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Technological Internationalisation in the Electro-Technical Industry: A Cross-Company Comparison of Patenting Patterns 1986-2000*

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Abstract

This paper addresses the issue of R&D internationalisation of two multinationals in the electro-technical industry (GE and ABB), by means of a patent data analysis. The overwhelming majority of both companies' R&D activities are concentrated to Western Europe and North America. The locational overlap between the two firms' activities is small. These results are consistent with findings from earlier studies that (1) there is little evidence to suggest that the 'production' of technology is globalised in a general sense and (2) that tapping knowledge from an industry's global lead location plays a very limited role in foreign R&D investments.

Key words: Internationalisation; U.S. patent data; Asea Brown Boveri; General Electric

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1. Introduction

The 'globalisation' of R&D by multinational corporations has been an important research theme in recent years. A number of studies suggest an increasing internationalisation of technological activities by the world's largest firms (cf. Cantwell & Janne, 2000; Gassmann & von Zedtwitz, 1999; Patel, 1995; Patel & Vega, 1999). However, the interpretation and significance of this development is widely debated. Some researchers, especially in the strategic management literature, have argued that the leading multinationals are now able to source, combine and leverage technical knowledge on a global scale, eroding the role of the traditional home-base: "...the geographic dispersion of business activities and the emergence of technological capabilities in foreign units are increasingly taken as indications that the multinational actively seeks out skills on a global basis and implements strategies for integrating knowledge within the multinational network" (Zander, 2002, p. 330). On the other hand, researchers in the technology and innovation field have emphasised that the core technological activities of these firms continue to be firmly embedded in the conditions of their home countries: "Thus our findings support the analyses that, far from being irrelevant, what happens in home countries is still very important in the creation of global technological advantage for even these most internationalised firms" (Patel & Vega, 1999, p. 154).

So far, the internationalisation of R&D mainly has taken place between the developed OECD countries in Europe and North America. The degree of internationalisation within this area, however, seems to vary considerably between firms from different industries and countries (Cantwell & Janne, 2000; Gerybadze & Reger, 1999). It should, therefore, be interesting to look closer at one particular industry and compare the internationalisation patterns of its leading firms. Is there an emerging tendency of a 'truly

global' pattern of technological activity, or is a geographic bias to historically established regions still the dominant pattern? Are leading firms in R&D intensive industries following the same basic internationalisation trajectory, or are there significant differences? Are there reasons to believe that the most internationalised firms also are the most successful and forward-oriented ones in terms of new knowledge and technology development, as is assumed in the international management literature (cf. Bartlett & Ghoshal, 1998; Doz et al., 2001) or could the existence of international R&D networks be interpreted in a rather different manner? These questions have inspired the paper presented here.

In the internationalisation research community, there seems to be a division of labour in terms of methodology: Students of the internationalisation of industries and groups of MNCs from different industries prefer quantitative approaches using patent data, whereas studies of the internationalisation of individual firms tend to rely on case studies and management interviews. Zander (2002) is a rare case where patent data analysis is applied to the study of one particular firm. In this paper, we take one step further and use patent data to compare technological internationalisation patterns of two leading firms within one sector: Asea Brown Boveri (ABB) and General Electric (GE) in the electro-technical industry. This allows us to go more into detail than is usual in more aggregated studies. In particular, we are able to search for different types of internationalisation (diversification and duplication) and different geographic patterns, and to apply a longitudinal approach, tracking and comparing the developments at firm level.

This paper is structured as follows. Section two contains a literature review and our research questions. In section three, the methodology is presented and discussed. Section

four contains a comparative analysis of the overall internationalisation pattern of ABB and GE. Some possible explanations for the found differences are discussed in section five. In section six we analyse the issues of duplication/diversification and collaboration in R&D internationalisation. Finally, section seven summarises the findings, discusses a critical interpretation of highly internationalised R&D and suggests areas for further research, both at a more aggregate and at a more detailed level.

2. Literature review and research questions

Many researchers have noted increasing levels of investments in foreign R&D and foreign patenting. For example, a comprehensive study of large firms in the pharmaceutical and electronics industries found that the share of R&D efforts the companies spent outside their home countries had increased from 6.2 percent in 1965 to 25.8 percent in 1995 (Kuemmerle, 1999). In a study of country-level patenting within OECD, Guellec & van Pottelsberghe (2001) reported that the share of cross-border ownership of patents had increased from 8.5 to 12 percent between the early 1980s and 1995. The share of patents involving at least two inventors from different countries more than doubled during the same period.

Several authors have argued that companies increasingly need to source advanced knowledge from dispersed locations, which is interpreted as the emergence of a new "global knowledge economy" (Doz et al., 2001). Such propositions tend to be related to assumptions of a changing character of multinational firms in general, and their R&D in particular, involving a transition from highly centralised structures to a less hierarchical "interdependent network of mutually supportive facilities" (Pearce, 1999), "double networks" (Zanfei, 2000) or other forms of "globalized approaches" (Niosi & Goldin, 1999). These notions of new international R&D structures are related to evolutionary

models of the development of the multinational enterprise: from ethnocentric entities, which “project” their home-grown strengths on an international scale, over poly-centric or multi-domestic organisations, which seek to build autonomous resource-bases in many markets, to transnational companies which build distributed structures of competence centres, each tapping into a distinctive national advantage (Berggren, 1999a; Gassman & von Zedtwitz, 1999).

Apart from case studies of single companies, internationalisation of R&D and other technological activities have mainly been studied at the level of industrial sectors, such as “chemicals and pharmaceuticals” and “electro-technical and electronics” or at the level of national states. The preferred methods have been surveys of R&D labs and patent data for groups of companies or countries. An important finding in the patent-based research is the persistence of country differences and the importance of size, both in terms of country size and ‘technological size’. With respect to the former, the smaller the country, the more internationalised the research of its companies. With respect to the latter, Guellec & van Pottelsberghe (2001) found that companies in large R&D intensive countries, such as the U.S., perform a dominant share of their inventing activity domestically, whereas countries with a small ‘technological basis’ (measured in number of patents) tend to have a higher share of this basis controlled by foreign applicants and are more likely to collaborate with foreign researchers. In small R&D intensive countries, such as the Netherlands, Sweden and Switzerland, companies tend to conduct a high share of their patenting activity in foreign locations. In contrast to assumptions about an increasingly global dispersal of knowledge and corporate R&D, the same authors reported a persistent importance of geographical and technological proximity. Countries with a common border enter into cross-border ownership and co-operate more than other countries, especially if there is a common language, and the closer two countries

are in their technological specialisation, the more they co-operate in research and patenting across borders.

Several survey-studies have highlighted the increasing importance for multinational R&D labs to take on not only home-base exploiting but also home-base-augmenting activities, such as product development or applied research (Pearce, 1999; Kuemmerle, 1999). There is weak support, however, to assume that technological sourcing plays an important role: “the major aim of multinational firms when establishing research facilities abroad is to adapt their products to local conditions rather than to ‘tap’ foreign technology: actually, the major stream of R&D investment abroad come from highly R&D intensive countries to low intensive ones rather than the opposite (as it would be the case if technology sourcing was the dominant objective)”. (Guellec & van Pottelsberghe, 2001, p. 1266.) Formulated slightly different, Patel & Vega (1999) arrived at a similar conclusion. “In a large majority (more than 75 percent) of cases, firms tend to locate their technology abroad in their core areas where they are strong at home. In a small minority of cases (10 percent), firms go abroad in their areas of weakness at home to exploit the technological advantage of the host.” (p. 154).

One problem in the research on internationalisation of R&D and the changing character of multinationals is the often undifferentiated use of terms associated with ‘globalisation’, for example “global strategies”, “globalization of innovatory capacity”, “technological globalization strategies” (Cantwell & Janne, 1999, pp. 243-45). However, as noted by Kuemmerle (1999) in their survey of research labs, “our findings about host countries confirm ... that FDI in R&D occurs primarily between a small number of highly industrialized countries” (p. 181). Similarly Guellec & van Pottelsberghe (2001) observed

that international patenting is a process mainly limited to the OECD states in Western Europe and North America.

It can be argued that globalisation does not presuppose globally dispersed corporations but is better seen as a process of emerging global markets with a convergence in their tradable prices: "... Although any one MNC may not be able to serve all markets or source from any location, overall they serve markets world-wide and link up to production locations across the globe and create global competition" (Perraton, 2001, p. 676). Nevertheless, much has been written in recent years on transnational corporations with global spread and global strategies. Therefore one aim of this paper is to take a more detailed look at the actual geographic distribution of innovatory activities (patenting) in two firms, which generally have been seen as global leaders in their industry. The literature referred to above has described and analysed important patterns at national and sector levels, but detailed comparisons on company level are rare so far.

