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The technological origins of radical inventions

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A B S T R A C T

This paper aims to trace down the origins of radical inventions. In spite of many theoretical discussions on the effect of radical inventions, the specific nature of radical inventions has received much less attention in the theoretical and empirical literature. We try to fill that void by an empirical investigation into the specific origins of radical inventions. We explore this issue by a close examination of 157 individual patents, which are selected from a pool of more than 300,000 patents. In contrast to the conventional wisdom that radical inventions are based less on existing knowledge, we find that they are to a higher degree based on existing knowledge than non-radical inventions. A further result that follows from our analysis is that radical inventions are induced by the recombination over more knowledge domains. The combination of knowledge from domains that might usually not be connected seems to deliver more radical inventions.

1. Introduction

Inventions come in many different forms ranging from incremental or run-of-the-mill inventions, to radical or breakthrough inventions. Most inventions can be characterized as incremental inventions. Incremental inventions consist of minor improvements or plain adjustments to existing products or technology. Their individual impact on the technological system is usually limited. Radical inventions on the other hand are generally considered as being a risky departure away from existing practice (Hage, 1980). Radical inventions exhibit key characteristics that are inherently different from existing products or technologies. They often lie at the hart of changes in technological paradigms (Nelson and Winter, 1982), thereby creating new technological systems and sometimes even new industries. Although incremental inventions might be a principal source of measured productivity growth, without the original radical invention they would not have been possible. Radical inventions are thus considered to be a crucial basis for a sequence of subsequent developments around this original invention (Mokyr, 1990).

In spite of many theoretical discussions on the effect of radical inventions (e.g. Ahuja and Lampert, 2001; Rosenkopf and Nerkar, 2001; Dahlin and Behrens, 2005; Tellis et al., 2009), the specific nature of radical inventions has so far remained relatively unclear. In fact, large-scale empirical studies into the technological origin of radical inventions are sparse and almost non-existing. Most previous studies on radical inventions have focused on the Schumpeterian size based discussion about the role of small and large firms in the creation of radical inventions and innovations. The empirical results of these studies however remain mixed (Scherer, 1991). Others have focused on organizational aspects influencing the development of radical inventions (for an overview see Chandy and Tellis, 1998). In order to advance theory and practice we will argue that it is critical to understand the specific technological characteristics that influence the development of radical inventions. In contrast to many existing studies we are primarily interested in the technological origins of radical inventions rather than the market success. We therefore depart from the commonly used innovation aspects and focus instead on the invention itself. In particular we would like to contribute to the classic discussion of whether radical inventions are based on completely new knowledge (Poel, 2003) or can be seen as an artefact resulting from the recombination of existing knowledge (Schumpeter, 1939; Fleming, 2001; Nerkar, 2003). A better understanding of the origins of radical inventions might guide organizations in their decisions to either focus on internal development for the creation of new knowledge or to resort to "open innovation" in their search for "neue combinationen" (Schumpeter, 1939). From a societal aspect, more knowledge about the origins of radical inventions is important because of the potential impact of this particular kind of inventions in creating new technological systems or even new industries.

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2. Theoretical background and hypotheses

