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Radical versus non-radical inventions

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Abstract

This paper looks at the special characteristics of radical inventions. It tries to identify those variables that differentiate radical inventions from non-radical inventions. Since radical inventions are very important for the economy as a whole and for the individual firm performances, understanding what makes radical inventions differ from non-radical inventions is very important.

For our research we made use of the EPO (European Patent Office) database on patents. We used the number of forward patent citations per patent to identify radical from non-radical inventions. For our analysis we used the backward patent citations per patent.

In order to test if the two groups we are considering are truly different and to see on what factors they differ we made use of discriminant function analysis.

Some of our main conclusions are that radical inventions are to a higher degree based on existing knowledge than non-radical inventions. Also the combination of emergent and mature knowledge is more important for radical inventions. A further result that follows from our analysis is that radical inventions are induced by the recombination over more knowledge domains as compared to non-radical inventions. Our research hints also on the importance of alliances and an open innovation system for the development of radical inventions.

Key words: radical inventions, patents, organizational learning, alliances.
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The making of radical inventions

Inventions come in many different forms ranging from incremental technical change 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 economic 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 show key characteristics that are inherently different from existing products or technologies. They often lie at the hart of sustained wealth creation for both the individual firm as well as for the society as a whole (Schumpeter 1975; Ahuja and Lampert 2001). Successful radical inventions tend to provide the opportunity for the inventing firm of gaining a sustainable competitive advantage and for the subsequent generation of economic rents (Achilladelis, Schwarzkopf and Cines 1990; Harhoff, Narin et al. 1999).

Few theorists and practitioners will question the fact that radical inventions have a profound influence on industry competition and on company survival. However, 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), the specific nature of radical inventions has so far remained relatively unclear. Apart from a number of insightful qualitative studies, large-scale empirical studies into the nature of radical inventions are sparse and almost non-existing. In order to advance theory and practice we will argue that it is critical to understand the specific characteristics that influence the development of radical inventions.

Ahuja and Lampert (2001) define radical or breakthrough inventions as “those foundational inventions that serve as the basis for many subsequent technical developments” (Ahuja and Lampert 2001: 523). 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 who's 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 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. In a similar vein we consider all inventions that serve as an important antecedent for later inventions as radical invention, and will study their particular nature in retrospect.

Hypotheses

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, Taylor 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. 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 nineteen thirties considered invention as new combinations or "neue combinationen" (Schumpeter, 1934: 65-66). Nelson and Winter (1982: 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. In a similar vein Hargadon and Sutton (1997) have described 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: 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 content 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). However, the majority of authors tend to expect that like incremental inventions, radical inventions are for a substantial part dependent on already existing but beforehand-unconnected 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.

Existing knowledge comes about in two different forms, mature knowledge, or mature technology, and emergent knowledge, or emergent technology. The recombination of existing knowledge can than 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: 527). 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 suffer from too much superficial new knowledge that only has a limited impact on 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: 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 (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, have more difficulty absorbing them.

People also have to get used to working with new technology and it often takes a long time to discover the specific characteristics of the technology. 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 on the other hand lead to new knowledge that only has a limited influence on later technologies, while depending on mature knowledge only could lead to new knowledge that is not innovative at all (Nerkar 2003). Mature technologies, on the other hand, are not always publicly known and are sometimes forgotten, not because they are not useful, but because at the time of their development they could not be employed. This, for examples has to do with the coevolution 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 potentially be very lucrative because it can facilitate the development of radical inventions. Therefore mature knowledge might eventually be used to its full potential once complementary technologies become available. The combination of mature and emergent knowledge involves the use of more different knowledge bases, which potentially leads to a higher chance of successfully developing radical inventions. 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, that is, 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) the technological competencies of large firms depend heavily on their past and are fairly stable (Granstrand, Patel et al. 1997: 13). Knowledge is thus “imperfectly shared over time and across people, organizations, and industries” (Hargadon and Sutton 1997: 716). This could potentially lead to the development of “core-rigidities”(Leonard-Barton 1995) and 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 for instance suggests that firms that rely more on their previously developed knowledge deliver more inventions, but these inventions are less relevant (Sorensen and Stuart 2000).

Research by Granstrand et al. (1997) and Patel and Pavitt (1997) 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, Patel 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), they 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 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.

Usher, writes about novel insight: “A solution emerged only when the geometric configuration presented all the elements of the problem and a possible solution”(Usher 1988:

63). The chances of this happening within one knowledge domain is much larger than this happening over different knowledge domains, but when this happens over different knowledge domains, the outcome has the prospect of offering better possibilities for a radical invention. So compared to inventions that are considered non-radical we can expect radical inventions to be based on a larger number of knowledge domains.

