ELSEVIER

Research Policy 31 (2002) 569–588

research policy

www.elsevier.com/locate/econbase

Market versus technology drive in R&D internationalization: four different patterns of managing research and development

Maximilian von Zedtwitz [a,*], Oliver Gassmann [b]

[a] International Institute for Management Development (IMD), P.O. Box 915, CH-1001 Lausanne, Switzerland
[b] R&D Technology Management, Schindler Corporation, CH-6031 Ebikon, Switzerland

Received 13 January 2000; received in revised form 2 October 2000; accepted 24 April 2001

Abstract

Research and development are subject to different location drivers. The analysis of 1021 R&D units, each distinguished by its main orientation towards either research or development work, reveals that research is concentrated in only five regions worldwide, while development is more globally dispersed.

Our research is based on 290 research interviews and database research in 81 technology-intensive multinational companies. We identify two principal location rationales—access to markets and access to science—as the principal determinants for four trends that lead to four archetypes of R&D internationalization: 'national treasure', 'market-driven', 'technology-driven', and 'global'. Their organizational evolution is characterized by four trends. The model is illustrated with short cases of international R&D organization at Kubota, Schindler, Xerox, and Glaxo-Wellcome.

Differences in R&D internationalization drivers lead to a separation of individual R&D units by geography and organization. Current belief is to integrate R&D processes; separation seems to contradict this trend. We argue that this need not be the case, for there are good reasons to maintain some independence between research and development.

Keywords: Globalization; Research and development; Archetypes; Trends; Locations

1. Introduction

1.1. Difficult internationalization of R&D

The internationalization of industrial R&D in recent years has been interpreted as the attempt of technology-intensive companies to exploit location-specific innovation advantages in order to compete in an increasingly globalized environment. Our empirical investigation confirms that in most multinational companies, "globalization of R&D is typically accepted more with resignation than with pleasure" (De Meyer and Mizushima, 1989, p. 139). Some practitioners have expressed reservations to substantially invest in international R&D because of the high execution costs and low project efficiency. At the same time, however, they recognize that the potential of international R&D is underestimated and insufficiently exploited. Their main concern is that useful means for effective implementation of international R&D processes are not in place. Thus, some companies aim "to create a culture in which employees realize that cooperation across regional and departmental boundaries", and "to combine internal expertise and know-how with that of top-performing research facilities worldwide" (Daimler-Benz, 1997, pp. 14–15).

* Corresponding author. Tel.: +41-21-618-07-99;
fax: +41-21-618-07-07.
E-mail addresses: zedtwitz@imd.ch (M. von Zedtwitz),
oliver_gassmann@ch.schindler.com (O. Gassmann).

0048-7333/02/$ – see front matter
PII: S0048-7333(01)00125-1

The establishment of international R&D networks and the management of transnational R&D projects are non-trivial and very risky endeavors. The principal challenges are imposed by the physical distance among R&D units, as well as between R&D units and corporate headquarters. Distance impacts communication in terms of frequency and quality, raises transaction costs, and introduces principal-agent related difficulties. Thus, problems of coordination and control prevent the exploitation of potential synergy effects. Local specialization leads to the occurrence of the not-invented-here syndrome and the compartmentalization along separate R&D functions. The definition of organizations along geographic boundaries often neglects the different responsibilities of R&D, hence creating sub-optimal resource and capital availability.

Managing transnational R&D projects is inherently more difficult than managing local projects. Data and information exchange cannot be achieved at the same quality and speed. Frequent travel puts high personal and emotional stress on the project manager. Despite modern communication technologies, the exchange of tacit knowledge, the creation of trust, and a common working culture require direct face-to-face communication. Social and family ties make senior R&D individuals geographically immobile and reluctant to accept even temporary overseas assignments. Leading R&D projects is thus mainly based on distant coordination, jeopardizing the necessary trust and commitment among remote teams.

1.2. Trends in R&D internationalization

Nevertheless, the potential benefits from international R&D are too significant to ignore. Research in R&D management have resulted in a better understanding of the determinants in international R&D, and many R&D organizations are being transformed to meet the new challenges. At the national level, estimates are in the range of 15–70% for individual European countries (average: 30%), 1–8% for Japan, and 8–12% for the US (see Fig. 1). These numbers vary with the investigating researcher and the unit of analysis used (e.g. patents, expenditures, personnel). A few exceptional companies from these countries exceed 90% of R&D internationalization.

There is a substantial amount of research in international R&D with an economic and quantitative background (see, e.g. Ronstadt, 1977; Behrmann and

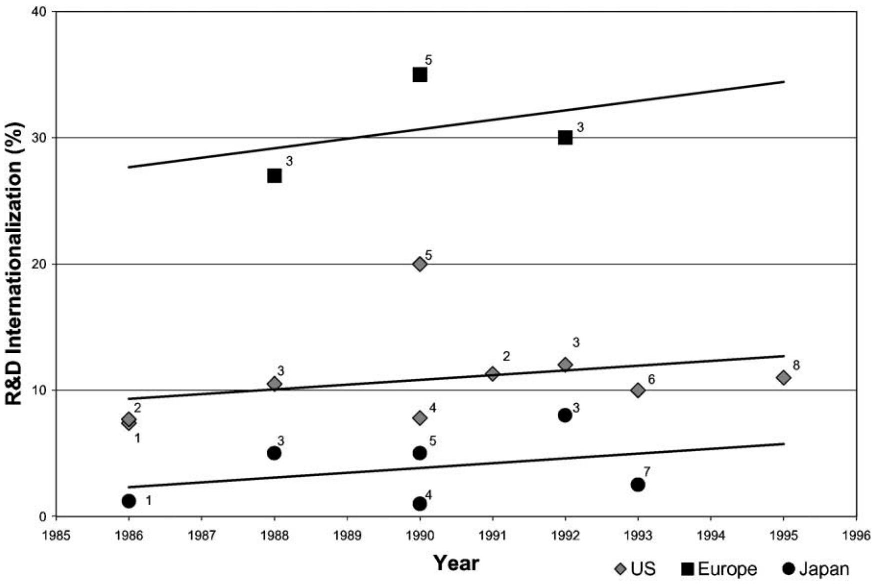

Fig. 1. Increasing internationalization of R&D in Europe, Japan, and US. Sources: 1. Dunning (1994), 2. Gates (1995), 3. Roberts (1995), 4. Patel (1995), 5. Buderi et al. (1991), 6. National Science Board (1991), 7. Kumar (1995), 8. OECD (1996).