The importance of radical inventions has been demonstrated in many different publications. (e.g. Ahuja and Lampert, 2001; Rosenkopf and Nerkar, 2001; Dahlin and Behrens, 2005). There is a clear consensus among scholars and practitioners that radical inventions are driving forces of technological, industrial and societal change. Whereas the impact of these inventions on the global economy has been described extensively in the literature, much less is known about the particular nature or origins of radical inventions. Apart from a few notable exceptions (e.g. Ahuja and Lampert, 2001) the technical content of a radical invention has not been studied extensively. Instead, existing studies focused on the issue of innovation rather than invention. In a seminal article, Ahuja and Lampert (2001, p. 523) define radical or breakthrough inventions as "those foundational inventions that serve as the basis for many subsequent technical developments". In this definition Ahuja and Lampert address the technical content of an invention. They do not consider the inventions that are radical from a user or market perspective, but instead they focus only on the technological importance of inventions. Second, they define radical inventions as those inventions that serve as a source for many subsequent inventions. Their premise is thus that radical inventions are those inventions whose technical content will be used by many successive inventions (see also Trajtenberg, 1990a; Trajtenberg, 1990b). Dahlin and Behrens (2005), on the other hand, consider technologies to be radical when they are: (1) novel, (2) unique, and (3) have an impact on future technology. The term novel needs some clarification. In this definition they include radical inventions that are constructed of already existing, but beforehand-unconnected knowledge (Hargadon, 2003). In order to be labelled as a radical invention, new knowledge, or the recombination of already existing knowledge must be unique. The last point in the definition of Dahlin and Behrens (2005), concerning the impact of radical inventions on future technology, is in line with the definition given by Ahuja and Lampert (2001). They also consider radical inventions as those inventions with a relatively major impact on future inventions. An invention is thus considered radical if relatively many subsequent inventions build on it. Therefore, impact on subsequent inventions can be seen as a proxy for radicalness. In a similar vein we consider all inventions that serve as an important antecedent for later inventions as radical invention. We thus use the impact of inventions on subsequent inventions as an approximation for the radicalness of an invention. In this study we will discuss their particular nature in retrospect. Hereby we will focus our attention solely on technological inventions.

The discovery of radical inventions is sometimes mystified and glorified. Many people still have an idealised picture of the lone inventor in a laboratory stocked away from the outside world for many years waiting for his/her moment of glory. The lone inventor is rather the exception than the rule (Hargadon, 2003). Although the lone inventor still exists (Dahlin et al., 2004) mostly a team of experts on different fields joins forces in order to develop radical inventions. Another myth is that radical inventions are always based on completely new knowledge (Poel, 2003). In fact, the recombination of existing knowledge is proposed by many scholars to be the ultimate source of novelty (Fleming, 2001; Nerkar, 2003). Even Schumpeter (1939) in the late 1930s considered invention as new combinations or "neue combinationen" (Schumpeter, 1934, pp. 65–66). Nelson and Winter (1982, p. 130) assert "... that invention in the economic system ... consists to a substantial extent of a recombination of conceptual and physical materials that were previously in existence". Even a simple rearrangement of components that are already in use, can, according to Henderson and Clark (1990), be a main cause of destabilisation in key industries. Fleming (2001) is one of the few scholars who investigated how firms create novelty by being a technology broker. Fleming states that "... an invention can be defined as either a new combination of components or a new relationship between previously combined components" (Fleming, 2001). According to Hargadon (2003) radical inventions are only rarely based on completely new knowledge. Most of the time radical inventions come from a recombination of already existing knowledge. "When ... connections are made, existing ideas often appear new and creative" (Hargadon and Sutton, 1997, p. 716). Particularly important in this respect is the recombination of beforehand-unconnected knowledge or unconnected knowledge domains (Hargadon, 2003).

However, large-scale empirical evidence is still unavailable and a number of scholars would contend that a radical invention is likely to be based on truly novel knowledge and thus goes beyond simple recombination, irrespective of examples of inventions based on the recombination of existing knowledge or the discovery of a new context for already existing knowledge (Poel, 2003). We believe that radical inventions originate from two basic sources, the recombination of existing knowledge as well as from the creation of truly novel knowledge. Therefore we hypothesize that radical inventions are generally based on existing knowledge.

H_1. Radical inventions are equally based on existing knowledge, as non-radical inventions.

