The Origins of Innovation:
An Analysis of the Finnish Innovation Database

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Abstract: We combine theory and empirical research on the origins of innovation to investigate the determinants of complexity and degrees of novelty in the emergence new innovations. We link up two important dimensions of technological change in both looking at the degree of novelty of the innovation (incremental/radical) and the complexity of the innovation (simple/complex). Using a novel dataset of major Finnish innovations from 1985-1998, we examine the role of technological opportunities, customers, breadth of collaboration with different communities of practice, the breadth of the sources of inspiration for the innovation, and competitive pressures in shaping the emergence of innovations. We find that taking into account both dimensions is imperative to the understanding of the origins of innovations.

Keywords: sources of innovation, radical innovation, complex innovation

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1. Introduction

The origins of technological innovation in the economic system remain a significant concern for business, governments and academic researchers. A substantial part of the recent literature on technological change focuses on the sources and impact of different types of innovations, including incremental, radical, architectural, modular, simple and complex types (Tushman and Anderson 1986, Anderson and Tushman 1990, Henderson and Clark 1990, Tushman and Rosenkopf 1992, Singh 1997). This literature focuses the effect of the introduction of different types of innovation and the competitive situation within industries and whether or not the innovation was a commercial success (Gatignon et al. 2002). Although we have learned a lot about the sources of innovation in general (Schmookler 1966, Rothwell et al. 1974, Rosenberg 1976, Mowery and Rosenberg 1979, Pavitt 1984, von Hippel 1988, Klevorick et al. 1995, Palmberg 2004), the origins of different types of innovations are insufficiently understood. Even though there is awareness that the origins of an innovation may affect the degree of novelty in the innovation (see for instance, Ahuja and Lampert 2001, Rosenkopf and Nerkar 2001) and that innovations differ in their complexity (see for instance, Tushman and Rosenkopf 1992, Singh 1997), there are to our knowledge no studies that combine the *radicalness* and *complexity* of innovations in attempts to understand the origins of new innovations. In other words, the link between the degree and complexity of innovation on the one hand, and the sources and determinants on the other, is a missing link in the study of innovation.

In this paper, we attempt to overcome this shortcoming in the literature, by combining the two dimensions of technological innovation – that is incremental/radical and simple/complex – to create a taxonomy of innovations where the origins of the innovations may differ according to where the particular innovation fit in the taxonomy. We contrast the sources of radical/simple, radical/complex, incremental/simple and incremental/complex innovations, exploring the factors that influence the emergence of these innovations (see Figure 1 for a depiction of the proposed taxonomy of innovations). In particular, we are interested exploring the sources, mechanisms and collaboration that give rise to each of the different types of innovation. In doing so, we are able to assist in

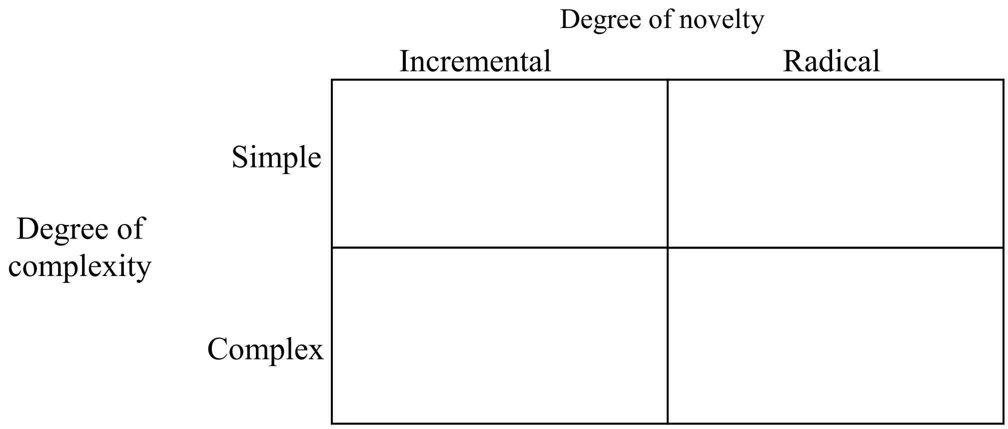

Figure 1: Degree of novelty and variety of knowledge bases in innovation

filling the missing link in the literature and to develop new theory and evidence on the nature of innovation. Applying a unique database on 540 Finnish innovations, drawn from a range of services, manufacturing and construction industries, and while using a multinomial logit model as the means of estimation, we find that the origins of innovation differ indeed, according to where each innovation is situated in our two-by-two taxonomy.

2. Empirical and theoretical background

Innovations can be classified according to many different dimensions. Perhaps the most used distinction in innovation studies is the distinction between incremental and radical innovation (see for instance, Mansfield 1968, Freeman and Soete 1997). According to Gatignon et al. (2002), incremental innovations can be defined as "those innovations that improve price/performance at a rate consistent with the current technological trajectory", while radical innovations "advance the price/performance frontier by much more than the existing rate of progress." However – as pointed out by Henderson and Clark (1990) – this distinction may fail to account for important aspects of technological change, given that innovation may be more or less systemic no matter whether the innovation is incremental or radical. As such there is strong evidence that there are numerous technical innovations that involve moderate changes in technology, but have dramatic competitive consequences (Clark 1987).