Another problem in current research on international R&D is a tendency to assume that geographic dispersal within corporations can be identified with integrated networks. In their study of the geographical dispersal of patenting in Europe, Cantwell & Janne (2000) take "the recent ability of multinational corporations to develop integrated technological networks" (p. 243) as their starting point without any further discussion of what the supposed "integration" would actually mean. Similarly, in a company-focused study, Gassmann & von Zedtwitz (1999) identified a general trend toward "the integrated R&D network", supposed to be characterized by an "unrestricted flow of information" and "partnership among all competency centers" (p. 243). No evidence that the companies listed in this category actually displayed these abilities was provided. Confusing structure with process, the existence of a dispersed R&D structure tends to be identified with real

knowledge-exchange and networking abilities, and the costs and efforts of creating and maintaining such networks are underestimated or ignored. Case studies of attempts at technology integration in diversified and duplicated networks have noted the technical and political problems these projects encounter, and the resulting cost and schedule overruns (Berggren, 1999b; Bresman & Birkinshaw, 1996). In the strategic management literature, both internationally diversified and duplicated R&D resources are seen as resources for cross-border innovation. Specifically, duplicated resources are supposed to enhance speed, flexibility and quality in “global-to-global innovation projects” (Bartlett & Ghoshal, 1998; Zander & Sölvell, 2000). The implicit assumption is that the more internationally dispersed and ‘transnational’ a company’s innovation activities are, the more successful the company.¹ The purpose of this paper is to compare the international pattern of R&D (here defined as patenting) of one American and one European firm – Asea Brown Boveri (ABB) and General Electric (GE) – in one industry, the electro-technical sector. Students of multinational companies have often portrayed these two firms as leading the industry in terms of technological development, internationalisation and global strategies (cf. Bartlett & Ghoshal, 1998; Doz et al., 2001).

At the end of the 20th century, this industry went through a period of far-reaching changes and consolidation along international lines. From a situation with national electro-technical suppliers in basically all OECD countries and several competitors in the larger market such as Germany and the U.S., the industry (outside Japan) was consolidated into a few internationally operating giants: ABB, Siemens and Alstom in Europe and General Electric in the U.S.

¹ One argument underlying this assumption is that multinationals have a larger number of different development paths to exploit as well as access to the specific characteristics of the local environments of their sub-units (Zander & Sölvell, forthcoming).

After a difficult restructuring process, involving substantial layoffs and closures of previous core activities, GE emerged in the late 1980s with a clear strategy only to invest in businesses where the company could achieve a leading global position, defined as No. 1 or No. 2 in global market share. GE's new leadership repeatedly stated "globalization" of the traditionally ethnocentric American company as a key strategic objective, emphasising the importance of major investments both in Europe and in Asia. Summing up the efforts of 10 years the GE President reported: "The European crisis in early 1990s was an opportunity for us and we have grown fourfold in Europe. In 1999 we will broaden our definition of globalization (to mean not only products and markets but) to attract the unlimited pool of talent world-wide" (Welch, 1998).

Formed by a merger between Swedish Asea and Swiss Brown Boveri & Cie in 1987, ABB went on to restructure the international electro-technical industry by acquiring a stream of firms in Western Europe, North America (e.g. Combustion Engineering and parts of Westinghouse), Eastern Europe and Asia. ABB soon became famous as a leading representative of a new type of globally oriented European company, "the most successful cross-border merger since Royal Dutch linked up with Britain's Shell in 1907" (Rapoport, 1992, p. 24), a "Model Merger for the New Europe" (Kennedy, 1992) and "one of the first truly transnational firms" (Katz, 1999, p. 120). ABB was selected as the continent's leader in technology and innovation management (Trapp, 1997), and presented by management researchers as a role model for transnational organisation and global innovation (Heimer & Barham, 1998; Bartlett & Ghoshal, 1998).

Both ABB and GE are diversified corporations, with a broad range of technological activities. ABB, however, has tended to diversify within the electro-technical sector with

products such as turbines, generator, transformers, switches, industrial robots and automation systems. By contrast GE comprises both strong operations within traditional electro-technology (power systems, transportation, electrical devices, etc.) and an array of unrelated businesses in for example broadcasting, medical systems and materials. This paper focuses on the technological activities (patenting) in the electro-technical businesses of the two companies in the period 1986-2000, as explained in detail in the following section. The following four research questions will be in focus:

(1) What is the evolving geographic pattern of R&D (measured by patents) in the two companies: Do they stick to their home bases or is there an increasing international dispersion of R&D activities? If so, does it signify a 'truly global' pattern or is there still a strong geographic bias to historically established regions?

(2) Are the two firms following the same basic internationalisation trajectory, or are there significant and sustained differences? If so, how could they be explained?

(3) Has the internationalisation of R&D resulted in duplicate or complementary activities/competencies? If so, are these patterns shifting over time – increasing or decreasing degrees of duplication, etc.?

(4) Is international dispersal of patenting activity related to a growing cross-border collaboration in terms of an increasing frequency of shared patents? If so, how could this tendency be interpreted?

3. Methodology

This paper is based on a comparative analysis of the patterns of technological internationalisation of ABB and GE over a period of 15 years divided into three sub-periods: 1986-1990, 1991-1995 and 1996-2000.²

As an indicator of technological activity, we use patents issued by the U.S. Patent Office (USPTO).³ Earlier patent data analyses have reported results primarily on an aggregated level of analysis, such as country, industry or product group (cf. Cantwell & Janne, 2000; Granstrand et al., 1997; Le Bas & Sierra, 2002; Miotti & Sachawald, 2003; Patel, 1995; Patel, 1996). Few patent analyses focus on a firm level. As mentioned earlier, an exception is Zander (2002), where patent data analysis is applied to the study of one particular firm (Asea/ABB 1946-1950, 1966-1970, 1988-1990). Another exception is Patel (1995), where some data on the patenting of a number of the world's largest firms are provided. By comparing technological internationalisation patterns of two firms within one industry, we aim to contribute to these researchers' attempts to broaden the use of patent data in internationalisation studies. The case study approach allows us to eliminate the influence of industry differences and makes it possible to report longitudinal data on a more detailed level than in a study of a larger number of firms.

² The process from patent application to patent issue normally takes one to several years from the application date. Hence, it was not feasible to collect data beyond year 2000. As for the starting year, ABB was formed in 1987 and we could have chosen another year than 1986. Since there is a considerable random variation in annual patenting of individual firms, however, it is important to consolidate data in periods of reasonable lengths, and of course, the same length. With a choice of five-year periods (the same as Zander (2002) in his study of ABB), 1986 became the natural starting year.

³ Nowadays, patent applications *are* published at the web site, but since this was not the case earlier we have to use issued patents to get comparable data.

Although a two-case study of course cannot be used as a basis for statistical generalisation, it can be added to cases used in other studies in a process of “analytical generalization” as described by Yin (1989/1991). Studies built on larger samples are essential to substantiate the paper’s tentative conclusions. Further, there is a need for studies at a more detailed project level. As discussed in the final section, studies of patenting cannot answer questions concerning the extent and importance of co-operation and knowledge integration in actual innovation activities, only provide broad indicators.

The selection of the electro-technical industry and the companies ABB and GE for an in-depth study was based on a number of considerations. First, this study is part of a larger project aiming at studying the strategic behaviour of firms in this industry in light of recent structural changes such as the deregulation of the electricity market. Second, the electro-technical industry is a science-based industry, which, often grouped together with the electronics industry, figures prominently in international patenting statistics. According to Cantwell & Janne (2000), electrical equipment and computing accounted for 38 percent of all European-located foreign-owned research in the period of 1987-1995. Third, one of us has studied the internationalisation of ABB in earlier research (cf. Berggren, 1999a & 1999b), which of course provided us with valuable background knowledge.

In the following, we will first discuss the major advantages and drawbacks of using patent data as an indicator of technological activity. We will then describe our data set and specify the measurements used to analyse the research questions identified in the previous section.

3.1. Patent data as an indicator of R&D activity

The use of patent data has become an accepted method of comparing the inventive or innovative performance of companies (Hagedoorn & Cloudt, 2003). Their advantages and disadvantages have been discussed extensively elsewhere (see, e.g., Hagedoorn & Cloudt (2003), Le Bas & Sierra (2002) and Pavitt & Patel (1991)) and will, therefore, only be mentioned briefly here.

In general, the major benefits of patent data are that they cover most fields of technology, are readily available over a long period of time and may be broken down in great statistical detail according to, e.g., firm and geographic location (Holmén & Jacobsson, 1997; Patel, 1995; Patel & Pavitt, 1991).

The main drawbacks may be divided into two categories (Patel & Pavitt, 1991).⁴ The first concerns the nature of the activity measured by patent statistics – not all types of activities are reflected in the patenting of a company.⁵ However, in large firms, patent data are usually a reasonable proxy for R&D activities. The second category concerns variations in the propensity to patent between technical fields, countries (countries of application as well as of origin of the patenting firm) and firms. Since the same patent classes are used for both firms and over time, differences in the propensity to patent between technical fields are not relevant here. With respect to variations in the

⁴ A third potential drawback is that patent classes cannot be linked to products or business areas, and thus to economic performance, without detailed discussions with experts in each individual product area. This disadvantage concerns the relationship between patenting activity and commercial success, an important issue but largely outside the scope of this paper.

⁵ The degree to which a technological activity is related to patenting probably differs between different types of activities, e.g. R&D, product development or production.

propensity to patent in different countries, patenting in the U.S. is usually considered to be a quite reliable measure (Pavitt and Patel, 1991). Differences in the propensity to patent between firms may be problematic when comparing firms' patenting in absolute terms. However, in this study, we are primarily concerned with relative measurements such as the share of 'foreign' patents and changes over time.

