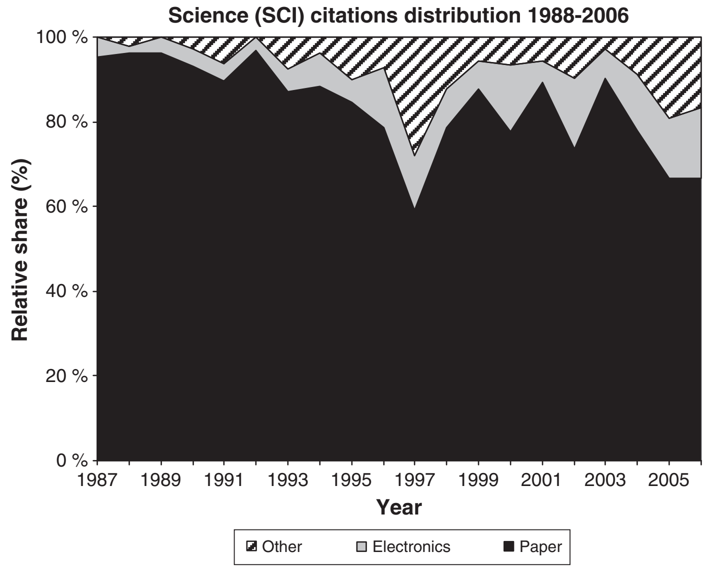

Fig. 4. The paper and printing firms' SCI covered citations to paper and electronics industry journals.

science and to the electronics industry science. Figure 4 shows that majority of the "scientific" (covered by SCI) citations are made within the industry and science boundaries related to the paper industry [52].

It is important to understand the different kinds of citations to non-patent literature and the quota of non-patent citations as indicator for the science-technology interaction is not sufficient. However, the manual work in categorising different citations is time consuming. Our findings however reveal that citations in patents to non-patent literature allow developing nontrivial indicators. The majority of all non-patent references are scientific journal references, which provide possibilities for large-scale analyses focusing on the extent to which technological developments are situated within the vicinity of scientific knowledge.

4.2. Backward citations (exploration)

The backward citation analysis to patents indicates that there seems to be real convergence in technologies, as the paper and printing firms' inventions more heavily borrow information or processes from the electronics field [62]. The analysed firms had made altogether 1,942,254 citations of previous patents, of which 211,110 (10.6%) were self-citations. Vertically integrated and downstream players have on average made most of the backward citations. Paper and printing firms have made an average of only 2.14 citation references to their previous patents. We analysed citations made of each cluster distribution top 50 IPC classes in the technological fields. The paper and printing firms' backward citations distribution to technological fields show a clear declining trend into mechanical engineering, whereas electrical engineering patents have been rising enormously in recent years [62].

The downstream players' backward citations are focused and have become over time even more related to computer and communication patents. Upstream players' backward citations are mostly concentrated on electronics and electrics, especially on semiconductor patents, whereas integrated players' citations have been increasing in the computer and communication technology. As a whole there seems to be quite a lot of horizontal spillover between competitors in the electronics industry, but the vertical spillover flow between firms in different industries is very low. The mean percentage of self-citations made is 10.6%. The fact that the percentages are much higher for vertically integrated players supports the notion that innovation is concentrated in very large firms (IBM, Nokia, Intel), and hence the likelihood that they will cite internally is higher. In the other groups, innovation is more widely spread among highly heterogeneous assignees. Interestingly, paper and printing firms' self-citations are predominantly related to the mechanical engineering and chemistry indicating that the capability and core competencies are still predominantly in the traditional fields. The patent analysis reveals that from the paper and printing industry point of view the most overlapping technology fields and spillover technologies are related to computer technology (G06K; G06F), audio-visual technology (G09F; G11B; H04N; H05K); semiconductors (H01L), and optics (G02F; G02B; G03F, G03G1) [62].

4.3. Forward citations (exploitation)

The forward citations have been used in trying to evaluate the significance of this industry transformation. The downside of using forward citations in evaluating the technological significance and the economic value is that they are not available until a substantial period after the granting of a patent, because time is needed to accumulate significant information about its citations. In practice this means that the analysis will be challenging for the evaluation of current or very recent innovations. Overall the

Table 5
Patent analysis for overlapping technologies.