Our fourth hypothesis is therefore:

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

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, Hoskisson 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 economic importance of the patent. Patents with higher numbers of forward citations are considered to also have a higher economic value for the firm possessing the patent (Harhoff, Narin 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 have on average higher stock market values (Hall, Jaffe 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 behaviour 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, Noma et al. 1987; Albert, Avery 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 of 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.

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 can not 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 appliance (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 1997.

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 its initial patent appliance. This means that for patents applied in 1989, we counted the citations till 1994, for patents applied in 1990 we counted the citations till 1995, etc. Since we can only use the patents between 1989 till 1997, 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 twenty might still seem rather arbitrarily 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 invention 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 en 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.

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. Our unit of measurement is thus an individual patent. 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 dependent variable (RAD) is thus 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 dicriminant 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, Narin 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, Henderson 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. These are thus the sectors where the backward citations of our studied patents come from. In the literature we find many indications pointing to a relationship between diversity of knowledge and radicalness of the invention. Our variable (SEC) is used to test this relationship.

As a control variable we use the revenues of the firms that applied for the individual patents (REV). This helps to eliminate the influence that the size of the firms might have on the results.

The function that we are studying then becomes:

$$RAD_{km} = f(COP_{km}, AGE_{km}, SPREAD_{km}, SEC_{km}, REV_{km})$$

Where: km = case m in group k.

Results

Based on the function discussed in the last section we want to investigate which variables are distinguishing between the two groups under investigation. We started with investigating the correlations between our independent variables. It turned out that there are no problems with correlation related issues. All correlations are well within the acceptable range.

Next we continued our examination by looking at the Wilks'Lambda and F values of the different variables, see table 1.

++++++++++++++++Table 1 About Here++++++++++++++++

Wilks'Lambda is a multivariate measure of the group differences over several variables, it is concerned with the ratio between the within group variance and the overall variance. A ratio near 1 is an indication of equality of group means, whereas a lower ratio is an indication of a larger difference between the various group means. The F-ratios are calculated for each variable in order to test the hypothesis that all group means are equal. From table 1 we see that although the Wilks' Lambda are high, the F values are high too, and the significance levels are low. The results of our discriminant analysis show that except for our control variable REV, all other variables are significant at the 1% error level. This thus supports a strong rejection of the hypothesis that all group means are equal. For all our independent variable we can therefore reject the hypothesis that the group means are equal.

Looking at table 2 we can evaluate the discriminatory power of the complete set of variables. This is an indication of the 'goodness' of the discriminant function.

++++++++++++++++Table 2 About Here++++++++++++++++

First we look at the eigenvalue, which is a measure for the relationship of the sum of squares of the between group and the within group. Higher eigenvalues indicate a more discriminating function. The discriminating power of the discriminant function is, according to the eigenvalue not very high. We then look at the canonical correlation, which represents the proportion of the total variance that is explained by the two different groups, and which is in this case more important here than the eigenvalue since we only have two groups. This coefficient is a measure of association summarizing the degree of relatedness between the two groups and the discriminant function. A value of zero means no relationship at all, while large positive numbers represent increasing degrees of association, where 1.0 is the maximum (Klecka 1980). A value of 0,472 for the canonical correlation indicates that the discriminating power of our discriminant function is medium.

Next the test of function column tests the hypothesis that the mean of the function listed is equal across groups. The Wilks' lambda here is the proportion of the total variance in the discriminant scores not explained by differences among groups. The value of Wilks' lambda of .777 indicates that the group means do differ. Next, the chi square value of 38,440 and a significance level of 0,000 also imply that the mean scores of the different variables for the two researched groups do differ significantly. The null-hypothesis that the two groups means are equal can therefore be rejected.

If we look at table 3, which reports the mean and standard deviation for the different variables for both groups, and when we combine these findings with the results we got from table 1 we can review our main hypotheses. Looking at the first variable (COP) we see that the group of radical patents cites more patents than the group of non-radical patents, 2,5541 compared to 1,2651. This variable is also significant (see table 1). Our first hypothesis is thus rejected. Radical patents are apparently even more reliant on the recombination than non-radical patents.

+++++++++++++++++Table 3 About Here+++++++++++++++++

We additionally looked at the percentage of citations to patents from other firms, compared to the percentage of citations of their own patents (self citations). It turned out that for both groups; about 75 percent of the citations are to patents from other firms. This implies that for new knowledge construction firms are very much relying on outside knowledge. The variable AGE is higher for the group of radical patents compared to the group of non-radical patents. Since we measure the age of a patent in months starting at 1 at the start of EPO and counting up, a higher value for AGE means that the group of radical patents is actually based, on average, on younger patents than the group of non-radical patents. The variable AGE is also significant. Emerging technologies apparently play an important role in the development of radical patents. This clearly confirms our hypothesis 2.