Simon (1969: 86) defines a complex system in general terms as “one made up of a large number of parts that interact in nonsimple way.” Accordingly, complexity concerns both the number of the parts involved in the system and the nature of the interconnections among those parts. Merges and Nelson (1990) make the distinction between discrete and complex technologies in the context of the appropriation of the returns from innovation. In the context of socio-political effects of innovation, Tushman and Rosenkopf (1992) develop a typology of products ranging from simple to complex. These are: (a) non-assembled products, (b) simple assembled products, (c) closed systems, and (d) open systems. Accordingly, the authors examine the nature and determinants of the product technologies for each of the four categories. Building on Tushman and Rosenkopf (1992), Soh and Roberts (2003) define complex technologies to be “technological systems involving a large number of inter-related subsystems arranged in a hierarchical order”. Hence, modularity can be seen to be one way to manage complexity by grouping elements into a smaller number of subsystems (Simon 1969, Langlois 2002).

The degree of complexity encompasses two dimensions of complexity: artefactual complexity and development complexity. Artefactual complexity refers to the degree of complexity of the final product and developmental complexity refers to the degree of complexity involved in design and production of the product. Artefactually complex products involve systems of modules and components that need to be integrated in order to allow the product to be functional. Developmentally complex products require extensive design and production processes in order to be produced, but they may themselves be relatively simple artefactually products. For example, pharmaceutical products, such as aspirin, are artefactually simple, but developmentally complex and capital goods, such as an electricity network, are simple to construct but complex to integrate. In our study innovations have to have at least medium artefactual complexity *and* high developmental complexity in order to be deemed “complex” rather than “simple”.

However, it should be underscored that while this paper is concerned with different types of innovation in terms of the origins of different types of innovation, it is not concerned with the consequences of innovation – radical or complex.

3. Hypotheses

Generally speaking, we suggest that radical innovation is driven by technological opportunities and inputs from single or few sources of knowledge, including universities and users. In contrast complex, innovations, involving many sub-systems, are conjectured to be driven by collaboration with suppliers and users that may possess key knowledge inputs with respect to each of the subsystems. Below, we discuss the origins of innovations for the four types of innovation with respect to environmental factors, collaboration, and R&D intensity in turn.

Environmental factors

Technological opportunities comprise the set of possibilities for technological advance and may be measured as the returns to R&D, given demand conditions, the current level of technology, and the appropriability regime (Klevorick et al. 1995: 188). As resources are devoted to R&D and projects are completed, the pool of opportunities can be depleted. However, the pool of opportunities are refilled through the sources of opportunity, including the advance of scientific understanding; technological advance originating outside of the industry; and through new possibilities opened up by feedbacks resulting from current innovations (ibid, 1995: 189). Accordingly, whenever the pool of opportunities is replenished it is implied that a period of incremental change is replaced by a period of ferment – a period in which radical innovations materialize (Tushman and Anderson 1986), possibly to the extent that a new technological paradigm emerge (Dosi 1982). The theory of recombinant invention (Utterback 1994, Fleming 2001) provides another related argument for why new technological opportunities may lead to radical innovations. According to this theory, inventors' experimentation with the combination of new components and new configurations of previously combined components leads to less technological success on average, but increases the variability that can lead to technological breakthroughs associated with radical innovation (Fleming 2001). However as technologies mature, the likelihood that high-utility combinations of the technology's elements have not been tried or exploited already must eventually decline (Ahuja and Lampert 2001). As a result, new technological opportunities offer the possibility of radical combinations and re-combinations. However, not only do new technological opportunities open up the search space to radical innovations, new technological opportunities may also allow innovations of an architectural kind (Henderson and Clark 1990). In other words new technological opportunities may allow technologies that hitherto were separate to be combined in a complex fashion. In sum, we conjecture:

H1a New technological opportunities advance radical and complex innovations

In many cases advances in basic scientific research has led to radical innovations – in particular in science-based industries (Nelson 1959, Levin et al. 1987, Klevorick et al. 1995). Although basic scientific research may eventually lead to a technological breakthrough, it is fundamentally uncertain when and where the results of basic research may be applied (Nelson 1959, Pavitt 1993). In the words of Nelson (1959): "Moving from the applied-science end of the spectrum to the basic-science end, the degree of uncertainty about the result of specific research projects increases, and the goals become less clearly defined and less closely tied to the solution of a specific practical problem or the creation of a practical object." Accordingly, the reason why basic science has often led to radical breakthroughs can be related to the fact that basic research address fundamental questions that are not necessarily constrained by the solution to a practical problem, and moreover, that the results of the research are fully and freely disseminated to a large community, so that the sources of new ideas are numerous and diverse. In sum, we hypothesize:

H1b Scientific breakthroughs foster radical innovations

The behavioral theory of the firm (Cyert and March 1963) argues that one of the types of search firms undertake is "problemistic search" (i.e. search triggered by a problem). Such search is triggered when managers find that organizational performance is below their aspiration level. Accordingly, if an organization is under competitive pressure (for instance through pressure from price competition or rival innovation) it may increase its search for innovation when decision makers judge that upgrading their technology and product portfolio can solve the performance problems. For instance, firms with soaring profits may enter R&D races to restore profitability (Kamien and Schwarz 1982, Antonelli 1989). Greve (2003: 689) goes on to suggest that performance below aspiration level not only makes managers search for solutions, but also makes them more likely to accept risky solutions. The proposition that managers become less risk-adverse when under strain also finds empirical support (see e.g., Bolton 1993, Greve 1998). Accordingly, since risk aversion is likely to fall when the organization is under competitive pressure and since greater uncertainties are involved when undertaking radical innovation, given that such an innovation process typically involves the lack of knowledge about the precise cost and outcomes of different alternatives in addition to a lack of knowledge of what the alternatives are (Nelson and Winter 1982, Freeman and Soete 1997), we expect that firms will attempt to engage in more radical innovation projects, when they are under competitive pressure. In sum, we submit the following:

H1c *Competitive pressure from the external environment fosters radical innovation*

Collaboration

Early in the life of a radical technology there is generally a lot of technological and market uncertainty that needs to be resolved (Utterback and Abernathy 1975, Nelson and Winter 1982, Afuah 2004). Accordingly, the resolution of these uncertainties often requires new knowledge from lead users (Urban and von Hippel 1988, von Hippel 1988). Such lead users are sophisticated users that perceive the particular needs before other, otherwise similar users, and such lead users may therefore benefit earlier from successful upstream radical innovations when compared to the average users in the market.