In addition to these general pros and cons of patent data, there are some issues that are particularly important in this study. A *disadvantage* of using U.S. patent data is that they will probably result in an over-estimation of domestic R&D for GE and of foreign R&D for ABB (Patel & Vega, 1999) as well as in an over-estimation of the U.S. share of ABB's foreign patenting activities. Estimating the size of different types of biases is very difficult, and would make an interesting subject for further research. However, as mentioned above patenting in the U.S. is usually considered to be a quite reliable measure, in spite of e.g. variations in the propensity to patent in different countries, and according to Patel & Pavitt (1991, p. 6), "... the international distribution of the sources of US patenting show statistically highly significant similarities to the international distribution of business enterprise R&D expenditure". Moreover, according to the head of patenting of ABB Corporate Research Sweden and the former head of patenting of ABB Carbon, U.S. patenting have been the preferred way of patenting for ABB – in all locations – since the company entered the U.S. market in the late 1980s. One further argument in favour of using U.S. patent data is that they have been used in a large number of previous studies (basically all studies referred to in this section, among others), which provides a basis for comparison of our results to those of other researchers. A particular *advantage* for this study is that U.S. patents provide information

about the location of the inventor, which makes it possible to identify where the R&D underlying the invention was carried out (Zander, 2002).⁶

3.2. Data set

This paper is based on a new and previously unpublished data set, which has been compiled from information supplied via the U.S. Patent Office's web site.

The data set was built up in two steps. First, we had to define the electro-technology field, a task that was not trivial. Earlier studies provided little help as most definitions of sectors and industries provide very little information about what patent classes are included in each sector/industry and, furthermore, do not define electro-technology as a separate sector.⁷ We therefore decided to use the patent classes in which ABB was active as an approximation, since we knew that ABB's activities were largely confined to the electro-technical industry, in contrast, e.g., to GE, which also comprised operations in aerospace, aircraft engines, plastics and medical equipment. The patent classes are listed in the appendix. In total this approach yielded roughly 3,400 ABB patents and 11,700

⁶ Assuming that inventors typically carry out research in their home country.

⁷ As an example of the former, Patel (1995) divides 569 large firms into a number of "product groups", but provides no information on how the classification was done in more detail. Cantwell and Vertova (2004) similarly present 56 technological sectors without describing which patent classes are included in each sector. An example of the latter is Gambardella and Torristi (1998) who provide a list of patent classes divided into five "industry classes". Patent classes that seem to be related to electro-technology are distributed over several industry classes. Furthermore, a number of largely irrelevant classes from an electro-technical point of view are included in the same industry classes as seemingly relevant patent classes, and some electro-technically relevant classes seem to be missing. Similarly, Cantwell and Vertova (2004) categorise three technology fields that seem relevant to our study ("Power Plants", "Nuclear Reactors" and "Electrical Devices and Systems") as three different "industrial types" ("Mechanical", "Other" and "Electrical" respectively).

GE patents for the 15-year period. Of course, there is a risk that minor GE patent classes that have been excluded may still be of relevance to the electro-technical field, which would possibly distort the results of the analysis. However, in a sample including every tenth GE patent in the studied period, the major patent classes of GE and ABB largely overlapped. Those of GE's largest classes that were not included in our study were classes unrelated to the electro-technical field, in which ABB had no patents at all. To include them would have introduced a major source of distortions.

For the classes in our sample, all issued patents applied for by ABB and GE respectively in the period 1986-2000 were identified and recorded. For each of these patents, we recorded application date, inventor name, inventor country, inventor state (for U.S. inventors), assignee name, assignee country, assignee state (for U.S. assignees) and current U.S. patent classes (main class and sub-classes). When more than one inventor were stated, all were included in the data set. Thus, in contrast to many other studies we are able to study the development over time of the relative share of 'shared' patents, which presumably is an indicator of R&D co-operation between different national locations.

There were three main difficulties in building this data set. First, patents applied for by subsidiaries are often granted under a different name than that of the parent company. Identifying subsidiaries and consolidating patents under the names of the parent companies was a necessary but difficult task, which had to be done manually. We used the annual reports of the two companies to identify first-order, majority-owned subsidiaries. Subsidiaries were considered part of the company from the year of

acquisition to the year of divestment.⁸ Second, as mentioned above the patent evaluation process in some cases takes more than the three and a half years that elapsed between the last date of application in our study and the time our dataset was built. Thus, the last period is probably slightly underestimated. Third, although the date of application is stated in the patent document, all other data is updated at the date of issue. We have defined our sub-periods based on the date of *application*, which has two major consequences for our study: (1) We may have attributed the patent to the wrong country of origin in some cases, due to inventor movements between application and issue dates.⁹ However, this does not seem to be a big issue – most inventors in our data set seem to remain in the same location throughout all three time periods. (2) A patent assigned to, e.g., ABB might not have belonged to ABB at the application date, and a patent originally applied for by ABB may now be assigned to another company. Thus, some of the patents in the dataset may not belong there and some may be missing. One specific case is that of ABB’s Power Generation sector, which was acquired by Alstom in 2000 after a short period of joint ownership. Some of the patents applied for by ABB in the last period within this sector are now probably assigned to Alstom in the USPTO database.¹⁰

⁸ This implies that, due to the gaps between R&D efforts, patent application and issue of patent, some patents may not be the result of R&D activities in the studied companies in the studied periods. However this approach is more correct than the most common approach, which is to consolidate patent data for one year only (cf. Patel & Vega (1999)).

⁹ For example, in our ABB data we found a patent with one Swedish and one English inventor. In an interview, we were told that the Englishman was working in Sweden at the time of application, but later moved back to England.

¹⁰ In the period of joint ownership, patents seem to have been assigned to “ABB Alstom Power”. These patents are included in our dataset.

3.3. Measurement

As described in the previous section, this study addresses the following aspects of the internationalisation patterns of ABB and GE: (1) overall degree of internationalisation of R&D, (2) internationalisation trajectories in terms of what countries the firms are pursuing R&D in, (3) duplication versus diversification, (4) international collaboration and (5) R&D internationalisation and financial success. In the following, measurements for some of these aspects will be described.

Overall degree of internationalisation. The overall degree of internationalisation is measured by the share of U.S. patents in the data set originating outside the companies' respective home countries. In most internationalisation studies, 'home country' is defined as the country in which a company's parent company or headquarter is located. However, such a definition could be misleading. First, research labs etc. are not necessarily co-located with management functions. Second, in cases of mergers between companies of different geographical origin, defining the home country based on the location of the resulting parent company will discriminate at least one of the original locations. We have, therefore, chosen the following definitions. We consider the home country of ABB to be Sweden-Switzerland-Germany.¹¹ (This will, of course, provide quite different results than a 'traditional' definition, which would have ABB as a Swiss company.¹²) GE is considered to be a U.S. company.

¹¹ Asea Brown Boveri (ABB) was formed in 1987 as a merger between Swedish Asea and Swiss Brown, Boveri and Cie (BBC), which both had technological activities in their respective home country. In addition, BBC had a long history of R&D in Germany before the merger with Asea.

¹² For example, in a Gerybadze & Reger (1999) study, ABB was defined as a Swiss company, resulting in a "foreign R&D ratio" of 90 percent.

Duplication versus diversification. This question concerns the degree to which several locations are active within the same technological fields. It is measured by the number of ‘unique’ patent classes (patent classes in which only one country is active), the share of patents in unique patent classes and the average number of active countries per patent class. High values in either of the two first measures indicate a high degree of diversification and a low degree of duplication, whereas the opposite is true for the last measure.

International collaboration. International collaboration is measured by the share of patents that are ‘shared’ between inventors from different countries of origin. When included, ‘shared’ patents are distributed proportionally between their inventors. For example, when a patent has one Swedish and one German inventor, half a patent is added to the total patent count of both Sweden and Germany.

4. Divergent patterns of R&D internationalisation

The distribution of patents between domestic and foreign locations of ABB and GE is presented in Table 1.¹³ A first obvious observation is the striking difference in overall level of internationalisation. Whereas the percentage of ABB patents (including shared patents) from locations outside its home countries increased from 17 percent to 41 percent during the 15 year time period, GE’s patenting outside its U.S. home-base started at the much lower level of 4 percent to reach the still very modest 7 percent-level in 1996-2000. On the basis of this difference it could be argued that R&D at ABB seems to be organised in a multinational and possibly transnational mould, in contrast to the predominantly U.S.-centred character of technological activities at General Electric.

¹³ In all tables and figure, ‘domestic’ refers to USA for GE and Sweden/Switzerland/Germany for ABB (see section 3) and ‘foreign’ to all other countries.

TABLE 1 IN ABOUT HERE

A closer look at the temporal pattern of the foreign share of patenting, however, gives a picture that may qualify this overall characterisation (see Figure 1). At GE, the share of foreign patenting increased between all three periods, with a slightly more rapid increase between the last two periods. ABB's foreign patenting more than doubled between 1986-1990 and 1991-1995, but then fell back somewhat between 1991-1995 and 1996-2000. Due to the limitations of data it is not possible to analyse this difference any further here, but it may be noted as a caution against simplified views of monotonously increasing levels of internationalisation in globally competing companies.