	Industry sector/overlapping technologies	Paper and printing ($n = 18$)	Upstream electronics ($n = 26$)	Vertically integrated electronics ($n = 23$)	Downstream electronics ($n = 17$)
Patents (IPC4) 1978–2006	Computer technology	8,970	23,701	80,709	29,516
	Audio-visual technology	6,685	10,410	32,315	3,650
	Semiconductors	5,224	29,519	29,761	241
	Optics	16,863	8,036	9,926	204
Cit. received Average cit. (Self-cit. %)	Computer technology	6,007 0.67 (5.2%)	66,343 2.80 (9.9%)	**364,230** **4.51** **(14.8%)**	**82,245** **2.78** **(12.8%)**
	Audio-visual technology	6,319 0.95 (8.7%)	25,745 2.47 (7.7%)	**144,502** **4.47** **(9.2%)**	11,847 3.25 (5.1%)
	Semiconductors	4,000 0.77 (4.0%)	**86,032** **2.91** **(13.3%)**	**146,562** **4.92** **(11.9%)**	1,567 6.5 (1.8%)
	Optics	**13,384** **0.79** **(10.3%)**	**25,919** **3,23** **(7.2%)**	39,456 3.98 (5.9%)	1,024 5.02 (6.8%)

paper industry players' have received on average fewer citations than the other players. The paper industry players make an average received 0.91 citations, while upstream (2.36), downstream (2.79) and integrated (4.14) players have received averagely more citations [62].

Table 5 shows a data of the patents and citations received to the overlapping technology areas. The high figure of citations received of integrated players indicates that the patents have been technologically and economically significant. On the contrary the low figures of citations made and received by the paper and printing firms indicates that the spillover effect from emerging fields have not been so tremendous and the importance of new inventions have not been, at least so far, so extensive compared to other players.

4.4. Pioneering innovations, 2nd order citations, technology cycle time

The distribution of pioneering innovations is quite similar compared to patent distribution, and so the players' have these more radical innovations mostly to their own strong technological fields. However, the paper and printing firms' pioneering innovations have increased especially in optics, semiconductors, computer technology, and the basic communication processes, but compared to the other electronics industry actors, the firms still have made substantially less pioneering innovations [61]. In the sample there were totally 306 inventions which have received at least 100 citations, and from these innovations over 60% were made by integrated players. When looking 10 most cited pioneering innovations, the dominant player IBM have made 9 and Texas Instrument one of these breakthrough innovations Interestingly, when looking also cites of second generations citations, there seem to be huge variation between the first and second generation citations. Basically, the patents which have been cited both in first and second generation can be thought to be a real breakthrough and long lasting innovations, while some of the pioneering patents seem to be superseded quite quickly with some new innovations. The patents which have been cited both in first and second generation can be thought to be a real breakthrough and long lasting innovations, while some of the pioneering patents seem to be superseded quite quickly with some new innovations (see [61]). However, the long accumulation process of forward citations restricts their use in the evaluation of current or very recent innovations.

Technology cycle time (TCT) was applied to measure technological innovation progress for the industry players. Overall all the electronics industry players have on average quite similar TCT values (Table 6). Downstream players seem to have on average fastest technological progress, but there is also a lot of variation between different years. Paper and printing companies have a longer median age of cited patents and also there is a lot of variation. On average it seems evident that the paper and printing companies prior art is relatively older and only in years 1985 and 1987 it was lower than the other players.

Table 6
Average values of technology cycle time.

Industry actor	TCT average (1978–2006)	Standard deviation
Paper and printing ($n = 18$)	7.57	1.37
Upstream electronics ($n = 26$)	5.50	0.49
Vertically integrated electronics ($n = 23$)	5.25	0.61
Downstream electronics ($n = 17$)	4.89	1.37
All	5.80	0.42