Fischer, 1980; Hirschey and Caves, 1981; Pavitt, 1984; Pearce, 1989; Cantwell, 1995; Dalton and Serapio, 1995). For instance, based on the investigation of the share of US patents by large foreign firms, Cantwell and Janne (2000) observe a significant increase of international R&D activity measured by patent origin, particularly for European and to a lesser degree for US firms.

This work has led to a number of R&D classification schemes (see Medcof, 1997 for a concise review). More and more, managerial aspects entered the discussion (e.g. Rubenstein, 1989; De Meyer and Mizushima, 1989; Granstrand et al., 1992; Boutellier et al., 2000). Location factors and overseas determinants have been studied as drivers for R&D decentralization (e.g. Howells, 1990; Serapio and Dalton, 1993; Beckmann and Fischer, 1994; Brockhoff, 1997; Odagiri and Yasuda, 1996); this work is extended by contributions from business and policy strategy, R&D management, and international management.

Often, the contracted term "R&D" beguiles us into disregarding the inherent differences between research and development. The necessities of science, compared with the needs of engineering and development, entail different managerial problems (see, e.g. Leifer and Triscari, 1987). Most contributions that distinguish between research and development management neglect the international dimension (e.g. Eldred and McGrath, 1997a,b; Iansiti, 1998). Knowledge transfer and diffusion have been identified as major management challenges in international R&D contexts. Kuemmerle (1997) and Chiesa (1996) suggested models of R&D organization that center around the knowledge creating and transferring capabilities of R&D laboratories.

In an earlier contribution (Gassmann and von Zedtwitz, 1998, 1999a,b), we have outlined trends and evolutionary patterns for international R&D organization based on internal distribution and allocation of R&D resources. Differences between research and development in terms of location rationales and work culture effectuate different geographical distribution and concentration in different regional centers. In this paper, we propose a model of R&D internationalization that focuses on external sources of knowledge as well as the exploitation of home-based-generated but locally implemented forms of knowledge.

What are the factors that influence the differences in internationalization between research and development, and what managerial difficulties emerge from this phenomenon? Based on our analysis of 81 companies representing 1021 R&D sites, we seek to make the following contributions.

- We identify four archetypes of international research and development dispersion: national treasure, market-driven, technology-driven, and global.
- We highlight the importance of two principal internationalization forces in R&D: access to local science and technology, and access to local markets and customers.
- We observe and present four trends in internationalizing R&D, each aiming to capture specific advantages for conducting research as well as development in particular locations.
- Although seamless integration calls for collocation and close collaboration, we argue that there are significant benefits achieved by geographical and functional separation.

2. Research methodology and data sample

2.1. Two phases of interview-based research

Given our research focus on the patterns of internationalization of industrial R&D, we chose the R&D organization of individual companies to be our unit of analysis. For each of these organizations, our research followed three principal logical steps. First, we sought to determine the extent of internationalization for both research as well as development.[1]

[1] Although we followed the company internal denotation as closely as possible, we had to establish a terminology that would allow us to classify our findings. Hence, 'R&D' comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications (OECD, 1996, p. 7). Commonly accepted definitions apply: 'research' is defined as the process of discovering new scientific knowledge which has the potential to act as a platform for the subsequent development of commercially viable products and manufacturing processes. There is no expectation that the outputs of research will have immediate commercial value. 'Development' is the process of creating new products and processes that do have commercial value, through the application of currently available platforms or scientific knowledge (Medcof, 1997, p. 303).

Secondly, we examined changes in the international R&D structure to deduce emerging patterns of R&D internationalization over time. Thirdly, we confirmed these patterns in follow-up research, analyzing managerial challenges of conducting multi-site R&D and strategic decisions made by senior R&D personnel.

Different types of data were needed in each step, and different data-collection methods were used to ensure the quality and accuracy of subsequent data analysis. As a first step, R&D locations were compiled by means of company publications and third-party R&D databases. Unclear R&D orientations of individual sites were resolved in follow-up interviews. This provided us with a comprehensive overview of the physical and geographical structure of a firm's R&D organization.

In order to determine how R&D units were integrated within the wider R&D organization, we developed a semi-structured interview guideline focusing on functional and hierarchical linkages, participation in corporate-wide R&D programs, establishment and ramp-up of R&D sites, as well as the management of selected transnational R&D projects. Our interviewees were R&D directors and senior R&D managers. In some companies, we were able to participate in workshops and R&D project meetings. Combined with internal documentation on R&D organization, presentations by R&D personnel as well as memos from R&D managers, these semi-structured data helped us (in a second step) to determine the reasons and patterns of how companies internationalized their R&D function. Finally, we reported our findings to the interviewed companies and sought their feedback to correct erroneous interpretation and classification.

We conducted a total of 290 interviews using this semi-structured interview guideline. Total 136 interviews in 24 companies were carried out in a first phase between March 1994 and September 1996, 154 interviews in 50 companies in a second phase between October 1996 and December 1998. We targeted multinational companies in science and technology-intensive industries (see Table 1), since these industries rank among the highest in terms of average R&D to sales ratio, ranging between 4.2% for motor vehicles and 12.6% for telecommunications. Furthermore, they are characterized by a high degree of international division of labor. Fig. 2 shows a comparison of R&D and sales for those 46 companies in the investigation sample. Internationalization of sales was computed analogous to the internationalization of R&D: the share of international sales in relation to total sales.