FIGURE 1 IN ABOUT HERE.

Figure 2 provides more detailed breakdowns of the 'foreign' patenting in the two companies. In the entire period 1986-2000, ABB's foreign patenting was dominated by the U.S., with Finland and Great Britain following at a distant second and third place. Together these three locations accounted for more than 80 percent of ABB's foreign patenting. The company's highly publicised strategy to 'go east', moving operations and investments from Western to Eastern Europe, and from America and Europe to Asia, is not reflected in its pattern of technological internationalisation. Japan and Taiwan were the only Asian countries figuring among the ten most important foreign patenting locations, but their joint share of ABB's foreign patents remained at the insignificant level of 2.4 percent and other major Asian countries, such as India where ABB had significant subsidiaries, were virtually absent. At GE, important locations for foreign patenting were France, Japan, the Netherlands and Canada.

FIGURE 2 IN ABOUT HERE

If the first observation of the ABB-GE comparison pointed to a striking difference in their levels of internationalisation, a second observation would be the basic similarity they display in regional distribution. In both companies technological activities are geographically highly concentrated to a rather small set of OECD-countries in Western Europe and North America (see Figure 3). By and large, this geographic bias seems to be a persistent phenomenon during the studied period. Both companies are competing on global markets, but so far globalisation has hardly affected the dispersal of their technological activities. This is in line with findings from earlier studies, as pointed out in section 2 (e.g. Kuemmerle (1999) and Guellec & van Pottelsberghe (2001)).

FIGURE 3 IN ABOUT HERE

At a more detailed level, a comparison of ABB and GE reveals some interesting differences in the geographic distribution of their patenting, however. Of their five most important patenting locations, home-bases included, ABB and GE have only one country in common. That is rather unsurprisingly the United States, the major source of all U.S. patents. All other countries on the top five-lists differ. In the GE case they are France, Japan, the Netherlands and Canada; in the ABB case they are Switzerland, Sweden, Germany and Finland.¹⁴ Given GE's low level of foreign patenting any interpretation of

¹⁴ In the period 1991-1995, Sweden was a major foreign location for GE as well. However, this was due to a temporary joint venture between GE and the Swedish company Ericsson concerning the development of mobile telephones, which probably was motivated more by Ericsson's expertise in mobile phones than by Sweden's general strength in the type of communications technologies that these patents concern.

this divergence has to be cautious, of course. Nonetheless, the comparison of the international patenting pattern of ABB and GE does not seem to be in line with the argument that R&D investments of international companies are increasingly targeted to source knowledge from the industry's international technological lead locations: "An emerging view emphasises that FDI in R&D is not only 'pushed' by the firm-specific advantages of the investor, but may also be 'pulled' towards centres of innovation located in recipient countries as a means for the investor to acquire and develop new capabilities" (Le Bas & Sierra, 2002, p. 590). In that case we would have expected to find the two firms to carry out significant R&D in the same national locations, for example in Germany or France, which they with the exception of the U.S. do not. It could be argued that technological systems of innovation are more likely to be found on the regional than national level, but if the corporations are not active in the same country this argument becomes irrelevant (as for the U.S., see next section). Thus, our preliminary conclusion is in line with the observations (discussed in section 2) on the as yet overall limited role of technological sourcing in international patenting.

5. Globalisation pressure versus firm trajectories: Explaining the differences between firms

When analysing the striking difference in overall degree of internationalisation noted above, several possible explanations come to mind. An obvious first issue is the effect of *country differences*, as discussed in section 2. In general, U.S. firms are much less internationalised in their technological activities than European firms, both in terms of conducting innovatory activities abroad and sharing patents with residents in foreign locations. In a study of the world's largest firms, Cantwell & Janne (2000) reported an average foreign share of patents of less than 10 percent for U.S. firms in the period 1987-1995, as compared with 32.5 percent for European firms. The gap is particularly wide

between the U.S. and small European countries such as Sweden and Switzerland, with Germany somewhere in between, but closer to the U.S. level (Cantwell & Janne, 2000; Guellec & van Pottelsberghe, 2001). It should be noted here, however, that in the general ABB-GE comparison, Sweden, Switzerland and Germany are grouped together as one single domestic entity for ABB, which reduces the country effect.¹⁵

A second explanation could be that the two companies differ in terms of *home country advantages*. As mentioned above, some authors claim that firms invest in R&D abroad to gain new advantages or complementary assets, which are not available in their home country. Since the U.S. in general is one of the most technologically advanced locations in the world, GE may possibly have weaker incentives to go abroad in its technology-seeking activities than ABB. The prominent role of the U.S. in ABB's foreign patenting might also be interpreted as a support for this line of reasoning.

However, we have found no evidence that ABB invested in the U.S. because of the strengths of its R&D system in electro-technology. The increase of U.S. patenting within ABB followed in the wake of major acquisitions, above all the purchase of Westinghouse and Combustion Engineering, which were motivated by market access arguments, as explicitly stated by top management. Commenting on these acquisitions the annual

¹⁵ Applying an aggregate perspective it could be asked if ABB's patenting would appear as more international than GE even if "Europe" was treated as its home "country", equivalent to U.S. as the home base of GE. The answer in short is yes, but the relevance of such a comparison is highly debatable. Europe is far from being a unified continent, and huge differences in institutions, culture, language, legal systems, etc. still prevail. Already the definition of Germany, Sweden and Switzerland as the home country of ABB is problematic. Germany and Switzerland do share a common language and border, but Sweden and Switzerland are separated not only by language and culture but also by taxation and trading regimes (Switzerland not even being part of the EU), educational structures and corporate regulation.

report for 1988 stated: “North America accounts for some 30 percent of the world potential for ABB’s products but initially only for 12 percent of its sales. Within five years, North America should account for twice as much of ABB’s total sales” (p 22). Further, technological activities in specific sectors are hardly spread evenly across the 50 states of USA. If there were world-leading systems of innovation in electro-technology they would probably be concentrated in one or a few prominent regions. So if technology sourcing were the main motive for ABB’s R&D activities in the U.S., we would expect to find significant parts of the patenting activities of the two firms concentrated to the same states. This does not seem to be the case, however. For example, in the first sub-period the main five U.S. locations of GE (in terms of U.S. patenting) were the states of New York, Ohio, New Jersey, Connecticut and Indiana, whereas ABB’s main five U.S. locations were the states of Connecticut, Pennsylvania, Florida, Georgia and Tennessee (see Table 2). Thus, the two firms only had the location of Connecticut in common, and for GE this location contributed less than 5 percent of the total number of patents with U.S. inventors. There may be important centres of electro-technical knowledge generation outside the GE top-list, but given the enormous importance of this corporation in the American electro-technical industry since its inception, it is reasonable to expect more of locational overlap if technology-seeking was a major motive for the US investments of ABB. This lack of overlap suggests that ABB has been pursuing a “home-base augmenting” approach, but establishing this for a fact would require knowing the complete map of electro-engineering science and technology activities in the U.S. Constructing such a map is beyond the scope of this paper, and more detailed studies are, thus, needed.

TABLE 2 IN ABOUT HERE

A third and related possible explanation is the differences in terms of the *importance of the domestic market* for the two companies. Despite a strategic orientation towards globalisation since the late 1980s, the international revenues of GE (excluding GE Capital Services) accounted for less than 40 percent in 1990 as well as 2000 (see Table 3). This is significantly lower than the share of ABB sales outside Sweden, Switzerland and Germany, which amounted to 72-77 percent in the studied period. The importance of the domestic market in the case of GE is only a partial explanation, however. Compared to a 35-45 percent foreign share of total sales, a 7 percent share of R&D outside the U.S. is still unimpressive in comparison to ABB's larger than 40 percent foreign share of patenting in the last two sub-periods.

TABLE 3 IN ABOUT HERE

Forth, and finally, differences in the degree of internationalisation could also be a question of *persisting strategic differences*. In particular, the choice of growth strategies and strategies for R&D may have an influence on the internationalisation pattern. Both ABB and GE have made extensive use of acquisitions. However, in the case of ABB – itself a result of a merger – acquisitions have been of a larger scale and involved more of technological duplication than in the case of GE. From that perspective, the internationally dispersed patenting activity at ABB could be seen as a by-product of a growth strategy driven by efforts to achieve market access and international scale, rather than as a result of an explicit and intentional strategy to build an international R&D structure.

6. Complementarity or collaboration in international R&D?

Above, the R&D internationalisation of ABB and GE was described in terms of the overall degree of internationalisation and the distribution between different locations. From a capabilities point of view, internationalisation may come in two conceptually distinct, but frequently parallel, forms: international duplication and international diversification. In the case of duplication, geographically dispersed units maintain technological capabilities in the same field(s) of technology, whereas in the case of diversification, geographically dispersed units represent unique fields of technological expertise (Zander & Sölvell, 2000).

A first observation is that there were differences between the companies, not only with regards to the overall internationalisation pattern and the distribution between countries, but also with regards to duplication (see Figures 4 and 5).