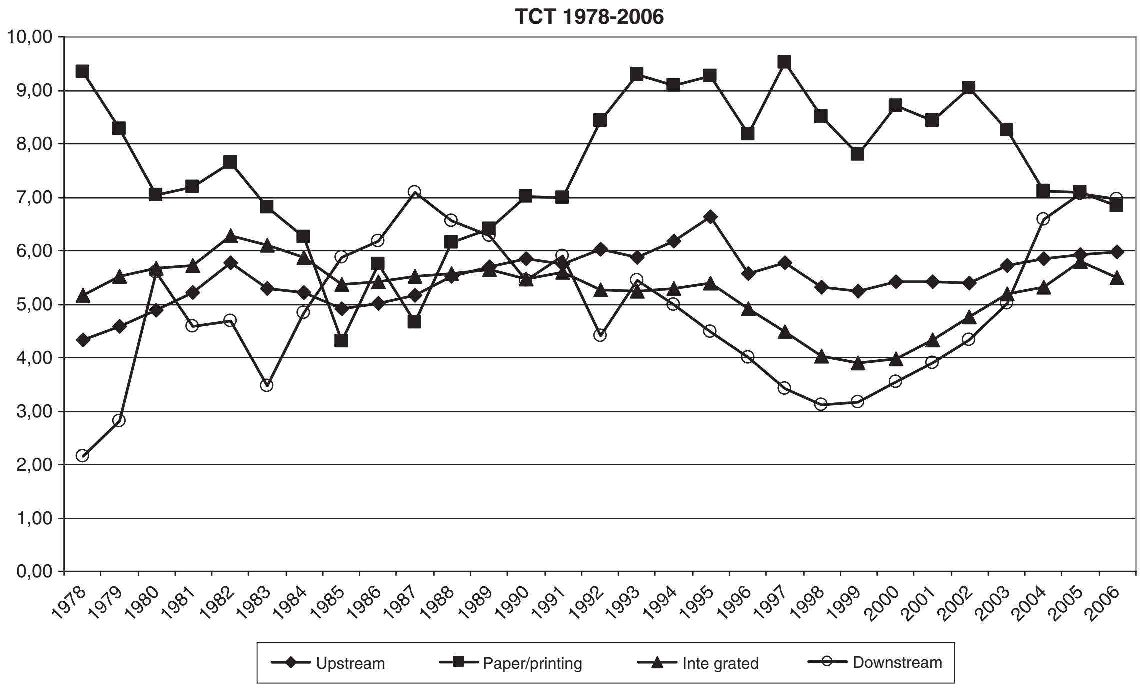

Fig. 5. The players' TCT trend 1978–2006.

The TCT trend for the paper and printing companies was decreasing in years 1978–1987 indicating a fast technological progress and new knowledge was added to the knowledge base. The second faster period for new knowledge was from years 2000–2006. These trends are quite in line with the growth of beyond industry citations in the same time periods (Fig. 5).

Technology cycle time seems to be shorter in most important convergence periods where new beyond industry knowledge was absorbed to the knowledge base. Firms' competence development in new fields (self citation) is dependent on absorptive capacity. Scientific research, and more specifically basic scientific research, is a major dimension of this capacity to absorb and to internalize new knowledge [63]. All in all, summary of the methods used and empirical findings are presented in Table 7.

Table 7
Summary of methods and main empirical findings.

Method	Expected findings	Observation	Validity	Reliability
Non-patent literature (NPL) citations made	References to the scientific literature beyond the industry discipline increasing	Ambiguous results	Unclear	Medium (repeatable)
Backward citations (citations made)	Share of self-citations beyond technological domain increasing	Shows convergence (or fusion)	Yes (subject to limited case study results)	Strong. Corresponds to expected results, repeatable.
	Share of external citations beyond technological domain increasing	Shows convergence (or fusion)	Yes (subject to limited case study results)	Strong. Corresponds to expected results, repeatable.
Forward citations (citations received)	Share of self-citations beyond technological domain increasing	Does not show clear results	Unclear (due to limited observations)	Medium. Accumulation of data over time.
	Share of external citations received beyond technological domain increasing	Does not show clear results	Unclear	Medium. Accumulation of data in course of time.
Technology cycle time (TCT)	Rate of technological innovation high in the areas of convergence	Shows convergence (or fusion)	Yes	Strong/medium
	TCT is faster for firms generating new knowledge internally	Clear results in electronics; unclear in paper and printing due to the limited findings	Valid. Strong in electronics; weak in paper and printing	Strong
2nd order citations	Breakthrough innovations beyond technological domain increasing	Clear results in electronics; unclear in paper and printing due to the limited findings	Weak. Interpretation not clear	Medium (repeatable)

5. Discussion and conclusions

The main goal of the paper is to enhance understanding of the evolution of convergence and provide tools for anticipating the early stages of convergence. The paper uses patent citation data of the paper and electronics companies as a test environment to evaluate the importance of technological interfaces as a source of industry transformation. Patent data was collected from the 84 main players operating in the radio-frequency identification value chain. The test environment of selected patent data base is only used to use, develop and illustrate the patent analysis tools for researching convergence of industries. The patent citation indicators are used to illustrate overlapping technology areas and trajectory changes with the emergence of new technological opportunities. The use of different patent citation indicators (backwards, forwards, pioneering innovations, technology cycle time, non-patent literature citations, 2nd order citations) helps to recognise trajectory changes in the industry and shows macro situation of technology convergence. Empirically the presented patent citation methods give new insights regarding the analysis of the early stages of convergence. The patent data are used to identify overlapping technology areas and potential trajectory changes with the emergence of new business sectors. Patent citation indicators, such as references made to patents and non-patent literature and citations received, pioneering innovations, and technology cycle time are used to evaluate the importance of this technology-based industry transformation. Scientific, technological, and industrial knowledge differ greatly in the characteristics of their creation, and clarifying the linkage between them is not easy because the properties of knowledge generated in each stage are very different.

Patent indicators can give insight into the process of knowledge transfer from science to technology. The references to the scientific literature have been used in order to evaluate potential convergence in science bases. The average number of references made to the scientific literature within and beyond the scientific discipline has been used as a proxy. The relatively high number of citations to the scientific literature in electronics industry indicate that science seem to driving much more knowledge growth in electronics field than in the paper industry where learning by doing and the accumulation of advancements seem to be more important. The results of this study indicate, that the technological convergence have not meant converging knowledge basis in scientific fields. The empirical analysis revealed that there were little scientific and technology citations outside the own industry discipline. All in all, the relation between science- and technology-based convergences needs still further research.