As argued by Singh (1997), the fundamental challenge that firms face in commercializing complex technologies is developing the multiple competencies required. Although some complex technologies draw on similar knowledge bases, most complex technologies require the orchestration of components building on different knowledge bases (Patel and Pavitt 1997, Brusoni et al. 2001). Most firms have, however, only a limited ability to develop a broad set of competencies, since organizations must develop routines specialized to each technology (Richardson 1972, Nelson and Winter 1982). Since complex technologies entail many different subsystems, components and interfaces, often involving many different knowledge bases, organizations engaged in complex technologies, must also comprise of many differently organized, but closely integrated subunits (Burns and Stalker 1961). Accordingly, if the complex innovation is designed and created in-house in its totality, the resulting organization will be (too) organizationally complex.

Given that pure market exchange will not allow close enough coupling of the interdependent components and subsystems, a possible solution to these problems is to collaborate with suppliers and users of components in order to facilitate information exchange, mutual learning and other interdependent activities. In other words, such collaboration can facilitate complex coordination beyond what the price system can accomplish, while avoiding the dysfunctional properties sometimes associated with hierarchy (Teece 1992, Singh 1997). In the case of a modular complex system, organizations may often need to collaborate closely with suppliers and users in order to specify the relevant interfaces that make the modules interact within the overall architecture (Brusoni et al. 2001). In sum, we conjecture:

H2a *Collaboration with lead users increases the radicalness and complexity of an innovation*

H2b *Collaboration with suppliers increases the complexity of an innovation.*

Above we argued that scientific breakthroughs can sometimes lead to radical innovations. However, while private firms invest in basic research (Rosenberg 1990), they are unlikely to do so to a substantial extent because of private firms' inability to appropriate the returns from such investment (Nelson 1959, Pavitt 1993). Accordingly, most basic research is undertaken within universities (Geuna 2001, Pavitt 2001). However, scientific breakthroughs need to be translated into industrial practice in order to be able to affect innovations. One mechanism for translating scientific breakthroughs into industrial practice is for firms to collaborate with universities (Tether 2002). Accordingly, we hypothesize:

H2c Collaboration with universities fosters the radicalness of an innovation

Rosenkopf and Nerkar (2001) argue that the gains associated with the internal development of technology are not sustained unless the organization is able to integrate external developments and that boundary-spanning technological exploration across organizations affects subsequent technological evolution more than non-boundary spanning technological exploration. One reason for this can be that "do-it-alone" organizations may tend to conduct search in a myopic fashion that in turn leads to competence traps (Levinthal and March 1993). Collaboration can also be seen to be a way of increasing the variety of inputs of new knowledge needed to produce more radical and complex innovation. In the words of David Teece: "It is well recognized that the variety of assets and competencies which need to be accessed is likely to be quite large, even for modestly complex technologies. To produce a personal computer, for instance, a company needs access to expertise in semiconductor technology, display technology, disk drive technology, networking technology, keyboard technology, and several others. No company can keep pace in all these areas itself." (1986: 293). Along similar lines Tushman and Rosenkopf (1992) argue that the more complex the product, the greater the uncertainties and thus the greater the incentive for firms to share the uncertainties by engaging in inter-organizational relationships, including collaboration. More internationally dispersed sources of knowledge may also enhance the technological opportunity set of innovators (Cantwell and Janne 1999), thus resulting in more radical and complex innovations, especially in the small country case (as in our case), where the local technological opportunity set may be limited. In sum, we infer:

H3a No collaboration fosters simple and incremental innovation

H3b *The degree of national collaboration fosters simple and incremental innovation*

H3c *The degree of international collaboration fosters complex and radical innovations*

Level of R&D

The level of R&D is partially endogenous, since it is in part a function of the technological opportunities and the appropriability conditions facing the firm in industry in which the firm operate (Klevorick et al. 1995, Breschi et al. 2000). Nevertheless, some degree of managerial choice is left when it comes to the amount of resources each firm devote to innovative search in the form of R&D. Incremental innovation often emerge in conjunction with ordinary production activities (Freeman and Soete 1997), and although innovation activities are never costless it is reasonable to conjecture that search for radical innovation involves much larger and devoted projects, involving substantially larger investments in R&D. In addition, innovations which are both artefactually and developmentally complex, while involving a number of interfaces and subsystems are likely to require substantial investment in R&D. Accordingly, we posit:

H4 *The level of R&D is associated with radical and complex innovations*

In Figure 2, we have summarized our hypotheses for each of the drivers of the four innovation types, with the upper left corner (incremental/simple) as the benchmark.