FIGURE 4 IN ABOUT HERE

ABB was characterised by a high degree of duplication throughout all three time-periods. For a majority of patent classes, more than one location – on average 2-3 – was involved and the share of patents in ‘unique’ patent classes was small and decreasing (see Figure 4 and Figure 5). The high degree of duplication may, at least in part, be attributed to ABB’s fundamental strategy of growth by mergers and acquisitions (see section 5); the acquired firms were in most cases in similar rather than unrelated lines of business. In the late 1990s, many companies began to concentrate their R&D labs etc. to a few leading locations in order to decrease duplication and increase effectiveness (Gerybadze & Reger,

1999). As far as our data can tell, ABB seems to go have gone in the opposite direction, at least in the period reported here, and increased its level of technological duplication.

FIGURE 5 IN ABOUT HERE

GE's R&D structure seems to have been much less duplicated than ABB's, at least in the beginning of the period. The company went from a situation in which the average number of locations per class was 1.3 (see Figure 4) and in which unique classes represented 60 percent of the patents, to a more duplicated structure where only 15 percent of the patents were found in unique classes (see Figure 5). The average patent class, however, still received input from less than two locations (see Figure 4).

However, to a large extent the lower degree of duplication of GE is related to the dominance of its home country. When a very large share of patents originate in one country, that country is bound to have an exclusive share of many patent classes and the total number of countries per patent class is bound to be low. As a consequence, a low degree of duplication does not necessarily imply an internationally diversified R&D structure. As it turns out, none of GE's patent classes were unique to a foreign country (see Figure 5); foreign inventors only patented in classes where there were also U.S. inventors. In spite of the low degree of duplication in comparison to ABB, GE must, thus, be considered to be a case of "internationalisation by duplication". (However, it is interesting to note that the move towards a more duplication-oriented structure (in terms of a decreasing share of patents in unique patent classes) seems to have been more rapid than the overall increase in internationalisation.)

In order for the potential advantages of a geographically dispersed R&D structure to be realised, there must be “cross-fertilization” (Zander & Sölvell, 2002), either within individual technologies (in the case of duplicate capabilities) or across technologies (in the case of diversified capabilities). A necessary condition for such cross-fertilisation to occur is the existence of collaboration between inventors from different countries. One indicator of cross-national collaboration is the number and share of ‘shared’ patents, i.e. patents with inventors from two or more countries. The development of this group of patents for ABB and GE is presented in Figure 6.

FIGURE 6 IN ABOUT HERE

In both companies, the share of ‘shared’ patents increased substantially – three to four times – between the first and the last period. ABB’s share of ‘shared’ patents was much larger, however, especially if patents shared ‘intra-domestically’ (i.e. between two or more of the three home countries) are included. A possible explanation for this difference is that co-patenting is much more common for companies from small countries than for companies from large, technology-intensive countries (Guellec & van Pottelsberghe, 2001). Another difference between the companies concerns the rate of increase in number of patents over time. For ABB, the increase between the last two periods was much larger than that between the first two periods, whereas the increase in GE’s number of ‘shared’ patents was somewhat more evenly distributed over time.

With respect to how ‘shared’ patents are distributed between different regional locations of participating countries, there were some basic similarities between the companies as well (see Figure 7). Home countries seem to have play an important role in R&D collaboration for both companies – the domestic share of ‘shared’ patents was 68 percent

for ABB (44 percent if intra-domestically shared patents are excluded) and 53 percent for GE. Patents were primarily shared between inventors from European and North American countries, whereas Asian inventors played a minor role. The primary difference was that ABB's domestic share decreased in the second period, which probably was a reflection of the company's overall increase in internationalisation (see section 4). In the ABB case, approximately 40 percent of the 'shared' patents were the result of collaboration between two or more of the three home countries, i.e. without any 'foreign' collaboration partner. GE's increasingly balanced distribution of 'shared' patents between different foreign countries seems to be related to its overall increase in number of foreign inventor countries.

FIGURE 7 IN ABOUT HERE

In conclusion, this examination of the collaboration dimension of R&D internationalisation generally is in line with the results of the earlier analyses. Although a larger number and share of patents were 'shared' between an increasing number of foreign locations, home countries were still very important for both firms, and co-patenting was primarily concentrated to Europe and North America. In comparison to the analysis of the overall patenting pattern, 'foreign' countries had a somewhat larger share of GE's 'shared' patents than of ABB's (although the share of 'shared' patents was much lower), unless all intra-domestically shared patents for ABB are excluded.

It is, however, difficult to draw any conclusions with respect to the two companies' degree of cross-fertilisation between countries, especially considering that 'shared' patents are a rather crude measure of collaboration. There may be other reasons why certain names occur on a patent application than actual participation in a joint R&D

project. The issue, thus, needs to be investigated further, for example by discussions of specific cases of ‘shared’ patents with the inventors themselves.

7. Discussion

This paper has addressed the issue of R&D internationalisation of ABB and GE, two leading multinationals in the electro-technical industry, by means of a patent data analysis. In this concluding section we will summarise the results, elaborate on the interpretation of some of the findings and suggest issues for further research.

The comparison of the patenting patterns of ABB and General Electric has displayed striking similarities as well as distinctive differences. In both companies, the overwhelming majority of R&D activities were concentrated to their historic sites in Western Europe and North America. In both companies, the ratio of shared patents with inventors from several locations increased, although the level was much higher at ABB. In both companies, domestically located inventors continued to be involved in a majority of the shared patents throughout the studied period. In this sense none of them could be described as ‘truly global’ and had so far failed to realise the challenge announced by GE, “to attract the unlimited pool of talent world-wide” (Welch 1998). The results are consistent with findings from earlier studies that there is little evidence to suggest that the ‘production’ of technology is globalised in a general sense, i.e. that a range of firms from different countries and industries are actively pursuing R&D in a wide range of countries simultaneously (Patel, 1995 & 1996).

Within these regions, however, ABB was clearly more internationalised than GE, with a much larger share of patenting taking place outside its home base. To some extent this could be explained by the general propensity of large firms in small countries to patent

more in foreign locations than companies from big countries, especially Japan and the U.S., as found by for example Guellec & van Pottelsberghe (2001). This general country-size effect was reduced in our comparison, however, since all three historic locations of the ancestors of the ABB Corporation – Sweden, Switzerland and Germany – were included in our definition of its home base.

The domestic American market was undoubtedly more important for General Electric than the correspondent markets were for ABB, but this is not enough to explain why only 7 percent of GE's total patenting took place outside the U.S. Hence, we also pointed at the importance of differences in company strategies. In particular, the internationalised patenting pattern at ABB could partly be seen as a by-product of its formation as an outcome of cross-border mergers.

A closer comparison of the companies' overall patenting pattern revealed that of their five most important locations they had only one in common, the U.S., and within this location they favoured different states. This seems to be in line with the observation by Patel & Vega (1999) that tapping knowledge from an industry's global lead location plays a very limited role in foreign R&D investments. At a more detailed level, however, the results may lend themselves to different interpretations. The ABB case seems to be rather straightforward: the majority of its patenting outside the firm's home countries appear to be driven by market factors, such as acquisitions to gain market access. To explain the GE list of favoured non-American locations – France, Japan and the Netherlands – a more detailed analysis would be necessary. Maybe there are elements of “tapping” into foreign knowledge bases here at a niche or business unit level. If so, this could be consonant with a reformulated hypothesis of technology sourcing, where the notion of global lead locations is dropped in favour of the concept of a “global

knowledge economy” with niches or pockets of advanced knowledge dispersed internationally, as suggested by Doz et al. (2001). The problem with such a reformulation, however, is to identify independent measures of these dispersed knowledge locations.

In the strategic management literature it tends to be taken for granted that a high level of technological internationalisation, with a network of dispersed R&D centres constitutes an important competitive advantage (Bartlett & Ghoshal, 1993 & 1998; Heimer & Barham, 1998). The limitations of the traditional ethnocentric model, where companies project technologies developed at the home base on an international scale, are repeatedly pointed out (Gassman & von Zedtwitz 1999, Doz et al., 2001). If, thus, international R&D is a crucial part of strategies for global competition, then a positive relation between levels of internationalisation and financial performance could be hypothesized. ABB and GE did indeed differ starkly in terms of financial performance in the studied 15-year period, but to the advantage of the “ethnocentric “ GE. If the two most similar business segments of the companies are compared, Power Systems at GE and Power Generation at ABB, the profit margin reported by General Electric was consistently double the margin at ABB, and the disparity increased during the later part of the 1990s. This, of course, could be explained by a number of factors other than differences in international structure, such as market presence and technology strategies, successes or failures of major product development projects, etc. Nevertheless, the difference raises the issue of the relation between technological internationalisation and financial performance. The assumption that an increasing level of globalisation is an economic virtue in its own right needs to be tested in future studies building on larger samples than the pair of companies selected for this paper.

ABB and GE also differed with regards to the degree of international duplication: The patenting of ABB was characterised by a higher degree of duplication than that of GE (although technological duplication was on the rise). Both with regards to the cross-fertilisation between and within technology areas, ABB had a larger share of ‘shared’ patents than GE. This could be interpreted as an increasing trend of knowledge-exchange and co-operation between the different centres in its international R&D network, although co-patenting, as observed above, is only a preliminary indicator of actual R&D collaboration.