The recognized trends of the trajectory changes and growing overlaps of technological fields show indications for possible convergence between industries. Differentiating between external and self-citations within and beyond industry citations aids to provide more comprehensive prospects of future technology competitive environment. Convergence beyond industry border will lead to gradual capability merging and diversification to the fields as the spill-over effect increases. Citations received can be used as an indicator to evaluate the importance of this technology-based transformation and give insights to the future technology competition. The downside of using forward citations in evaluating the technological significance and the economic value is that they are not available until a substantial period after the granting of a patent, because time is needed to accumulate significant information about its citations. In practice this means that the analysis will be challenging for the evaluation of current or very recent innovations.

There are some inherent limitations in our analysis which requires further studies. First, this study has provided evidence on firms' patenting behavior in the selected market area (RFID) between distinct industries (the paper and electronics) and focused analysis on the most interesting technology areas from the paper and printing industry point of view. So, this study mostly evaluates technology development in converging environments. However, the question of how to effectively find converging technology areas from the patent data without ex ante or expert knowledge needs further research. If industry, technology field and search term independent analyses can be conducted from the patent data, then at least in our knowledge should be a unique approach and should be interesting for also analysing other industry settings. The future studies could use different kinds of similarity (and diversity) indicators for the determination of similarity between the patents using e.g. text documents found in the patent abstracts [64] or use semantic sensitivity measures meaning that documents conceptually very close but with vocabulary would be identified as similar. Secondly, we have made no attempt to differentiate the fusion and convergence of technologies and to connect patenting and product market competition. In order to evaluate analytically the competitive and complementary effects one challenging methodological problem is with the interaction of patents and product markets. The patent literature does not contain a reliable method to map patents to products markets. The indicators of market convergence, like product portfolios and customer trends, would provide us important insights into concrete effects of patents on product market competition. In the future studies this is best achieved in sectoral reviews that take into account the competitive interaction of firms both in technology and product markets [see 25]. The RFID and printed functionality sector provides interesting area to study emerging product markets as there is both convergence (totally new business segments for distinct industries) and elements of fusion of technologies (substituting conventional electronics and paper products). Thirdly, this study takes the view of patent applications as the appropriate unit of analysis. Regarding the significant differences in patenting procedures between countries, industries and technologies it is necessary to widen the analysis in the future to take account patent families, patent portfolios as well as strategic considerations relating patents. Fourthly, the stages of convergence requires further study, as patent citations analysis is used especially to analyse technology dominated emergence of convergence. The technological convergence in our test environment, however, has not mean convergence in sciences. Technology markets are related to science (science-technology interaction) and product markets (technology-application markets interaction). It seems evident that in reality the stages of convergence co-evolve and interact in rather complex ways compared to the linear model in which the progress of science was essentially exogenous and technological advances were merely the outcomes of applied research and development efforts. In the science and technology driven innovations it would be natural to think that in the long run supply factors (science, technology) are dominating in the early phases and demand factors (application, industry) in the late stage of the convergence process. Understanding more deeply the complex interaction between different stages in the convergence process would be useful for technology and policy makers helping for strategic R&D management. Fifthly, it should be remembered that there are several methodological issues in patent analysis which need to be taken account when interpreting the results. For example related to different patent systems, like EPO, USPTO, JPO, there are several shortcomings in our approach to study the all patent applications the firms have filed. Using only homogenous patent data would of course resolve some of problems. In the interpretation of the results country and industry specifics need to be taken account. Sixthly, there is also an aspect of 'complex product industries' [65,26] as the technological complementary might be one cause for overlapping technologies. These complex product industries are characterised by rapid technological change, "patent portfolio races, high citation rated among patents and a low link between quality indicators and value [66]. All in all, there is still a lot of room for development patent-based indicators in technology forecasting and convergence research.

The presented patent citation methodology provides new insights to the analysis of industry evolution, technological innovations and business development related to converging markets, technologies and sciences. The paper presents the conceptual analysis of methods in patent citation researches which have been applied to the one and same data material. Related to the empirical data we have got different results and made conclusions. Results and conclusions of the empirical part seem not to be in conflict with real observations in the industry. It has been possible to verify the patent citation analysis methods in relation to the empirical test environment. In the ongoing research it would be a contribution, if the worldwide patent data base and novel patent analysis methods could be used effectively for creating understanding in advance about the technology development, e.g. in the following fields: capability and competence development, technology diversification, technology competition, industry evolution, and industry convergences. Validation of these kinds of methods and tools could be exploited and further developed in many fields of research.

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