In the entire sample, only one company, Eisai, was significantly more internationalized in R&D than in sales. This exception requires an explanation. Like other Japanese drug makers, Eisai relied heavily on domestic sales. The 1990 export ratio for the seven largest Japanese pharmaceutical companies was 7.6% as compared with 70.1% for the seven largest Western

Table 1
List of 81 industrial companies considered in this study, sorted by location and industry groups

Company based in	Pharmaceuticals, chemicals, food	Electrical, information and software technology	Machinery, petro, automotive
Europe	Akzo-Nobel, AstraZeneca, BASF, Bayer, Boerhinger Ingelheim, Ciba Spec., Glaxo-Wellcome, Hoechst, ICI, Nestle, Novartis, Novo Nordisk, Hoffmann-LaRoche, Schering, Unilever	Bosch, Cerberus, Electroclux, Esec, Leica, Nokia, Siemens, Philips, SAP	ABB, BMW, Continental, DaimerChrysler, Elf Aquitaine, Hilti, Mahle, Mettler Toledo, Royal Durch/Shell, Schindler, Sulzer
USA	3M, American Home Products, BP-Amnoco, Bristol-Myers-Squibb, Chevron, Dow, Eli Lilly, W.R. Grace	AT&T, Compaq, General Electric, Hewlett-Packard, IBM, Intel, Lucent, Microsoft, Motorola, National Semiconductor, Texas Instruments, Unisys, United Technologies, Xerox	Exxon, Ford, General Motors, Honeywell
Japan, East Asia	Eisai, Kao, LG, Yamanouchi	Canon, Daewoo, Hitachi, Kobe Electric, Samsung, NEC, Sharp, Sony, Toshiba	Fujitsu, Haier, Honda, Hyundai, Matsushita, Mitsubishi, Toyota

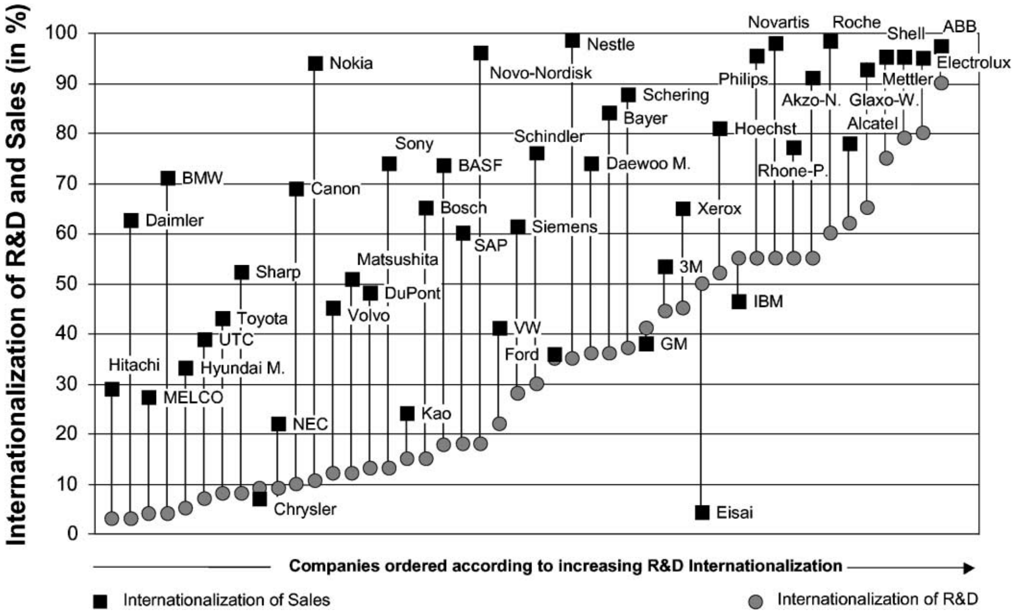

Fig. 2. R&D internationalization as compared to sales internationalization of 46 technology-intensive companies.

companies. Woodall and Yoshikawa (1997) argued that the low export rations of Japanese pharmaceutical companies may be explained by their weakness in basic research, ineffective R&D, and government intervention in drug pricing. Eisai's motivation for large international research investment can thus be seen to circumvent unfavorable domestic conditions. With two overseas research centers, Eisai's international engagement remained relatively small.

Almost all companies rank higher in internationalization of sales than of R&D: R&D is more centralized than the distribution of revenues. Not surprisingly, merger companies exhibit strong internationalization of sales as well as R&D (ABB, Royal Dutch/Shell, Mettler-Toledo). Moreover, companies with high sales internationalization are headquartered in small countries with small markets (Denmark, Finland, The Netherlands, Sweden, Switzerland).

2.2. Concentration of research and dispersion of development

We identified 1021 R&D locations in a total of 81 technology-intensive companies (Table 1). The home bases of the investigated companies were Europe (35 companies), USA (26), Japan (15), South Korea (4), and the People's Republic of China (1). In 1998, 13 of the 81 investigated companies ranked among the top 20 companies in the world, as measured by their market capitalization in Business Week (1998), 31 were among the top 100. These companies alone spent several dozen billion US dollars annually on international R&D activities.

The location data of the 1021 R&D units (Fig. 3 and Table 2) exhibit a strong concentration of R&D in the Triad regions of Europe, the US, Japan, as well as major regional centers in South Korea, Singapore, and other emerging economies along the Pacific Rim. Research is more concentrated than development. Total 73.2% of all research sites are located in the five regions of the northeastern USA (New Jersey, New York, Massachusetts), California, the United Kingdom, Western Continental Europe (in particular Germany), and the Far East (Japan, South Korea). The trend of research concentration is even more apparent if only foreign research locations are considered: 87.4% operate in the Triad.