Technological activities involving shared patents may involve different types of projects, however: development of new technologies and products or international consolidation of idiosyncratic technologies with varying national origins (to put it simply). In the latter case, projects could be expected to be less inventive and more preoccupied with standardisation and rationalisation. Sprawling technological duplication after its many mergers and acquisitions forced ABB to set up cross-border projects to standardise product platforms and technologies in core business areas. At General Electric, the level of technological duplication was much lower – as was the overall level of internationalisation – and the company needed to invest less in integrating competing technologies across borders. Further, as a result of its internationally dispersed structure, ABB had to prioritise cross-national cooperation, whereas the GE concept of “the boundary-less corporation” emphasised cross-functional and cross-divisional collaboration: “Co-location. One room, one coffee-pot, one team ...that’s is the ultimate boundary-less behavior” (Welch, 1992). As Riddersträhle (1996) has demonstrated in his in-depth case studies of global projects, cross-national co-operation in new product development tends to crowd out cross-functional co-operation and result in increased product costs and development lead-times. Part of the international patenting of ABB, a

corporation developed by a series of mergers and acquisition, may be seen as an indicator of this mundane necessity to get rid of costly duplication and overlaps. At the present stage, however, we do not know how much of ABB's shared patenting, if any, was related to international standardisation efforts. To explore this issue, there is a need for research on a more detailed level, where selected "co-operative" (co-patented) projects are analysed. Integrative cross-border capabilities for new technology and product development cannot be inferred on the basis of patent statistics or laboratory surveys, but have to be demonstrated to exist in actual innovation projects. Thus, the two-firm comparison presented in this paper points to a need for further research, both on a more aggregate level, to explore relationships between international patenting and performance, as well as more fine-grained studies of internationally shared patents, to investigate the actual degree of cooperation and innovativeness involved.

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TABLE 1: *Share of patents by different geographical locations ('shared' patents included in total number of patents)*

	ABB			GE		
	1986-1990	1991-1995	1996-2000	1986-1990	1991-1995	1996-2000
Domestic	0.823	0.542	0.547	0.954	0.935	0.907
<i>including 'shared' patents^b</i>	<i>0.834</i>	<i>0.565</i>	<i>0.586</i>	<i>0.961</i>	<i>0.950</i>	<i>0.928</i>
Foreign ^c	0.156	0.398	0.368	0.032	0.038	0.053
<i>including 'shared' patents^b</i>	<i>0.166</i>	<i>0.435</i>	<i>0.414</i>	<i>0.039</i>	<i>0.050</i>	<i>0.072</i>

^a Patents applied for by inventors from the companies' home country/-ies or shared between inventors from this/these country/-ies.

^b Here, 'shared' patents have been distributed proportionally between the countries of origin of the inventors and added to each country's share of the total number of patents.

^c Patents applied for by inventors from other countries than the companies' home countries.

TABLE 2: *Main U.S. locations in terms of relative share of total number of patents with U.S. inventors.*

ABB		GE	
Inventor state	Share*	Inventor state	Share*
CT	22,9%	NY	36,1%
PA	21,2%	OH	11,4%
FL	6,9%	NJ	6,4%
GA	6,4%	CT	4,9%
TN	6,4%	IN	4,1%

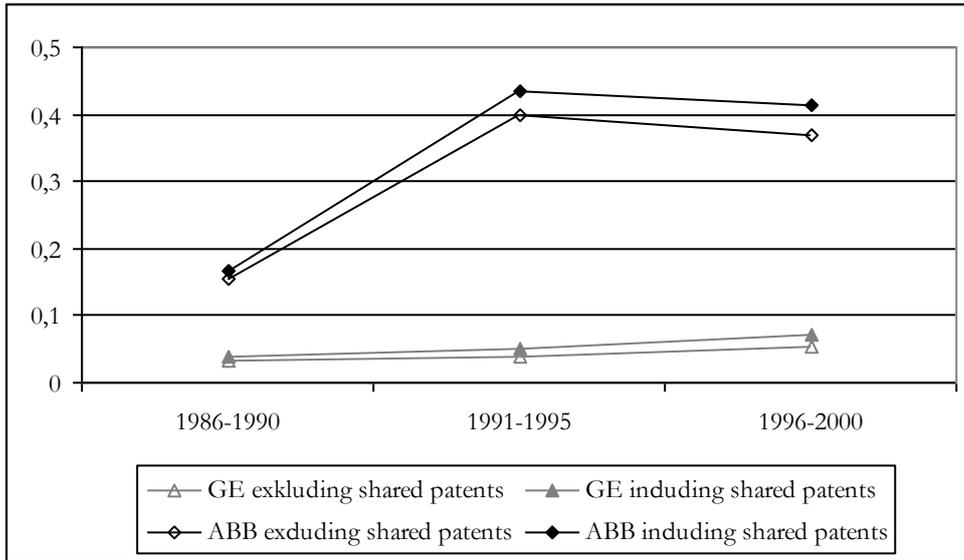
* Of total number of U.S. patents with a U.S. inventor.

TABLE 3: Revenues, total and 'foreign', in selected years.

	ABB			GE		
	TOTAL SALES (BUSD)	WHEREOF 'FOREIGN' (BUSD)	'FOREIGN' SHARE	TOTAL SALES (BUSD)	WHEREOF 'FOREIGN' (BUSD)	'FOREIGN' SHARE
1990	26.7	19.3	0.72	44.9	15.4	0.34
1995	33.7	24.7	0.73	46.2	20.1	0.43
2000**	24.7	18.9	0.77	69.5	26.7	0.38

* Excluding GE Financial/Capital Services.

** For ABB, the numbers are for 1999 since no country data were available for 2000.



* In all four cases, 'shared' patents are included in the total number of patents.

Figure 1: Foreign share of patenting

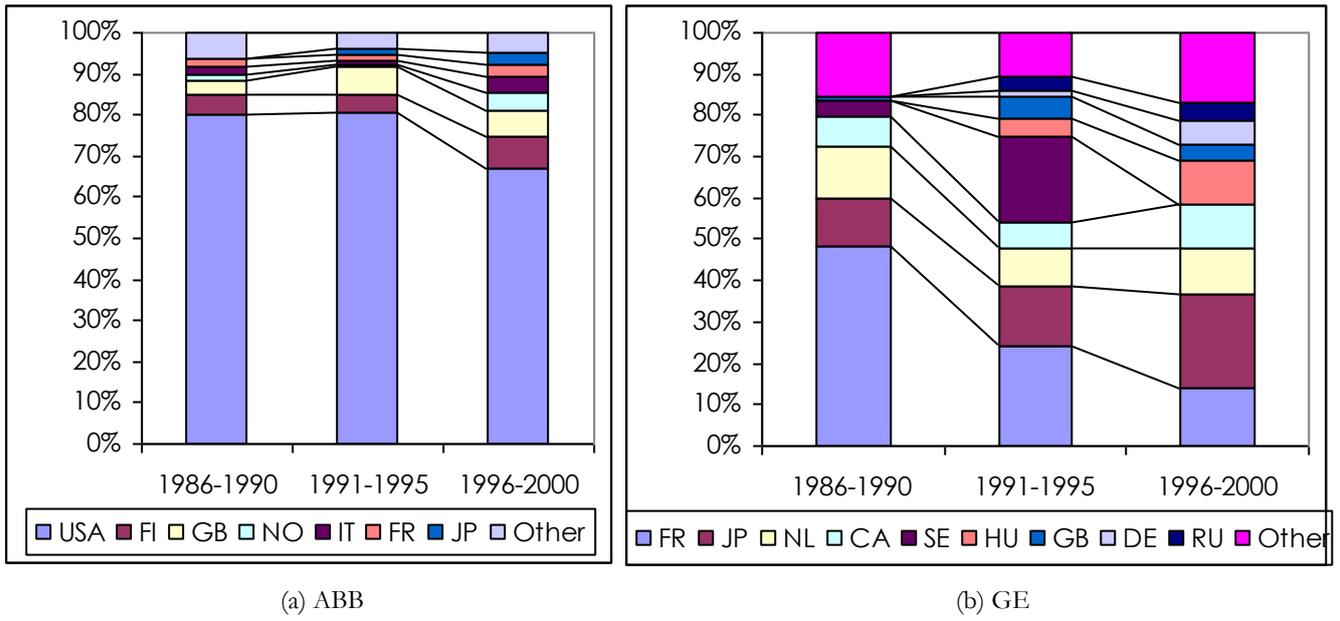


Figure 2: Different 'foreign' countries' shares of total number of 'foreign' patents (including 'shared' patents)