As discussed above, radical inventions are for a substantial part dependent on already existing but beforehand-unconnected knowledge. This existing knowledge comes about in two different forms, mature knowledge, and emergent knowledge. The recombination of existing knowledge can therefore be based on either "old" or mature knowledge, or on "new" or emerging knowledge, or on a combination of both. In the literature there is a debate going on about the importance of mature and emergent technologies (Ahuja and Lampert, 2001; Nerkar, 2003). Emerging technologies are technologies that have come to the market only recently, and that are considered to be cutting edge technology (Ahuja and Lampert, 2001). Emerging technologies offer many opportunities for developing new recombinant technologies. Emerging technologies can offer firms valuable new components that facilitate the development of radical inventions (Ahuja and Lampert, 2001). Firms, however often lack the deep understanding of emerging technologies, which is needed to develop radical inventions. Firms that tend to rely on emerging technologies often have difficulties in understanding the real properties of this knowledge and therefore can only contribute in a limited way in terms of developing future technologies (Nerkar, 2003). In contrast, mature technologies are well comprehended and have been tested and used in many different settings. They "are usually well understood and offer greater reliability relative to more recently developed and less tested" technologies (Ahuja and Lampert, 2001, p. 527). Firms, and especially incumbent firms, will prefer mature technologies to nascent technologies. They are more familiar with them, and they are more aware of the specific properties of the technologies. The outcomes of emerging technologies are much more uncertain. This is also related to the concept of absorptive capacity as introduced by Cohen and Levinthal (1990). Firms invest in R&D and as a result build up absorptive capacity in their organization. Absorptive capacity is generally path dependent and in line with a firms' current research. With emergent technologies, firms will thus, overall, face more difficulties in absorbing them. Firms that focus on the use of existing technologies may benefit from their high degree of absorptive capacity and are therefore often able to speed up the innovation process.

Firms that concentrate on emerging technologies might suffer from experimentation costs and limited output. Dealing with emerging technologies is often problematic. It often takes a long many of the emerging technologies turn out to be less viable then previously expected. Emerging techniques could also ask for different routines, which would require existing employees to change their current routines; routines the employees have been familiar with for a long time, and who are subsequently difficult to change (Nelson and Winter, 1982). Emerging technologies thus, on the one hand pose many opportunities but on the other hand also pose many considerable difficulties that are not easy to cope with in this particular stage of development. In spite of the difficulties that emerging technologies present, we still expect that firms will need emergent knowledge to produce radical inventions. Mature technologies are important, but there is an increasing consensus that emergent technologies are also very important, especially for radical inventions. We would thus expect that radical inventions are, as compared to non-radical inventions, to a higher degree based on emergent technologies.

Our second hypothesis is therefore:

H_2. Radical inventions are to a higher extent based on emergent technologies, as compared to non-radical inventions.

In spite of the expected positive relationship between emergent technologies and radical inventions, relying too much on emergent technologies will lead to new knowledge that only has a limited impact on future technologies, while depending too much on mature knowledge might not lead to very innovative ideas or might lead to incremental inventions only (Nerkar, 2003). Mature technologies provide very little opportunities for radical inventions. On the other hand, mature technologies are not always publicly known and are sometimes not used to their full potential at the time of their development and might consequently be forgotten, not because they are not useful, but because at the time of their development they could not be employed. This, for example, has to do with the co-evolution of complementary knowledge, institutions, or standards that are necessary in order to use the new piece of knowledge (Nerkar, 2003). In many cases mature technologies are complemented by other technologies in order to facilitate the rapid development of new inventions. Mature technology is generally well understood as compared to emerging technologies. The combination of mature and emergent technologies could therefore potentially be very beneficial because it allows new combination of different streams of knowledge that might facilitate the development of radical inventions. Furthermore mature knowledge might finally be used to its full potential once complementary technologies become available. We therefore expect that radical inventions are much more based on a combination of mature and emergent technologies.

Our third hypothesis is therefore:

H_3. Radical inventions are to a higher degree based on a combination of mature and emergent technologies than non-radical inventions.