4. The Finnish Innovation Database

In 1991, Finland experienced a major economic transformation through the collapse of its markets in the former USSR. Since the crisis, Finland's economy has grown tremendously, spurred on by the growth of mobile phone industry and other high technology industries. For example, Finland's share of R&D as a percentage of GDP rose from 2.0% in 1990 to 3.5% in 2003. In context of these major economic changes, the Finnish Innovation Database (Sfinno) was created by Technical Research Centre of

Degree of novelty

Degree of complexity		Incremental	Radical
	Simple	**A**	**B** H1a (+) H3a (-) H1b (+) H3b (-) H1c (+) H3c (+) H2a (+) H4 (+) H2c (+)
	Complex	**C** H1a (+) H3c (+) H2a (+) H4 (+) H2b (+) H3a (-) H3b (-)	**D** H1a (+) H2c (+) H1b (+) H3a (-) H1c (+) H3b (-) H2a (+) H3c (+) H2b (+) H4 (+)

H1a: Technological opportunities; H1b: Scientific breakthroughs; H1c: Competitive pressures.
H2a: Collaboration/lead users; H2b: Collaboration/suppliers; H2c: Collaboration/universities.
H3a: No collaboration; H3b: Collaboration breadth/national; H2c: Collaboration breadth/international.
H4: R&D level.

Figure 2: Overview of the proposed framework and hypotheses

Finland (VTT) with financial support of Tekes (the Finnish National Technology Agency). The database was designed to capture major technological innovations developed by Finnish industry during the 1980s and 1990s. The aim underlying the creation of the database was to identify the sources and types of innovation of Finland during a period of significant economic transition.

The definition of an innovation used in the creation of the database was derived from the Organisation of Economic Development and Co-operation's Oslo Manual (1992). The definition of innovation in the study "was an invention that has been commercialized on the market by a business firm and these innovations needed to be technologically new or significantly enhanced product compared with the firm's previous products". Only innovations that were commercialized by Finnish firms are included in the dataset.

The Sfinno database draws on two research tools – a list of innovations and a postal survey of innovators. For the first element, a list of innovations was compiled using a combination of three methods: 1) expert opinion, 2) reviews of trade and technical journals, and 3) interviews and validation with large firms. Of these three methods, expert opinion and literature-based reviews have been used in the creation of many other innovation databases (see for instance, Rothwell et al. 1974, von Hippel 1988, Pavitt et al. 1989, Kogut and Zander 1992, Acs et al. 1994). The first stage in the development of the innovation database was the creation of technical experts' lists of major Finnish innovations. 150 experts representing different industrial and technological fields from industry, the Technical Research Centre of Finland (VTT), Tekes and the leading Finnish universities of technology were asked to list the significant innovations developed in Finland from 1985 to 1998. In total, these technical experts identified 285 innovations. However, given that the technical experts were unable to identify the year of commercialization of innovation and describe origins of the innovations; additional methods were required to capture the number and sources of innovation in Finland.

The second stage in the creation of the innovation database was a literature review of the Finnish technical press. First, a population of journals that were eligible for innovation detection was defined. Journals were considered eligible as far as they were edited, independent and were published regularly; i.e. mere product listings or announcements, irregular publications or journals directly controlled by companies were not considered eligible. This approach resulted in a population of 60 trade or technical journals. In the next phase, all such journals were selected that regularly published edited and non-paid material about innovations. In total, 18 Finnish technical journals fulfilled this criterion. The VTT team read over these journals for years of the study (scanning close to 300,000 pages of technical material). They searched these journals for articles describing on the introduction of new products. The VTT team was careful to avoid technical articles that simply listed of new products. The technical journal review resulted in the identification of 1144 innovations. In addition, lists of award-winning innovations in the literature were also included.

Alongside the expert lists and technical journals, and due to the importance of a small number of large firms in the Finnish economy, the VTT team conducted a case-by-case analysis of the innovations of the twenty-two largest Finnish firms. The team was concerned that the expert lists and journal reviews would not fully cover the activities of these firms. The selection of firms was made on the basis of their R&D spending and patenting. A list of the innovations for each firm was produced from the existing database and these lists were then sent to the firm for validation. The firms were asked to pick out those products that they considered especially important and innovative to their firm. In this way, a group of 200 innovations were identified. In addition, a group of 226 innovations was identified other Finnish sources, such as government reports and background technical documents, by the VTT team.

Once the combined innovation database was created, the VTT team then compared results of the different classification methods. The results of these exercises confirmed that larger shares of innovations from smaller firms were identified by the literature review than by the technical experts' lists. However, the technical experts did not appear to have a bias in favor of innovations from large firms. Moreover, the share of innovations that were identified from more than one source is relatively small, indicating that the combination of different methodologies has indeed enhanced the coverage of the database (Pentikäinen et al. 2002). Another problem addressed by the VTT team was double counting of innovations. In order to avoid this, each innovation was checked for duplicates before they were added to the database. Almost 200 duplicate innovations were identified and removed from the database. In total and the basis of the three methods, 1678 innovations were identified.

Once the list of innovation was finalized, supplementary data on the innovations and firms who were responsible for these innovations was collected by using Finnish business register and patent databases at Statistics Finland. The basic data on the innovation includes: its name, a brief technical description of the innovation, its year of commercialization, its NACE industrial field and its patent technological class (ICP). Firm-level information included the firm official identification code, its name and address, industrial sector, number of employees, sales, number of patents and year of entry in the business register. In total, there were 1049 Finnish firms who had at least one innovation over the period of the study.