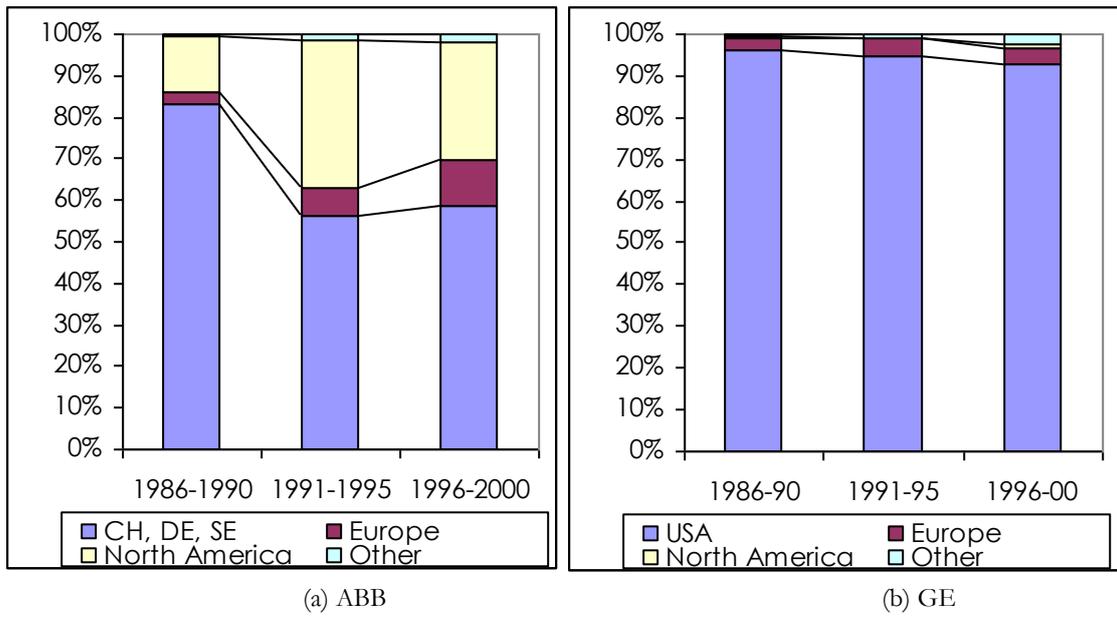
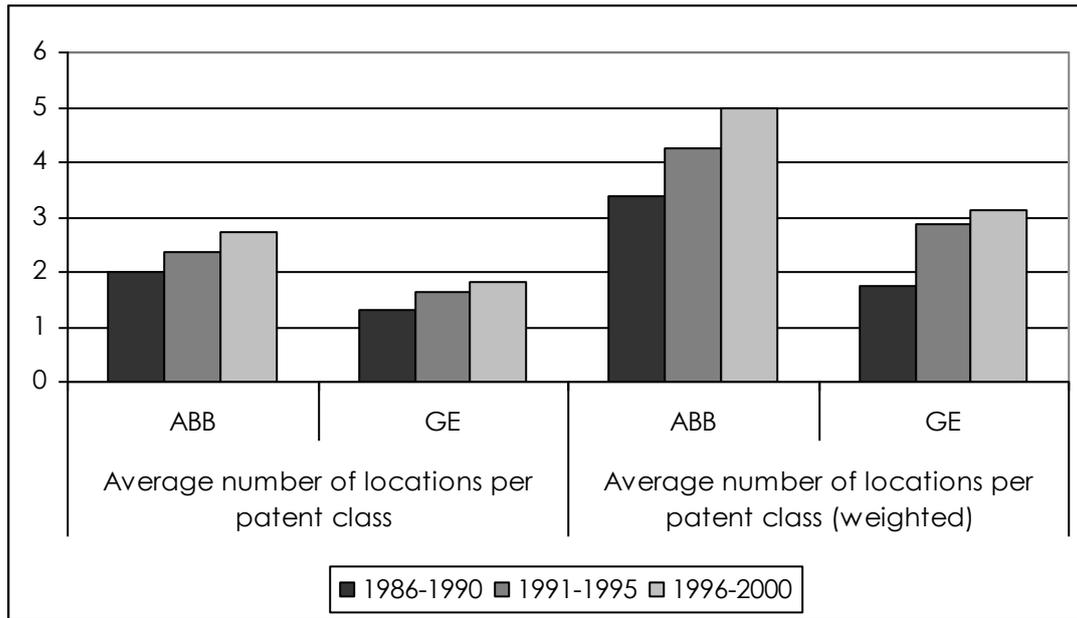
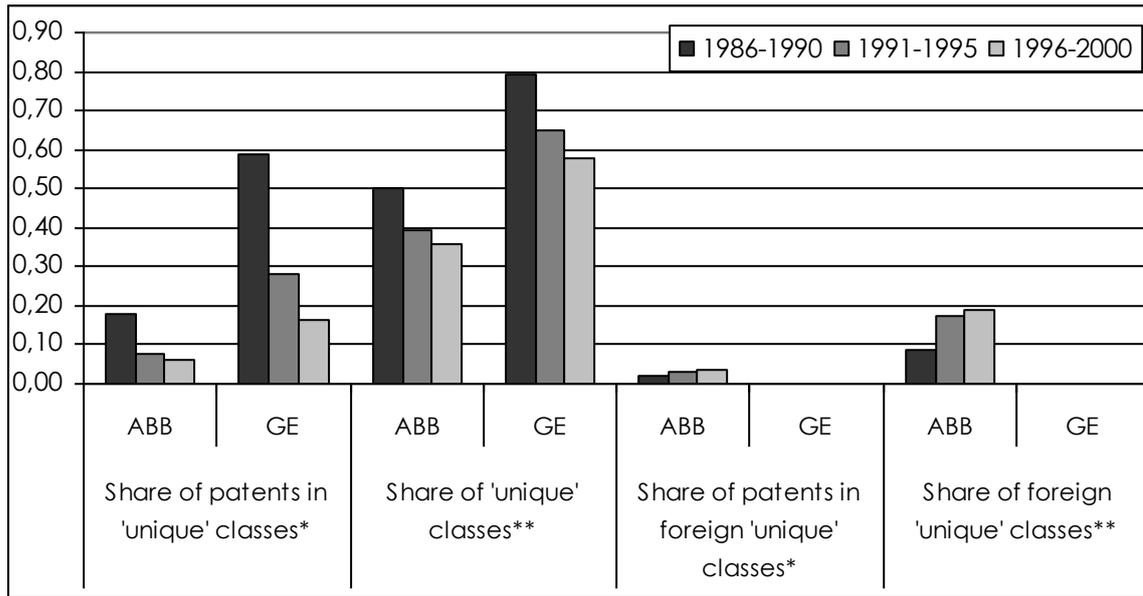


Figure 3: Different locations' shares of total number of patents



Notes: (1) The weighted average takes into account the number of patents in each class, so that duplication in larger classes is valued higher than duplication in smaller classes. (2) The category 'shared patents' is counted as a separate location.

Figure 4: Number of locations per patent class



* Share of total number of patents.

** Share of total number of patent classes.

Note: 'Unique' classes are patent classes represented in one single country.

Figure 5: 'Unique' classes

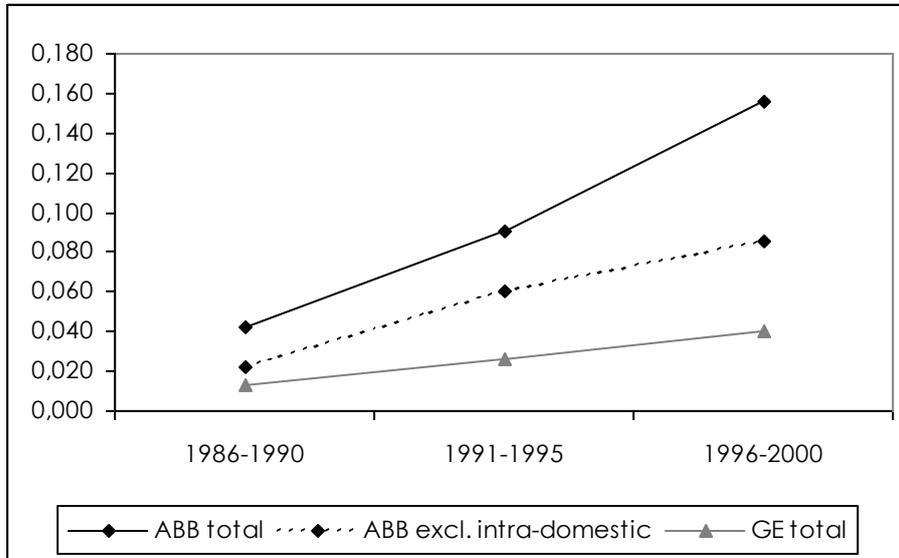
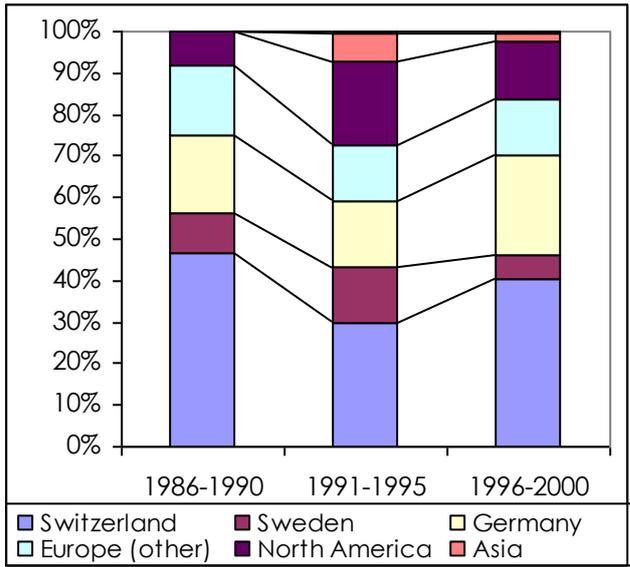
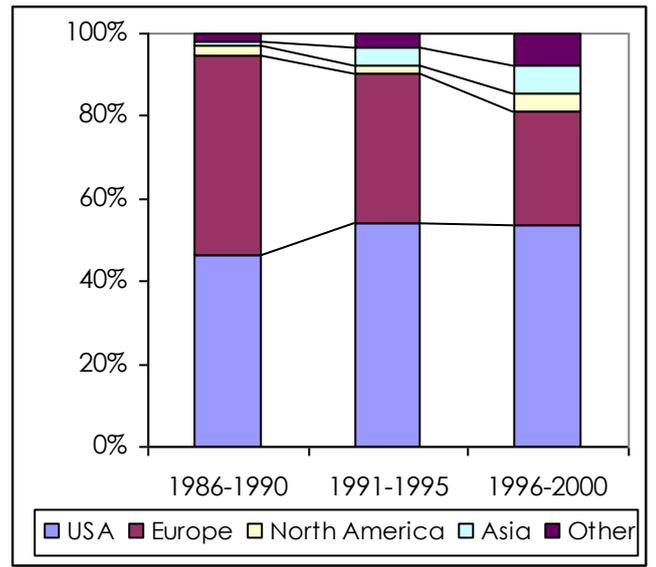