Despite the market advantages of combining technologies, firms also tend to search for new knowledge locally, i.e., within the current field of expertise of the firm (Stuart and Podolny, 1996), and within the same geographical confinement (Verspagen and Schoenmakers, 2004). Firms often treasure the convenience of technological and geographic proximity in their search process. They tend to stick to their current structures and routines. As a result, companies often suffer from bounded rationality and are therefore often dealing with only a limited subset of the total knowledge domain. According to Granstrand et al. (1997, p. 13) the technological competencies of large firms depend heavily on their past and are fairly stable. Knowledge is thus "imperfectly shared over time and across people, organizations, and industries" (Hargadon and Sutton, 1997, p. 716). This could potentially lead to the emergence of "competency traps" (Levitt and March, 1988). These traps could well prevent the firm from developing radical inventions. Research by Sorensen and Stuart (2000), for instance, suggests that firms that rely more on their previously developed knowledge deliver more inventions, but these inventions are less relevant.

Research by Granstrand et al. (1997), Patel and Pavitt (1997) and Brusoni et al. (2001) suggests that a firm's technological portfolio typically is larger than its product portfolio. The reason for this is that firms need to search for interesting technologies emerging outside their core technological domain. This broad perspective on technological competencies is thus necessary for firms in order to explore and exploit new technological opportunities (Granstrand et al., 1997). Firms that aim to innovate often need a broader knowledge base in order to do so. This also implies that radical inventions are based on various knowledge domains. Radical inventions not only serve as the basis for many successive inventions (Trajtenberg, 1990b), but can also be expected to build on a larger knowledge base (Rosenkopf and Nerkar, 2001). Differences in terms of the number of knowledge components that make up an invention will appear in all kinds of incremental as well as in radical inventions. A larger knowledge base on the other hand also points at the diversity in the number of different knowledge bases or knowledge domains that constitute an invention. Radical inventions can be expected to draw from a broader knowledge pool than non-radical inventions. If we assume that radical inventions are based on new combinations of already existing knowledge, as discussed before, then this combined knowledge legacy can be expected to come from various, different knowledge domains. In today's world it is very unlikely that radical inventions are based on just one single knowledge domain.

Our fourth hypothesis is therefore:

H_4. Radical inventions are based on a relatively large number of knowledge domains, compared to non-radical inventions.

3. Data

For our research we will be looking at so-called radical inventions. Inventions are associated with the development of a new idea, whereas innovations refer to the commercialization of this idea (Schumpeter, 1934; Hitt et al., 1993; Ahuja and Lampert, 2001). As discussed we will not be looking at the commercialization of an idea in this paper, but rather at the act of creating an idea. We are particularly interested in how an invention can be a catalyst for the development of subsequent inventions. We especially want to focus on those inventions that can be considered radical or breakthrough. Therefore we focus our attention to those inventions that serve as a basis for many successive inventions.

Patent data is the single most dominant indicator in invention studies. For a patent to be granted it must be novel, non-trivial, and useful. If a patent meets these requirements, a legal title will be created containing information on for instance the name of the inventing firm and also on the technological antecedents of the knowledge, the patent citations. In the European Patent Office (EPO) system, the patent applicant can include citations to prior patents (and prior technological and scientific literature), but ultimately it is the patent examiner from the patent office who determines what citations will be included in a patent (Michel and Bettels, 2001). Patent citations reveal the so-called "prior art" of the newly developed patent. Citations to other patents, the so-called backward citations, indicate on what preceding knowledge the new patent is based. They provide a kind of patent family tree. The citations from other patents to a patent, the so-called forward citations, on the other hand are an indication for the importance of the patent.

also have a higher economic value for the firm possessing the patent (Trajtenberg, 1990a; Harhoff et al., 1999). Forward citations are also considered to be a good indication for the technological importance of an invention (Dahlin and Behrens, 2005). Firms with more highly cited patents also enjoy economic benefits (Trajtenberg, 1990a) and have on average higher stock market values (Hall et al., 2001).