The second stage of the research involved a postal survey of the individuals who responsible for each innovation. Owing to various practicalities related to the extensive time period covered and organizational changes among the firms, a significant amount of preparatory work was required before mailing the questionnaires. Where the name of the individual was available, the questionnaire was addressed directly to them. Where the name of the individual was not available, the questionnaire was addressed to the Chief Executive Officer or R&D Director and they were asked to forward the survey to the person responsible for that innovation.

The questionnaire itself was developed through interviews and reviews of the previous literature on innovation. Questions were pre-tested with technical experts within VTT and piloted with range of Finnish companies. From pilot, several significant changes were made to the questionnaire, including removal sensitive and poor responded questions and improve phrasing and language. The postal survey was implemented in 1998. 1074 questionnaires were posted and 729 responses were returned, providing a response rate of 67 per cent. The firms were contacted five times in order to ensure a high response rate. The completed questionnaires were also checked for internal inconsistency and non-responses. Where there were non-responses or inconsistencies in responses, the VTT team contacted the respondent to capture the missing information.

The Sfinno Innovation database includes only major product, process and service innovations and, as Kogut and Zander (1992) suggest, these types of innovations are easier to track than minor innovations. Appendix X lists a sample of innovations from the Sfinno database. Major innovations include “Sauna-Stu - insulation material for new and renovated saunas” developed by Spu Systems in 1997, “Monospace: an elevator without machine room” developed by Kone in 1995, and “Mowjli – mobile office workstation using GSM links” developed by Nokia in 1997.

Although the Sfinno database includes innovations in “production methods” and “commercialization of new service concepts”, we focus on major product innovations and our sample includes 540 innovations, drawn from a range of services, manufacturing and construction industries. Product innovations included innovations that involved the "commercialization of the core technology of the firm" and the "development and integration of components and modules". Each innovation was also classified by degree of novelty from totally new, major improvement and incremental improvement and whether the product was new to the Finnish or global market.

Alongside the classification by novelty, innovators were asked to indicate the degree of complexity of the innovation in terms of artefactual and developmental complexity. The innovators could classify their innovations into four different complexity categories: 1) low artefactual complexity/ low developmental complexity (i.e. innovation is a simple unit); 2) medium artefactual complexity/ low developmental complexity (i.e. innovation is a unit and development is based on knowledge base from one discipline; examples include: electronic wheel chair, drill); 3) medium artefactual complexity/high developmental complexity (innovation is a unit and development is based on knowledge base from several disciplines. Examples include: pharmaceuticals, software, generators); and 4) High artefactual complexity/ high developmental complexity (innovation is a system consisting of several functional parts and development is based on several different disciplines; examples include: paper machine, mobile phone network, cruise ship). We combine category 3 and category 4 to be complex and 1 and 2 to be simple. In other words, in our study, innovations have to have at least medium artefactual complexity *and* high developmental complexity in order to be deemed "complex" rather than "simple".

Measures

Dependent Variable. Based on the discussion above we classify each innovation by a 4-variate composite variable from the indicator of novelty and complexity. The analysis revolves around the explanation of this variable. Table 1 displays the categories and the number of observations for each category. From the table it can be seen that the single largest group of innovations are of the radical/complex type. Here it has to be kept in mind that although some innovations have been classified as being of the incremental and complex (type A), they still have to be “major technological innovations”. Accordingly, many small Finnish incremental and simple innovations have been excluded from the database. The focus here is on significant innovations, as in the case of the classical “Project SAPPHO” innovation study (Rothwell et al. 1974). Table 2 breaks down the innovation types on the sectors from where they stem. From the table it can seen that incremental and simple innovations (type A) tend to dominate low tech sectors such as food & textiles; wood, furniture, pulp & paper; and metal products, but this innovation type is also dominant within medium tech industries such as machinery and transport equipment. At the other extreme, radical/complex innovations (type D) are unsurprisingly dominant within chemicals; electronics; construction and utilities; and within business services. Innovations stemming from the computer related service industry tend to be more of the incremental, but complex type (type C).

[Table 1 and 2, just about here]

Independent Variables. The independent variables in the analysis refer to two different levels of observations. Project level variables characterize the innovation project eventually generating the innovation. Firm level characteristics identify certain features deemed essential for innovation on the level of the innovating organization.

Firm specific characteristics. The innovating firm is characterized by its size (*size*) measured by the number of employees and its R&D intensity (*rdint*) measured by the fraction of sales spent on R&D prior to introducing the innovation. The major area of the firm’s activities is captured by ten industry dummies. Additionally we use a time dummy indicating the after-crisis innovation to capture changes in the macro economic environment firms operate after the crisis of the early 1990s.

Project specific characteristics. Include variables about the factors that inspired the innovation, information about the collaboration relationships during the innovation project and other project related information. Among the factors inspiring the innovation project we differentiate between technological opportunities (*stech*), technological breakthrough (*sbreak*), increasing price competition (*scomp*) and market opportunities (*smarket*). The collaboration relationships during the innovation project are characterized by variables indicating certain collaboration partners such as customers (*cocus*), suppliers (*cosup*), universities (*couni*) and competitors (*cocom*). Where our indicator does not only refer to collaboration but also requires relevant contributions of the collaboration partner as perceived by the manager of the innovation project. In addition to the specific collaboration partners we characterize the breadth of the national and the international collaboration network during the project (*codomdiv* and *cointdiv*).[1]

Table 3 characterizes the innovation types A to D and the complete sample based on the firm level and project level characteristics. From the table it can be seen that firms producing radical and complex innovations (type D) tend to have the highest R&D intensity as the mean is 22 per cent. Moreover, innovations of type D also tend to be more based on new technological opportunities, scientific breakthroughs and diverse, international collaboration, when compared to the other types of innovation. Collaboration with suppliers appears to be associated more with incremental and simple innovations (type A) than with other types of innovations from a descriptive point of view.