For our variable SPREAD we see that this variable is larger for radical patents than for non-radical patents. This third independent variable is also significant. Radical patents are thus based on a broader time spectrum of patents. This result is in line with our hypothesis 3.

For our variable SEC we find that the group of radical patents cites more sectors as the group of non-radical patents, 1,1757 compared to 0,7470. According to table 1 also this variable is significant. Hypothesis four is therefore accepted. Radical patents are based on more sectors, and thus based on more knowledge domains.

Our control variable indicates that larger firms have more radical patents, but this variable is only significant at the 10% level.

Discussion and Conclusions

In this study we investigated the nature, or origin of radical inventions, and compared this with the nature of non-radical inventions. We based our results on a sample of 157 individual patents selected from a pool of more than 300.000 patents. Although statistically sufficient, we need to consider that especially for our non-radical patent group, even though we selected them totally random, there is a chance that they do not fully represent the non-radical patent group. Also the decision to have our cut-off point for radical inventions at 20 is subject to discussion, although, as discussed before, we think that we ensured that we made the correct assessment. The discriminating power of our discriminant function is unfortunately not very high, although the individual factors show to be significant and discriminating between the two researched groups. As a complement to our current research, for future research it would also be interesting to investigate some of our 157 inventions deeper, maybe by using interviews at the involved companies. This could also further strengthen our current results.

Given these limitations, based on the results of our discriminant function analysis we still feel comfortable with our results and can come to some very interesting conclusions concerning radical invention. In contrast to the Communis Opinio 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. For radical inventions already existing knowledge seems of paramount importance. Radical inventions are also to a higher degree based on emergent technologies, and especially on a combination of mature and emergent technologies than non-radical inventions. As discussed before, the use of emergent technologies might be more difficult for companies because of the newness of the technology. This finding might also be very important in the light of the rise of open innovation. Based on our results we can see that open innovation might be an important contributor in the development of radical inventions. Alliances and open innovation systems might facilitate the diffusion of knowledge over firms and within firms much better, adding to the chances of recombining mature and emergent knowledge. This is something that certainly needs to be investigated further in future research.

It also shows the importance of speed in understanding emergent technologies. Firms that are quick in understanding the possibilities that emergent technologies posses and that therefore are able to combine this knowledge with mature and well-understood knowledge might be better at delivering radical inventions. The results also show that caution is needed with discarding mature technologies too quickly; they might be useful in a later, different setting.

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. Also this might be enhanced by alliances and an open innovation system. By the use of alliances firms will be able to more easily tap into knowledge that otherwise would be unreachable for them.

Our results also have bearing on the internal management of firm knowledge. It shows the need for more coordination of the knowledge within the firm, and more internal openness. Different divisions might possess knowledge that, when put together, could potentially deliver a radical invention. It might be beneficial for firms to have multidisciplinary teams of people from all over the firm to work together and scan the internal as well as the external environment for possible beneficiary combinations of knowledge. Technology brokers might here also convey an important influence.

Our research thus hints on the importance of alliances and an open innovation system for the development of radical inventions. It can also help firms to focus their attention to the most important factors leading to the development of a radical invention. Not just the new scientific knowledge but also to the recombination of already existing knowledge, mature and emergent, from different knowledge domains is vital. The most important lesson that follows from these results might be that there could be many more radical inventions out there, waiting to be discovered by researchers that are able to recombine previously unconnected knowledge. Researchers that are able to look over their own narrow research borders, both in time as well as in a technological and a geographical sense, and that are willing to use outside knowledge and share inside knowledge might be the masters of radical invention.

Tables

	Wilks' Lambda	F	Sig.
COP	,844	28,585	,000
AGE	,958	6,794	,010
SPREAD	,936	10,533	,001
SEC	,894	18,449	,000
REV	,980	3,195	,076

Table 1: Tests of equality of group means

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
	,287	100,0	100,0	,472
Test of Function	Wilks'Lambda	Chi-Square	df	SIG.
	,777	38,440	5	,000

Table 2: Eigenvalue and Wilks'Lambda

	Mean	Std. Deviation
COP non-radical	1,2651	1,29807
AGE non-radical	138,5635	27,95243
SPREAD non-radical	12,2651	20,51952
SEC non-radical	,7470	,76259
REV non-radical	24180624	24706586
	Mean	Std. Deviation
COP radical	2,5541	1,71330
AGE radical	149,6747	25,13730
SPREAD radical	26,0541	32,03974
SEC radical	1,1757	,41737
REV radical	32492395	33326894

Table 3: Group statistics.

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