In the research of Harhoff et al. (1999) it was shown that firms are willing to pay the renewal fees only for important inventions, which leads firms to have only the maximum patent protection for important inventions, leaving less important inventions with a shorter patent protection period. This behavior leads to more citations for important inventions since they have a longer patent-life, but on the other hand they also find that, of the patents with a full-term patent protection period, the citation frequency rises with the economic value of the invention, as reported by the firm.

In line with the research of Ahuja and Lampert (2001) we will use forward patent citation counts to identify radical inventions, and will consider inventions radical if they serve in a more than average way as the basis for subsequent inventions. Patent citation counts are considered to be good estimators of the technological importance of inventions (Narin et al., 1987; Albert et al., 1991). Highly cited patents are also considered an important indicator for radical inventions (Trajtenberg, 1990a). We will base our definition of radical inventions on Ahuja and Lampert's (2001) definition, as described above. Dahlin and Behrens' (2005) definition is also in line with the definition given by Ahuja and Lampert. Dahlin and Behrens (2005) define inventions as radical if they are (1) novel, (2) unique, and (3) have an impact on future inventions. Since patents are supposed to be novel and non-trivial, covering more or less prerequisites 1 and 2, their definition is the same, in the case of patents, as the one by Ahuja and Lampert (2001). So we are looking for patents with a more than average influence on subsequent patents. We will be using the EPO (European Patent Office) database of patent data as our primary data source.

Patent citations are often referred to as "noisy indicators" of knowledge flows (Jaffe et al., 1998, 2000). The reason being that large parts of patent citations may not be related to a particular knowledge flow due to the fact that patent citations are included not only by the inventor, but as well by the patent attorney of the firm and the patent examiner in the patent office. Recent research has concentrated on the distinction between inventor citations and non-inventor citations (Alcacer and Gittelman, 2006; Criscuolo and Verspagen, 2008). Where Criscuolo and Verspagen propose only to consider inventor citations as knowledge flows, Alcacer and Gittelman conclude that the bias introduced by the examiner citations is not necessarily bad, since both inventor citations and examiner citations might track each other closely. Also, in the EPO system, inventors might make use of knowledge without being aware of the existence of a patent for this piece of knowledge, or without even bothering to include a citation. Inventors also might simply forget to include a citation, or even deliberately not include a citation for strategic reasons. In all these cases a knowledge flow exists but is not visible in the inventor citations. However un-logical these examples might sound in the US Patent and Trademark Office (USPTO) system, in the EPO system they are not. Especially in the EPO system, which we are using for our research, it is the patent examiner of the patent office who is ultimately responsible for including all the patent citations that are necessary, and not the inventor. Together this might also be the reason why Criscuolo and Verspagen's (2008) finding that inventor citations and examiner citations in EPO do not track each other differs from the findings of Alcacer and Gittelman (2006) for USPTO. Also in terms of legal reasons inventor and non-inventor citations in USPTO will track each other more closely than these citations will do in EPO. Furthermore, due to the different requirements of EPO and USPTO, much more related to the prior art of the invention, as would follow from the examples given here before. So in contrast to Criscuolo and Verspagen (2008) we do not feel that in the EPO system it is only the inventor citations that should be considered when looking for knowledge flows. Although we agree with them that, especially when compared to USPTO, inventor citations in EPO very probably do indicate a knowledge flow, in EPO also non-inventor citations might very well be an indication of a knowledge flow. In other words, we cannot exclude the possibility that a non-inventor citation indicates a knowledge flow in the EPO system. In USPTO there is furthermore the problem that applicants include even remotely related citations just to make sure that they do not run any risk of compiling an incomplete list of citations (Michel and Bettels, 2001) which practice introduces "noise" already at the inventor citations. EPO citations can thus be considered less "noisy", for the included citations are less influenced by the fear of legal repercussions (Criscuolo and Verspagen, 2008). Duguet and Macgarvie (2005) finally conclude that patent citation counts are relevant for knowledge flows, although not for all the channels though which firms obtain knowledge. Admitting thus that patent citation are a "noisy" indicator of knowledge flows we still feel confident that they can be used as an indicator of knowledge flows for our purpose, especially since we are using the less "noisy" EPO data. Further, even though we collect our data on the individual patent level, for our analysis we make use of aggregated scores for the two groups of patents that we consider, and as an aggregated variable patent citations are considered to be useful regardless of their individual "noisiness" (Jaffe et al., 2000).