[Table 3, just about here]

Multivariate analysis

Means of estimation

We apply a multinomial logit model as the means of estimation to assess the importance of the different kinds of origins of innovation for each of the innovation types with incremental/simple innovations (A) as the benchmark and we report results for the determinants of innovation for the three other categories of innovation types - radical/simple (B); incremental/complex (C); and radical/complex (D). We estimate the

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1 We use an entropy index to construct a measure of diversity for the national and international collaboration network of the project.

model for 540 innovations. We use both project specific and firm specific exogenous variables.

Presentation of the results

Table 4 reports the results of the multinomial logit regression, where the incremental/simple (A) innovations represent the base category. The Hausman test in Table 5 indicates that we cannot reject the independence of irrelevant alternatives.

[Table 4, just about here]

We visualize the results of the analysis by means of odds ratio plots. Generally, odds ratio plots facilitate the discussion of the results of multinomial regression model (Long 1997, Chapter 6). Figure 3 to 6 contain the odds ratio plots for the regression. In a rather intuitive way, odds ratio plots capture all the information also contained in Table XX3. Each row in the plot represents an independent variable. The plotted letters A-D indicate the category of the innovation. The bottom scale indicates the estimated coefficient $\beta_{k,m|n}$, where k is the independent variable, n is the base category and m is the category under investigation. The top scale indicates the factor change coefficient $\exp(\beta_{k,m|n},\cdot\delta)$, with δ being 1 for dummy variables k and std(x_k) for continuous variables x_k. It gives the change in the odds of the dependent variable being m rather than n if x_k changes by δ. In addition to the information about the size of the coefficients and the odds ratio change the plots also convey information about the significance. A connecting line indicates that the parameter estimates are not significant on the 10% level. Vertical spacing in the graph does not carry any meaning. It only makes the connecting lines more visible. Take for example the size of the commercializing firm captured by *lsize* in Figure 3. With the size of the commercializing company the odds to create a incremental/simple innovation (A) increases relative to generating an simple and radical innovation (B). Increasing size also means that the odds of incremental/complex innovations (C) increase relative to the odds of type A or type B innovations. There is no significant effect on the odds between type

D and type A or type C innovations, though. However, increasing size of the company improves the odds of generating a type D innovation relative to type B.

[Figure 3, just about here]

Results

With respect to Hypothesis 1a ("New technological opportunities advance radical and complex innovations"), Ahuja and Lampert (2001) show that a firm's creation of breakthrough inventions is positively related – up to a certain level – to its exploitation of new technological opportunities. Our results show that new technological opportunities (*stech* in Figure 4) increase the odds of radical/complex innovations (D) relative to the odds of incremental/simple innovations (A) or incremental/complex innovations (C). On these grounds H1a attains partial support only: We find evidence that among complex innovations new technological opportunities foster radical innovations. However, new technological opportunities do not do so among simple innovations. Additionally, new technological opportunities increase the odds to improve in both dimensions simultaneously, i.e. to generate a complex and radical innovation rather than a simple and incremental innovation.

[Figure 4, just about here]

With respect to H1b ("Scientific breakthroughs foster radical innovations"), involving scientific breakthroughs as a driving force for the innovation project as captured by *sbreak* in Figure 5 increases the odds for a radical innovation relative to the odds of an incremental/complex innovation, regardless of the complexity of the radical innovation. The odds ratios in the complexity dimension are unaffected by scientific breakthroughs as a point of departure for the innovation project. The odds of incremental/simple to the odds of all other types of innovations are not influenced by scientific breakthroughs.

Hypothesis 1c states that competitive pressure from the external environment increases radical innovation ("Competitive pressure from the external environment fosters radical innovation"). However, competitive pressures in terms of pressure from rivals' innovation success or increased price competition increase the likelihood of incremental innovations relative to radial innovations, regardless of the complexity. The complexity of an innovation is unaffected by the competitive pressures igniting the commencement of the innovation project. Based on our analysis, hypothesis H1c cannot be confirmed — in fact, our evidence suggests the opposite. Yet, firms experiencing rival innovations or increased price competition from competitors have incentives to change their internal routines and hence set free some innovation potential previously buried by risk aversion or everyday business practices. However, the selection of a strategy to fight the immediate threat to companies' sustained profits is not random and incentives are not the only drivers of radical innovation. Substantial resources are required too – resources that may not be available to firms under external pressure. Cost efficiency considerations and previous commitment to certain types of products, processes or business practices will induce companies not to change to radically. Accordingly, to fight the immediate assault towards the company's profits, companies may typically not be able to conduct large scale systematic R&D to develop radical innovations. Rather, it seems that companies search for the easy way out of the competitive challenge by starting to innovate incrementally.

In other words, when under competitive pressure, firms appear to focus on updating exiting products in an incremental way based on the exploitation of existing ideas, rather than focusing on the exploration associated with radical innovation (March 1991), when such innovation may require long-term commitments in order to become successful. Accordingly, our findings are consistent with the view that competitive pressures may substantially reduce or remove the organizational slack of firms (Cyert and March 1963), and that organizational slack may be needed to produce radical innovations, since such slack may allow for more wide innovative search (Knight 1967, Özcan 2005).