Although, the main regional centers for development largely coincide with the regional centers for research, development is more evenly distributed among

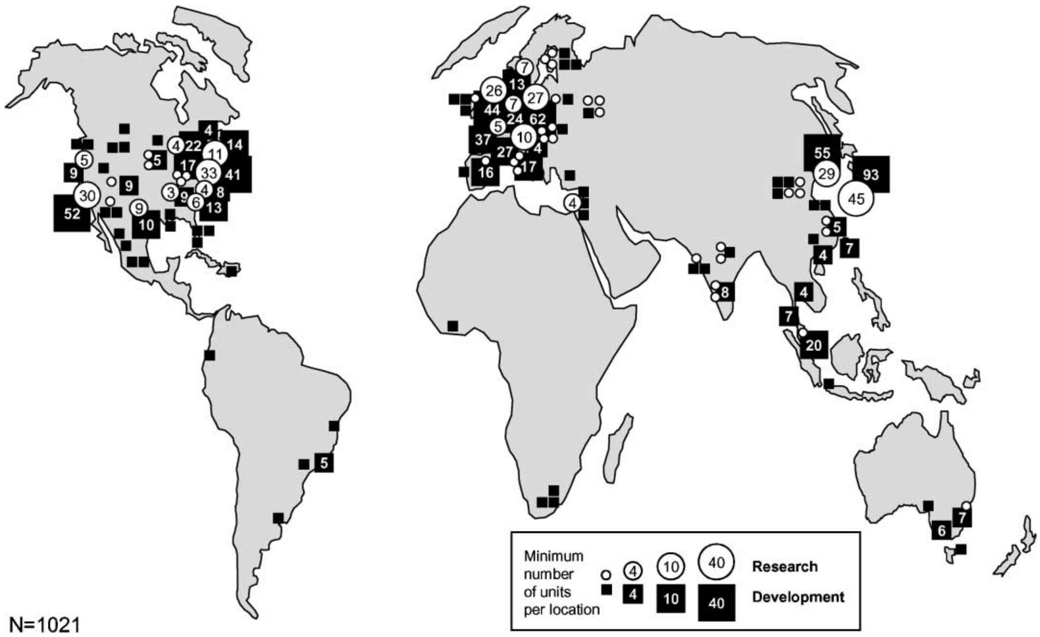

Fig. 3. Concentration of R&D in Europe, Japan, and US.

European countries and the northeastern US, and extends into southeast Asia, Australia, Africa, and South America. Only slightly more than half (53.4%) of all development sites are located in the eight most development-intensive countries. Development sites from 19 countries must be considered in order to account for a similar share in worldwide development (74.2%) as the top eight countries in research (73.2%).

Moreover, research and development sites of the same company are not necessarily collocated. For instance, AstraZeneca operates research as well as development units in the US. A research unit in Waltham, Massachusetts focuses on infectious diseases. Since there is no complementary development in the US, their research findings are transferred to a development laboratory in Sweden. Of IBM's 10 international R&D

Table 2
R&D orientation and location of 1021 R&D sites[a]

$N = 1021$	Research	Development	International	Domestic	International research	Domestic research	International development	Domestic development
US	107	197	153	151	54	99	53	98
Europe	98	254	258	94	60	198	38	56
Japan	45	93	48	90	17	31	28	62
4 Tigers[a]	30	86	34	82	1	33	29	53
4 New tigers[b]	–	12	12	–	–	12	–	–
OAC[c]	4	8	12	–	4	8	–	–
RoW[d]	15	72	84	3	15	69	–	3
Total	299	722	601	420	151	450	148	272

[a] Hong Kong, Singapore, South Korea, Taiwan.
[b] Indonesia, Malaysia, Thailand, Vietnam.
[c] Other advanced countries
[d] Rest of the world.

locations, only the Tokyo site maintains both research and development in the same building. Similar separation of research and development can be observed at DaimlerChrysler, Hewlett-Packard, Canon, and others. Why do we observe this separation of research and development, when everyone claims that the integration of R&D processes would be so important?

3. Four archetypes of R&D internationalization

The decision about where to establish new R&D units is made by higher management, usually in consultation with representatives from the R&D and strategy departments. This decision considers R&D-specific factors such as the quality of input at the new site (through tapping local talent, engaging in local scientific cooperation, etc.), the quality of expected output (cooperation with local customers and local development, market proximity, etc.), and the general operating efficiency (critical mass, project hand-over, cost issues, etc.) of this R&D unit. The decision is also affected by R&D-external factors, such as tax optimization, reliability and stability of the local political and social system, and image enhancement.

Mergers and acquisitions distort the picture of R&D expansion based on internal growth. Ronstadt (1978) noted that about a quarter of all R&D investments that he had studied were incidental through M&A activity of the parent company, and none of these acquisitions had pursued with the intent to gain access to the organization's R&D resources. Ronstadt's observation has been confirmed, e.g. by Pausenberger and Volkmann (1981) and Håkanson and Nobel (1993).

During our interviews with R&D directors, we aimed at disentangling the different factors and drivers that had led a specific R&D configuration. This required their input and insight as people who were intimately familiar with the history of their R&D organizations. The relative importance of science versus engineering in a given company also appeared to play a role. Furthermore, we analyzed principal R&D internationalization strategies and their actual implementations. Based on these considerations, we identified two principal drivers that were responsible for natural R&D internationalization: the quest for external science and technology, and the quest for new markets and new products. These gave rise to four archetypical forms of international R&D organization (Fig. 4):

1. domestic research and domestic development: national treasure R&D;
2. dispersed research and domestic development: technology-driven R&D;
3. domestic research and dispersed development: market-driven R&D;
4. dispersed research and dispersed development: global R&D.