While using the EPO database we might encounter two inherent problems. The first has to do with the difference of the number of patents applied per measuring year. Previous research (see Schoenmakers, 2005) has shown that in EPO data the number of patents applied increases from the start of EPO in 1978 till about 1989. From thereon the number of patents applied stays more or less stable. We cannot use the period where the number of patents applied is not stable, since patents who get applied in a period where there were relatively few other patents applied will have, only because of this reason, less chance of receiving forward citations compared to a patent that is applied in a period with more other patents applied. This is the case, simply because there are more patents that potentially could cite the specific patent. This is especially true since we know that the bulk of forward citations are received within the first four to five years after the initial patent application (Schoenmakers, 2005). Since we do not want the number of forward citations per patent to be dependent on the number of patents applied in a given year but only on the technological importance of the patent, we need to confine our research to that period where the number of patents applied in EPO is more or less equal, which is the period from 1989 till 1998.[2]

A second problem might occur when we compare patents from different periods with each other. Older patents will have a higher chance of receiving forward citations, simply because the period over which the citations are counted is longer compared to younger patents. In order to tackle this problem we counted for every patent the number of forward citations it received up till five years after

[2] Normalization of the measuring years would also have been possible that would have been the other option to correct for the differences in numbers of patent per year. This would have made it possible to use a longer time period. We choose however to correct this problem by only considering the years with more or less equal numbers of patents. An important reason for our choice was that since the time period that we consider is relatively short we can also expect that other variables, which we cannot control via normalization or otherwise, are more or less constant over the measuring period. We therefore felt that using our approach was the most

its initial application date (usually the filling date of the patent).[3] This means that for patents applied for in January 1989, we counted the citations up to and including those applied in January 1994, for patents applied in February 1989 we counted the citations until February 1994, etc. Since we can only use the patents between 1989 till 1998, the last year we used patents from is 1993. A similar approach is used by earlier research (Schoenmakers, 2005). Eventually we got a list of 300,119 patents that were applied for in the period from January 1989 till December 1993 with their individual numbers of forward citations.

Since we expect, in line with Ahuja and Lampert (2001) and Dahlin and Behrens (2005), that radical inventions are a rather rare phenomenon, we selected only the most highly cited patents as our group of radical patents. The highest cited radical patent received 54 citations and the least cited 20 citations. We put our cut-off value at 20 citations based on the before mentioned expectation that truly radical inventions will rather be an uncommon occurrence, and we observed that many patents have 19 or less citations, whereas only very few have more than 20 citations. Although this cut-off value of 20 might still seem rather arbitrary, one has to consider the severity of the mistake that we might make. We could either forget to include some of the truly radical inventions or we might include some non-radical inventions in our radical group. In both cases this could only weaken our results, meaning that if we find a difference between radical and non-radical inventions, our results could even have been stronger if we had used a different cut-off point. We therefore feel confident that our cut-off point is not leading us to make a major mistake. Since the mistake of excluding some of the radical inventions from the radical group would altogether lead to the highest chance of making the smallest mistake we choose to be rather conservative with marking inventions as radical. We are therefore convinced that the construction of our group of radical inventions is suitable for our research questions. We ended up with a group of 96 radical patents.

For the construction of the non-radical inventions we randomly selected 96 patents from the group of patents with less than 20 forward citations. For both groups we collected the necessary variables using, besides EPO, Worldscope. We ended up with 74 patents in the radical group and 83 patents in our non-radical group for whom we had sufficient information to perform the analysis.