Regarding Hypothesis 2a (“Collaboration with lead users increases the radicalness and complexity of an innovation”) we find that collaboration with lead users during the innovation project increases the odds of radical innovation among the complex innovations (see Figure 5). The odds for innovations of type D relative to the odds for innovations of type C increase with customer collaboration. At the same time customer collaboration decreases the likelihood to generate a complex innovation among the incremental innovations: the odds of type C innovations fall relative to the odds of type A innovations. Hence, we find only support for the hypothesis among he complex innovations. So for this type of innovations your findings are in line with the findings of Fritsch and Lukas (2001) and Tether (2002), who find that radical innovators tend to collaborate more with costumers on innovative activities. However, we find the opposite of what H2a suggests among the incremental innovations. We find no support for Hypothesis 2b (“Collaboration with suppliers increases the complexity of an innovation”) as in our analysis the collaboration with suppliers (*cosup*) does not significantly change the odds of any type of innovation.

In Table 4 we observe that our sample supports Hypothesis 2c (“Collaboration with universities fosters the radicalness of an innovation”) as the odds of radial innovations increase relative to the odds incremental and simple innovations (type A). At the level of complex innovations we find no evidence for the influence of university collaboration on the radicalness of innovations (type C vs. type D). In addition, we find that collaboration with universities fosters complex innovations (type B) among the incremental innovations (type A). Put it simply, university collaboration reduce the odds of incremental and simple innovation relative to all other innovations. This findings is at odds with Tether (2002), who finds that more radical innovators do not collaborate more with universities than other innovators do.

[Figure 5, just about here]

Figure 6 shows that innovation projects which involve no collaboration at all (*cono*), increase the likelihood of generating incremental innovations relative to radical innovations. The complexity dimension is not affected by the absence of collaboration. Accordingly, Hypothesis H3a ("No collaboration fosters simple and incremental innovation") is only partly supported by our findings. Nevertheless, our findings are consistent the findings of Fritsch and Lukas (2001) and Tether (2002), who find that radical innovators tend to collaborate more on innovation than other firms and with the results obtained by Rosenkopf and Nerkar (2001), affirming that exploration within firm boundaries has less impact on subsequent technological evolution as measured by subsequent patent citations. One possible interpretation for this result is that patents that are quoted by future patents tend to reflect more radical inventions when compared to less quoted patents. Hypothesis 3b asserts that the degree of national collaboration promotes simple and incremental innovation ("No collaboration fosters simple and incremental innovation"). However, the degree of national collaboration, as captured by the diversity of the domestic collaboration network (*codomdiv*), has no significant effect on the odds ratios of the innovations. The only exception is that the degree of national collaborations reduces the odds of radical innovation among the complex innovations. Concerning Hypothesis 3c ("The degree of international collaboration fosters radical and complex radical innovations"), we find that the degree of international collaboration, captured here by the diversity of the international collaboration network within the innovation project (*cointdiv*), has a positive influence on the likelihood of radical and, at the same time, complex innovations. All other types of innovations are rather unaffected by the breadth of the international collaboration.

[Figure 6, just about here]

Hypothesis 4 contends that the level of R&D is associated with radical and complex innovations ("The level of R&D is associated with radical and complex innovations"). In Figure 3 the level of R&D (*rdint*), scaled by the sales of the innovating firm, improves the odds of complex innovations relative to the odds of simple innovations. This holds true for both incremental and radical innovations. Accordingly, our data does not confirm that the level of R&D influences the odds of radical innovations relative to incremental innovations. Hence, our analysis can only partly support hypothesis H4.

5. Conclusion

In this paper we have suggested that the origins of innovation are different according to the type of innovation identified in our taxonomy (simple/incremental; simple/radical; complex/simple; or complex/radical). We found that the origins of innovation do indeed differ according to the type of innovation, although our theoretical expectations were not always met. In particular, we found that new technological opportunities and collaboration with lead users appear to increase the radicalness of complex innovations. Scientific breakthroughs tend to enhance the radicalness of innovations, regardless of the level of complexity, while R&D intensity tends to increase the level of complexity, regardless of the degree of novelty of the innovation. University collaboration tends to reduce the probability of producing simple and incremental innovations.

With respect to our three "geographical" collaboration variables we found that "no collaboration" involved in the innovation process tends to decrease the level of radicalness of the innovation, while for national collaboration, such collaboration tends to lower the odds of radical innovation among complex innovations, and finally, the degree of international innovation enhances the probability of bringing about a radical innovation which is at the same time complex. Accordingly, the overall picture is (with some qualifications) that the (geographical) width of collaboration tends to enhance the radicalness and complexity of innovations. Collaboration with suppliers was found to have neither an effect on the degree of complexity nor on the degree of novelty of the innovation, while competitive pressure had the opposite effect of what we expected from theory – such pressures appears – as an empirical observation – to reduce the level of novelty and complexity in innovations.

We believe that the subject of the origins of different types of innovation is a fertile field of research, although the relevant mechanisms are subtle and not easy to trace – theoretically or empirically. Nevertheless, we see this paper as a first step in trying to unfold this research agenda.