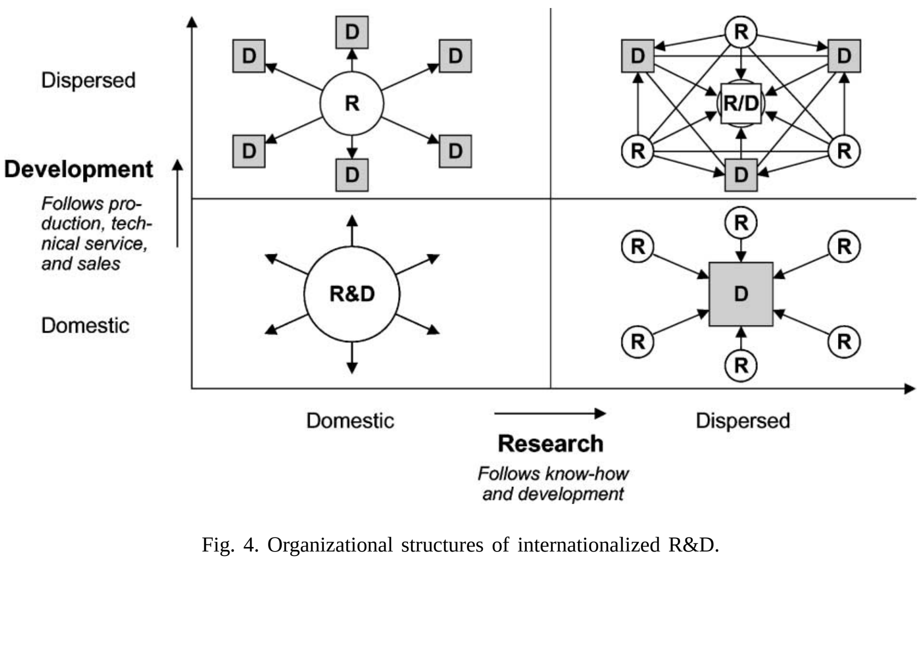

Fig. 4. Organizational structures of internationalized R&D.

Most of the 81 R&D organizations that we studied fall clearly into one of these four categories: 'national treasure' R&D accounts for 10 companies, 'technology-driven' for 7, 'market-driven' for 42, and 'global' for 19. As noted above, special circumstances in the process of R&D internationalization give rise to inconsistencies and hence a <100% fit with the proposed categories. In total, three R&D organizations were hard to assign to one of the four archetypical forms. In these ambiguous or unclear cases, international R&D was either not determined by either science or market access, or the drivers for internationalization were too mixed to warrant a discernible classification. Wherever we observed strong substantiation for either market or science access, we categorized accordingly.

The following four case studies illustrate the effects of these drivers on the management of R&D internationalization.

3.1. National treasure R&D: domestic research and domestic development

The R&D organization with both research and development at the home base is called the 'national treasure' model. R&D is kept at home, because core technologies are easier to control or critical minimum mass is important (see, e.g. Patel and Pavitt, 1992). There is little R&D at the international level, although important technological advances may be monitored from home via local representative offices and international patent scanning. Companies with a national treasure R&D organization are either in a strong dominant design position in its main technologies or their principal market is domestic. Neither requires much adaptation for foreign markets. R&D management is ethno- or geocentric, with foreign experts usually limited to advisory or consulting roles. The home-based management style is viable as long as technological dominance can be maintained.

The Japanese machinery company Kubota owned a strongly centralized R&D organization (see Fig. 5; data in these examples are 1999 figures, unless otherwise noted). Kubota established a technology development headquarters to ensure company-wide coherence of all R&D carried out in four central R&D laboratories and 49 R&D units in five divisions. All central R&D laboratories and most of the R&D units were located in the Osaka-Kyoto area (central Japan). Kubota invested about 4.5% of its sales in R&D, and 15% of this amount was reserved for technology development. About 430 researchers were employed in the central R&D laboratories, and some 1600 R&D engineers worked in plant- and factory-based R&D units.

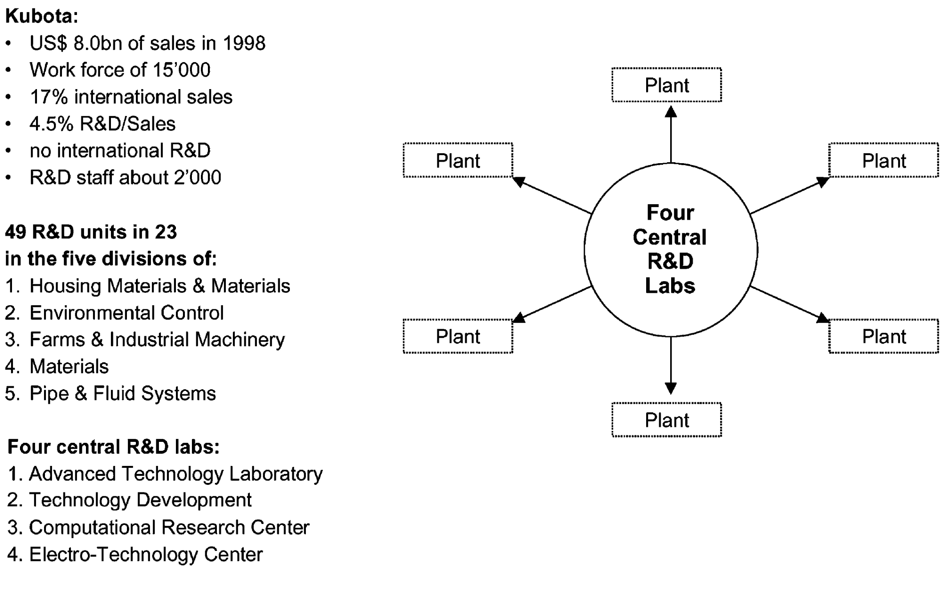

Fig. 5. Kubota's national treasure R&D organization.

Kubota had no international R&D locations, since the domestic market was still dominant (about 83% of total sales). However, strong linkages existed between global production sites and the home-based R&D organization, since the production sites were a principal provider of new market needs and customer feedback. A computerized information network connected the entire corporation, rationalizing corporate functions and accelerating the innovation process by giving employees worldwide access to Kubota researchers and their work. Kubota thus engaged in a variety of international research and development projects, while retaining the efficiency advantage of centralization.

3.2. Technology-driven R&D: dispersed research and domestic development

In 'technology-driven' companies, research is more internationalized than development. Access to local centers-of-scientific-excellence and the relative scarcity of scientific personnel at home drives a substantial share of the technology identification and creation process abroad. Development remains centralized because of a number of factors, including scale effects in the development process (e.g. establishment of technology platforms, access to specialized testing equipment), proximity to central control and decision making, protection of commercial results, synergy effects (e.g. improved communication during the innovation process, technical cross-fertilization), or the high information and coordination costs associated with international R&D projects. These centralization factors are less important in research as long as the scientific results are easy to communicate to the R&D center and the mission of each research lab is sufficiently focused.