A small note on the use of patent citations in our research is necessary here. Although we are using patent citations both as a means of assigning patents to either one of the two groups, and as independent variable we feel confident that we can do this. We use the patent's forward citation to be able to assign the patent to one of the two groups and we use the patent's backward citations as dependent variable. So although we use patent citations in both instances the two groups of citations come from two different sources and can therefore be regarded as independent.

Finally, in Appendix A we highlight a few of the patents in the radical group to give the reader some understanding of the type of patents that are in this dataset. Also in this appendix we show the distribution of the radical patents over the different patent classes and over the different measuring years.

4. Methods

In order to test if the two groups we are considering, the radical inventions and the non-radical inventions are truly different and to see on what factors they differ we made use of discriminant function analysis. Discriminant function analysis is a statistical technique allowing us to study the difference between two or more groups of items with respect to several variables simultaneously. Its primary goal is to distinguish those variables on which groups differ (Tabachnick and Fidell, 1996). Discriminant analysis will aid us in analyzing the differences between groups, and provide us with the weights of the influence of the different individual variables on this difference. Discriminant analysis is thus the appropriate technique for us here, since we want to establish that the two groups differ, and we are especially interested to know on which factors.

Patents applied at the European Patent Office will represent the inventions that we are studying in this research. We thus collect information on the individual patent level, but as discussed before, patents are assigned to two different groups, radical inventions and non-radical inventions, based on the number of forward citations they receive over a specific time period. Our unit of analysis is thus the group of radical and non-radical patents.

Our dependent variable (RAD) is a dummy variable with value zero (0) when the patent is assigned to the non-radical group and one (1) if the patent is in the radical group. This is another important reason why we are using discriminant analysis. Normal regression analysis can only handle a continuous dependent variable, discriminant analysis is on the other hand able to work with a categorical dependent variable as we are using here.

As a first independent variable we use the number of times a patent is citing other patents (COP). Some scholars assert that radical patents are based on completely new knowledge; knowledge that was not available in the market before, while others especially point at the recombination of beforehand-unconnected knowledge as a source of radical inventions. For scholars in favour of the first viewpoint the assumption is, that, if a relatively large amount of citations for a new technology is to scientific literature, than this is an indication of novelty (Carpenter et al., 1981), since the new technology in that case is than not based on already existing technologies, but instead on science itself (Dahlin and Behrens, 2005). Ahuja and Lampert (2001) for instance simply count the number of backward citations and postulate that patents that cite no other patents apparently have no technological antecedents (Ahuja and Lampert, 2001), which would then be an indication for the originality and creativity of the technology (Trajtenberg et al., 1992). Our expectation is however that the discovery of truly novel radical knowledge, in the sense that the knowledge components itself were never before established, is a rather rare phenomenon, occurring only very infrequently. Further in the EPO system it is the patent examiner who is ultimately responsible for the inclusion of “prior art”. The chances of an examiner including no, or only a very limited number of backward citations is, already for legal reasons, very small (Michel and Bettels, 2001). Using our variable COP we will be able to test both assumptions.

The second independent variable we use is the mean age of the patents that our studied patents are based upon. This is thus the mean age of the patents that receive the backward citations. From the literature we know that radical patents might be using younger knowledge. Younger knowledge is on the one hand interesting for the opportunities it gives for the development of new knowledge, but is on the other hand more difficult to use since people are not yet quite familiar with the knowledge. Our variable (AGE) is meant to gain us more insight into this phenomenon.

Our third independent variable is the spread of the age of the backward citations (SPREAD). Some studies point to the fact that making use of old and emergent knowledge can produce radical inventions. Knowledge might be developed in a time when this knowledge is not readily usable. Complementary knowledge or techniques might first have to be developed. With our variable SPREAD we can investigate this relationship.

As a fourth independent variable we included the number of different sectors where the knowledge for a new patent comes from.

[3] We also collected data for a six year citation period but the results remained the

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