Figure 6: 'Shared' patents (share of total)



(a) ABB



(b) GE

Figure 7: 'Shared' patents by inventor country share.

Appendix: Patent classes defined as “electro-technology”

CLASS	DESCRIPTION
15	Brushing, scrubbing and general cleaning
24	Buckles, buttons, clasps, etc.
26	Textiles: cloth finishing
29	Metal working
33	Geometrical instruments
34	Drying and gas or vapor contact with solids
48	Gas: heating and illuminating
52	Static structures (e.g. buildings)
53	Package making
55	Gas separation
60	Power plants
62	Refrigeration
70	Locks
72	Metal deforming
73	Measuring and testing
74	Machine element or mechanism
75	Specialized metallurgical processes, compositions for use therein, consolidated metal powder compositions, and loose metal particulate mixtures
81	Tools
91	Motors: expansible chamber type
92	Expansible chamber devices
95	Gas separation: processes
96	Gas separation: apparatus
99	Foods and beverages: apparatus
100	Presses
101	Printing
105	Railway rolling stock
110	Furnaces
117	Single-crystal, oriented-crystal, and epitaxy growth processes; non-coating apparatus therefor
118	Coating apparatus
122	Liquid heaters and vaporizers
123	Internal-combustion engines
126	Stoves and furnaces
134	Cleaning and liquid contact with solids
137	Fluid handling
138	Pipes and tubular conduits
140	Wireworking
141	Fluent material handling, with receiver or receiver coating means
144	Woodworking
148	Metal treatment
156	Adhesive bonding and miscellaneous chemical manufacture
162	Paper making and fiber liberation
164	Metal founding
165	Heat exchange
166	Wells
169	Fire extinguishers
174	Electricity: conductors and insulators
175	Boring or penetrating the earth
177	Weighing scales
180	Motor vehicles
181	Acoustics
184	Lubrication
187	Elevator, industrial lift truck, or stationary lift for vehicle

188	Brakes
191	Electricity: transmission to vehicles
192	Clutches and power-stop control
198	Conveyors: power-driven
200	Electricity: circuit makers and breakers
201	Distillation: processes, thermolytic
202	Distillation: apparatus
204	Chemistry: electrical and wave energy
205	Electrolysis: processes, compositions used therein, and methods of preparing the compositions
206	Special receptacle or package
208	Mineral oils: processes and products
209	Classifying, separating, and assorting solids
210	Liquid purification or separation
212	Traversing hoists
213	Railway draft appliances
218	High voltage switches with arc preventing or extinguishing devices
219	Electric heating
220	Receptacles
222	Dispensing
226	Advancing material of indeterminate length
228	Metal fusion bonding
235	Registers
237	Heating systems
239	Fluid sprinkling, spraying and diffusing
241	Solid material comminution or disintegration
242	Winding, tensioning, or guiding
246	Railway switches and signals
248	Supports
250	Radiant energy
251	Valves and valve actuation
252	Compositions
257	Active solid state devices (e.g. transistors, solid-state diodes)
261	Gas and liquid contact apparatus
264	Plastic and nonmetallic article shaping or treating: processes
266	Metallurgical apparatus
267	Spring devices
269	Work holders
276	Typesetting
277	Seal for a joint or juncture
285	Pipe joints or couplings
290	Prime-mover dynamo plants
292	Closure fasteners
293	Vehicle fenders
294	Handling: hand and hoist-line implements
296	Land vehicles: bodies and tops
307	Electrical transmission or interconnection system
310	Electrical generator or motor structure
312	Supports: cabinet structure
313	Electric lamp and discharge devices
315	Electric lamp and discharge devices: systems
318	Electricity: motive power systems
320	Electricity: battery or capacitor charging or discharging
322	Electricity: single generator systems
323	Electricity: power supply or regulation systems
324	Electricity: measuring and testing

327	Miscellaneous active electrical nonlinear devices, circuits, and systems
329	Demodulators
330	Amplifiers
332	Modulators
333	Wave transmission lines and networks
335	Electricity: magnetically operated switches, magnets, and electromagnets
336	Inductor devices
337	Electricity: electrothermally or thermally actuated switches
338	Electrical resistors
340	Communications: electrical
342	Communications: directive radio wave systems and devices (e.g. radar, radio navigation)
343	Communications: radio wave antennas
345	Computer graphics processing, operator interface processing, and selective visual display systems
346	Recorders
348	Television
349	Liquid crystal cells, elements and systems
356	Optics: measuring and testing
358	Facsimile and static presentation processing
359	Optics: systems (including communication) and elements
361	Electricity: electrical systems and devices
362	Illumination
363	Electric power conversion systems
365	Static information storage and retrieval
366	Agitating
367	Communications, electrical: acoustic wave systems and devices
368	Horology: time measuring systems or devices
370	Multiplex communications
372	Coherent light generators
373	Industrial electric heating furnaces
374	Thermal measuring and testing
375	Pulse or digital communications
376	Induced nuclear reactions: processes, systems, and elements
377	Electrical pulse counters, pulse dividers, or shift registers: circuits and systems
378	X-ray or gamma ray systems or devices
379	Telephonic communications
380	Cryptography
381	Electrical audio signal processing systems and devices
382	Image analysis
384	Bearings
385	Optical waveguides
392	Electric resistance heating devices
403	Joints and connections
405	Hydraulic and earth engineering
406	Conveyors: fluid current
407	Cutters, for shaping
408	Cutting by use of rotating axially moving tool
409	Gear cutting, milling, or planing
411	Expanded, threaded, driven, headed, tool-deformed, or locked-threaded fastener
414	Material or article handling
415	Rotary kinetic fluid motors and pumps
416	Fluid reaction surfaces (i.e. Impellers)
417	Pumps
418	Rotary expansible chamber devices
419	Powder metallurgy processes
420	Alloys or metallic compositions

422	Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing
423	Chemistry of inorganic compounds
425	Plastic article or earthenware shaping or treating; apparatus
426	food or edible material: processes, compositions, and products
427	Coating processes
428	Stock material or miscellaneous articles
429	Chemistry: electrical current producing apparatus, product, and process
431	Combustion
432	Heating
435	Chemistry: molecular biology and micro biology
436	Chemistry: analytical and immunological testing
438	Semiconductor device manufacturing: process
439	Electrical connectors
440	Marine propulsion
441	Buoys, rafts, and aquatic devices
442	Fabric (woven, knitted, or nonwoven textile or cloth etc.)
451	Abrading
454	Ventilation
455	Telecommunications
472	Amusement devices
475	Planetary gear transmission systems or components
483	Tool changing
501	Compositions: ceramics
502	Catalyst, solid sorbent, or support thereof: product or process of making
505	Superconductor technology: apparatus, material, process
514	Drug, bio-affecting and body treating compositions
518	chemistry: fischer-tropsch processes; or purification or recovery of products thereof
523	Synthetic resins or natural rubbers -- part of the class 520 series
525	Synthetic resins or natural rubbers
549	Organic compounds -- part of the class 532-570 series
568	Organic compounds -- part of the class 532-570 series
585	Chemistry of hydrocarbon compounds
588	Hazardous or toxic waste destruction or containment
700	Data processing: generic control systems or specific applications
701	Data processing: vehicles, navigation, and relative location
702	Data processing: measuring, calibrating, or testing
703	Data processing: structural design, modeling, simulation, and emulation
705	Data processing: financial, business practice, management, or cost/price determination
706	Data processing: artificial intelligence
707	Data processing: database and file management, data structures, or document processing
709	Electrical computers and digital processing systems: multiple computer or process coordinating
710	Electrical computers and digital processing systems: input/output
711	Electrical computers and digital processing systems: memory
714	Error detection/correction and fault detection/recovery
D10	Measuring, testing, or signalling instruments
D12	Transportation
D13	Equipment for production, distribution, or transformation of energy
D15	Machines not elsewhere specified
D23	Environmental heating and cooling; fluid handling and sanitary equipment
D25	Building units and construction elements
D9	Packages and containers for goods