Xerox is a good example of a company with a strong focus on technology (see Fig. 6). Over the past two decades, the document processing industry has been substantially affected by electronic and information technologies. As a result, Xerox Research—which was originally modeled along the lines of earlier centralized research organizations—was gradually decentralized (see Myers and Smith, 1999). There were five research sites worldwide: Webster (New York), Palo Alto (California), Mississauga (Canada), and two locations in Europe: Grenoble (France), Cambridge (UK). Each site had a specific research focus and was strategically located to leverage area industry and academic competencies relevant to that region and research focus. Research and technology development at Xerox was centrally managed under the corporate research and technology group with direct line-of-site to the CEO. Corporate research and technology had an average annual headcount of 1320; about 80 of which are in Europe.

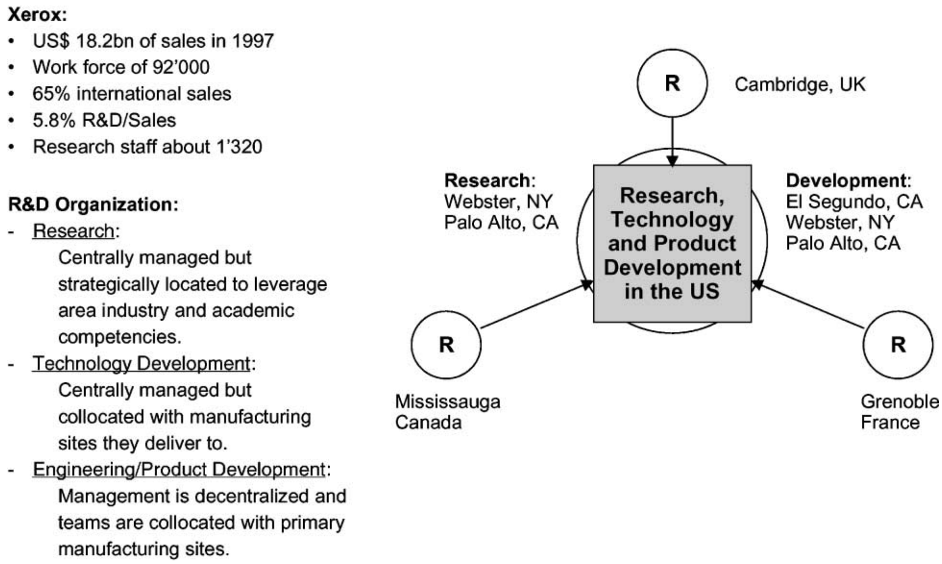

Fig. 6. Xerox's technology-oriented R&D organization.

Technology centers developed and delivered new technology to business groups. Although, management of the technology centers was centralized, resources were located as to align with the development groups and manufacturing sites they delivered to. The three primary technology centers had offices in El Segundo (California), Webster (New York), Palo Alto (California). Engineering was found mainly in the same locations. Product development teams were geographically collocated with the primary manufacturing sites serving their respective product markets. The largest manufacturing site was in Webster, New York, responsible for approximately 65% of Xerox manufactured end products. The second largest manufacturing site in the US was El Segundo, California. Although, there were no manufacturing facilities in Palo Alto, California, this site was the third largest development center in the US. Development in Palo Alto focused primarily on software product development.

3.3. Market-driven R&D: domestic research and dispersed development

Companies with highly dispersed development and little internationalized research have typically followed the call of the market; therefore they constitute the 'market-driven' model. Business development is dominated by customer demands and not by scientific exploration. Research is of low significance in the overall R&D effort and is kept at home to retain critical mass. Technology monitoring is carried out from home or in association with local development groups. The benefit of conducting research internally is often questioned, and research is under pressure to provide added value to product development and new business creation.

R&D at Schindler, a worldwide leader in elevators and escalators with a turnover of over 8 billion Swiss Francs, was characterized by the market-driven paradigm (see Fig. 7). Schindler's core mission was to be a global service company with strong customer orientation. In this industry, it was considered crucial to respond to regional customer requirements such as codes, standards, and passenger behavior. Many of the company's 45 000 employees worked in technical service or in direct customer contact. On the other hand, Schindler had to realize global synergies in product innovation.

In order to combine global efficiency with local effectiveness, Schindler organized R&D around three levels.

1. *Corporate R&D* was responsible for system engineering, development of key components, and

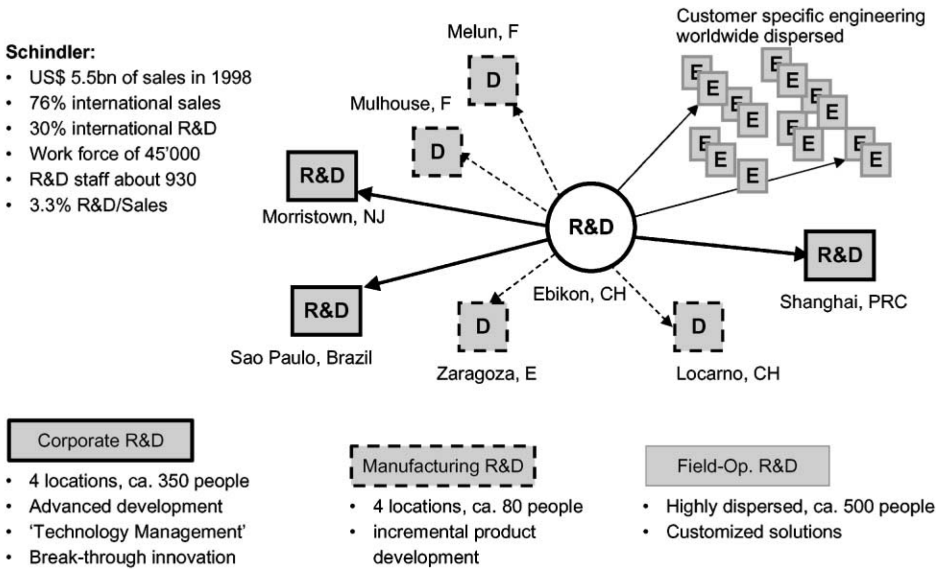

Fig. 7. Schindler's market-driven R&D organization.

breakthrough innovations. This R&D took place mainly in Ebikon (Switzerland), Morristown (New Jersey), Shanghai (China), and Sao Paulo (Brazil). A special department of corporate R&D, 'Technology Management' was responsible for advanced development, technology monitoring, competitor analysis, and strategic technology management, with the principal location in Ebikon and minor outposts in Morristown and Shanghai.