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Table 1: Number of innovations split on out taxonomic categories

	Incremental	Radical
Simple	(A) 146	(B) 108
Complex	(C) 140	(D) 148

Table 2: Sectoral distribution of types of innovation in per cent (n=540)

Sectors	Incremental/ Simple (A)	Radical/ Simple (B)	Incremental/ Complex (C)	Radical/ Complex (D)	Row per cent	Per cent of total
Food and textiles	64	14	11	11	100	5
Wood, furniture, pulp, paper & publishing	40	33	19	7	100	7
Chemicals	26	31	12	31	100	7
Metal products	46	22	17	15	100	7
Manufacture of machinery and equipment	34	19	21	26	100	18
Electronics	14	11	33	41	100	16
Transport equipment	45	25	15	15	100	3
Construction and utilities	0	23	38	38	100	2
Trade and postal services	22	29	27	22	100	9
Business services	15	23	24	38	100	18
Computer related service activities	8	15	56	21	100	8
Per cent of total	26	21	25	27		100

Table 3: Descriptive statistics (mean)

Variable	All (N=540)	A (N=146)	B (N=108)	C (N=140)	D (N=148)
	Mean	Mean	Mean	Mean	Mean
lsize	4.219	4.722	3.321	4.350	4.240
rdint	0.137	0.064	0.092	0.160	0.220
stech	0.200	0.103	0.208	0.150	0.338
sbreak	0.133	0.062	0.160	0.064	0.250
scompet	0.406	0.500	0.292	0.507	0.297
cocus	0.819	0.829	0.792	0.779	0.865
cosup	0.531	0.548	0.566	0.486	0.534
couni	0.420	0.315	0.500	0.429	0.459
cono	0.130	0.199	0.123	0.121	0.074
cointdiv	0.433	0.366	0.369	0.426	0.552
codomdiv	0.760	0.639	0.778	0.827	0.803
acrisis	0.596	0.568	0.604	0.614	0.601

Table 4: Results of the multinomial logit regression

Variable	depvar = B		depvar = C		depvar = D	
lsize	-0.169	**	0.1279	*	0.082	
rdint	-0.530		2.5407	*	3.431	**
stech	0.520		-0.1089		0.730	
break	0.715		-0.2248		0.817	
scompet	-0.724	*	0.2929		-0.921	**
cocus	-0.176		-0.5953		0.217	
cosup	0.068		-0.3519		0.116	
couni	1.499	***	1.2893	***	1.315	***
Cono	-1.705	**	-0.5745		-1.982	**
cointdiv	-0.107		0.3136		1.049	*
codomdiv	0.123		0.5982		-0.334	
Constant	0.116		-2.6495	**	-2.235	*
No. obs	540					
LR chi2 (63)	276.93	***				
McFadden R2	0.186					
C&U R2	0.428					

Table 5: Hausman test for IIA

Omitted	chi2	df	P>chi2
A	8.99	50	1.00
B	0.00	1	1.00
C	0.00	1	1.00
D	12.51	49	1.00

Figure 3: Odds ratio plot of the multinomial regression model – part 1

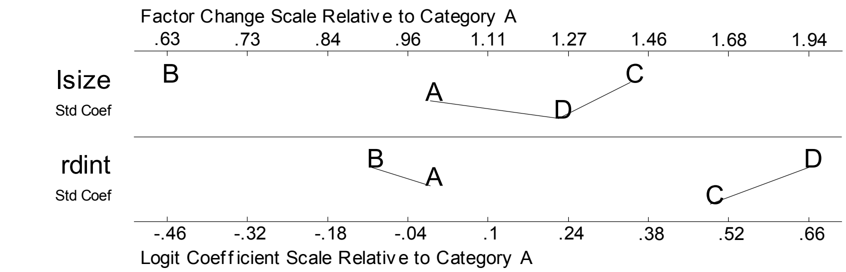

Figure 4: Odds ratio plot of the multinomial regression model – part 2

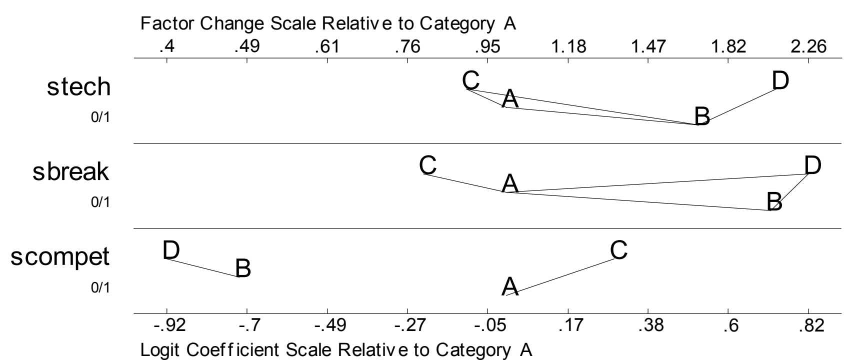

Figure 5: Odds ratio plot of the multinomial regression model – part 3

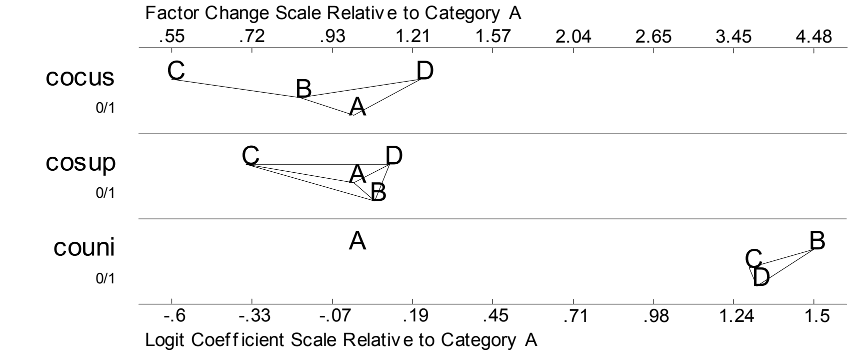

Figure 6: Odds ratio plot of the multinomial regression model – part 4