2. *Manufacturing R&D* was collocated with the component factories. Being responsible for incremental product improvements, these activities were located in Spain (Zaragoza), France (Mulhouse, Melune), Switzerland (Locarno), USA (Gettisburgh, Sydney), Malaysia (Ipoh), and China (Shanghai).
3. *Field engineering* was responsible for customized solutions, including local adaptation of the elevator to specific customer requirements. These engineering activities were conducted at every large field organization distributed over the 100 countries in which Schindler is represented.

These three levels enabled the organization to make best possible use of its competencies. Synergies and platform concepts are brought in through corporate R&D, while local solutions were found locally near downstream activities. Recently, Schindler also showed signs of more and more technology-driven internationalization. The systematic internationalization of corporate R&D and the establishment of innovation outposts for technology management indicated that Schindler was heading towards a global R&D organization.

3.4. Global R&D: dispersed research and dispersed development

Finally, 'global' companies have distributed research as well as development worldwide. These companies aim for global coordination of their R&D activities; most of them feature integrated R&D networks. Centrifugal forces have become stronger than centralizing forces. Research is located where there is high-quality scientific input expected from centers-of-excellence. Development labs conform to local demands and standards. The additional costs of maintaining transnational R&D are offset by the creation of business and market advantages. In global R&D networks, local science can be quickly absorbed and adapted for utilization elsewhere, and single development centers can take the lead to prepare products for global market launch. Managing R&D in this environment is significantly more complex and more costly than in the traditional R&D organization.

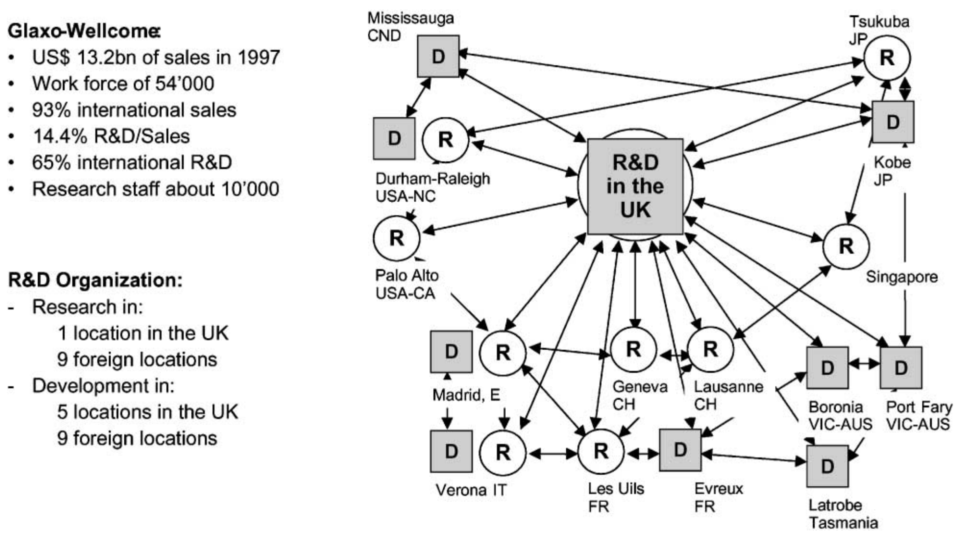

Fig. 8. Glaxo-Wellcome's global R&D organization.

'Global' R&D organizations have been established, for instance, in the highly competitive pharmaceutical industry. Headquartered in the UK, Glaxo-Wellcome had a 4.72% share of the US$ 275 billion global pharmaceutical market in 1998. It was the second largest pharmaceutical company both in Europe and the US, with market shares of approximately 5 and 6%, respectively. In 1998, seven of its products were in the world top 50. Being pharmaceutical company, Glaxo-Wellcome identified disease areas of unmet medical need and determined mechanisms by which they might be addressed, mainly through developing and registering new medicines.

Formed in 1995 by the merger of two major companies, Glaxo-Wellcome's R&D was distributed around the world (see Fig. 8). Principal sites for R&D were Stevenage, Greenford, and Ware in the UK; Research Triangle Park and Palo Alto in the USA; Tsukuba Science City, Japan; Verona, Italy; Les Ulis, France; Madrid, Spain; Mississauga, Canada. Research locations focused on special areas. The two major research centers in Stevenage, Hertfordshire, UK and in the Research Triangle Park in North Carolina covered the widest range of research areas. They were supported by smaller locations focusing on, e.g. anti-microbial and anti-fungal research (Madrid), bioinformatics (Geneva), or disease models (Lausanne) and the Affymax Research Institute in Palo Alto, California, which was engaged in technology development in screening and combinatorial chemistry.

4. Two principal forces and four trends in internationalizing corporate R&D

Although, complete integration of globally dispersed R&D activities is associated with high coordination and social costs, few companies can afford to ignore the benefits of local product adaptation or tapping into foreign science clusters. Operating with constrained resource availabilities in R&D (budget, manpower, etc.), management will prioritize its efforts as to why and when to internationalize R&D. Summarizing location factors found in the literature as well as the analysis of our four archetypes, we can make the following conclusions.

1. Access to local markets and customers: If forces of local markets and customer compliance prevail, the company will develop a decentralized development structure.
2. Access to local science and technology: If critical scientific knowledge is globally dispersed, international research outposts will be established to feed back technological information to development.

R&D internationalization, however, does not necessarily stop there. Once the R&D organization has reached—driven by either of the two principal internationalization factors of access to science or access to market—a satisfactory mode of operation, the respective other factor may prevail in driving further R&D internationalization. This leads to four principal trends of internationalization in research and development (see Fig. 9).

1. Trend 1: *internationalization of research*: If the company has no or difficult access to science from its home base, it may have to establish local research units which directly tap into scientific communities, centers-of-innovation, and local talent pools. This is often the case when the company's R&D center is located in a country with strong engineering but relative scarce scientific research capabilities (e.g. Daimler between 1988 and 1996, Canon between 1988 and 1992, Eisai).
2. Trend 2: *internationalization of development*: If the company's business requires local product adaptation and intensive customer cooperation, it is likely that local development units are established that deploy and implement technology created at the R&D center. Foreign markets have become more important than the domestic market. However, the main technological inputs originate at the home base (e.g. Leica in the 1980s and 1990s, SAP and Unisys in the 1990s).
3. Trend 3: *development follows research*: In science and technology-driven industries, development units may bring prospective new business opportunities from research to the market. These development units are often located close to the local research site and characterized by high personnel and infrastructure integration. However, their organizational structure and their reporting lines are different (e.g. Canon between 1993 and 1998, and Xerox in France recently).
4. Trend 4: *research follows development*: The evolution of local development sites and the necessity to

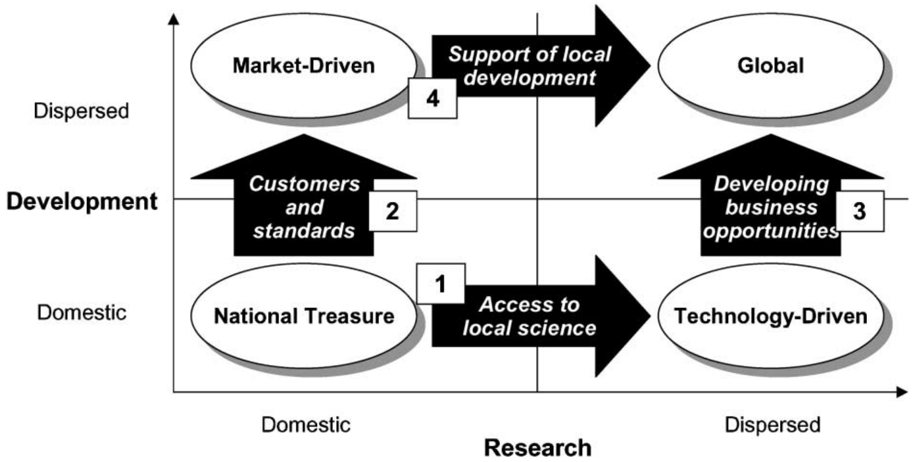

Fig. 9. Principal determinants and trends in internationalization of research and development.

provide more substantial research support locally may result in the on-site establishment of research units. In the strive to establish competence-based R&D networks, local development units become exclusively responsible for a particular technology, and hence must acquire the necessary research capability to support subsequent development and maintenance of this technology (e.g. Schindler between 1997 and 1999).

Only corporations with large resources to spend on R&D will be able to opt for concurrent internationalization of both research and development. They often do so in separate research and development organizations. For instance, IBM internationalized research around the same time as development, establishing a fairly independent research organization (IBM Research) and retaining development in the IBM business units. IBM Research has followed trend 1, while development at IBM followed trend 2. In the 1980s and 1990s, IBM developed an integrated R&D network by aligning worldwide R&D activities and guiding both R&D organizations towards the 'global' model. A similar development took place at Hewlett-Packard and Philips. In general, however, resource constraints and industry requirements will tip the balance towards one of the two major internationalization trends.

Reorganizations of R&D structure (as they often follow mergers and acquisitions of the parent companies) may seemingly lead to a reversal of above trends. Cost saving and the exploitation of synergy effects being a principal motivation for M&A activity, redundant R&D units are closed down or collocated. For example, after the merger of Astra and Zeneca, Astra's former Rochester, New York lab was moved to a newly established R&D site in Waltham, Massachusetts, which also integrated R&D activities from Zeneca's development unit in Wilmington, Delaware, and two other Astra sites in Worchester and Cambridge, Massachusetts. However, AstraZeneca's overall investment in R&D in the US was maintained or even expanded, since other R&D units in Sweden and the UK were being cut in staff simultaneously.

Similarly, a strategic initiative to strengthen corporate research and development at Schindler has led to a reduction of research sites. These sites however were not eliminated but, except in one case, moved to the supervision of business units as their work has become increasingly product-oriented. Hence the significance of international development has been improved, giving corporate research the flexibility to concentrate on strategic investments in technology development in China.

Such events can be seen as corrections to 'jungle growth' internationalization in R&D. They are aimed at reducing the costs of conducting R&D both domestically and abroad, improving local effectiveness of development (e.g. project management constraints and synergy building) and global utility of research (e.g. economies of scale and platform/competence management).

5. Discussion

5.1. International R&D literature revisited

A number of management researchers have come close to describing similar structures as the four archetypes proposed in this paper. Most recently, Kuemmerle's (1997) study on the role of individual R&D sites distinguished home-base-augmenting laboratories with the objective to create knowledge and then transfer it back to a central R&D site, from home-base-exploiting laboratories that commercialize knowledge by transferring it from the company's home base to the laboratory site abroad. Chiesa (1996) recognized that in the same firm, different R&D structures are developed for experimentation and exploitation activities. Both external sources of knowledge as well as internal dispersion of R&D resources affect the resulting R&D structure. Knowledge acquisition and absorption is a means to reduce uncertainty. Von Boehmer et al. (1992) applied Pearson's (1990) uncertainty map to the location of international R&D activities, finding differences between application engineering and technical development.

The four archetypes are a concept based on external factors driving R&D internationalization. If we compared the archetype concept with a model based on internal coordination and competition (Gassmann, 1997; Gassmann and von Zedtwitz, 1999a,b), the 'national treasure' companies appear to fall within the geo- and ethnocentric paradigm, the 'technology-driven' companies relate best to the hub-model, 'market-driven' companies follow typically polycentric R&D internationalization, and the companies denoted here as 'global' are found to be either striving for integrated R&D networks or retain a polycentric decentralized R&D configuration. This latter model is based on Bartlett's (1986) work on the structure of multinational companies as well as Perlmutter's (1969) basic behavioral patterns of multinational corporations.

The four archetypes also describe the evolution of an entire R&D organization based on the roles of its individual R&D units. While many authors deepened our understanding of the multitude of different location factors for individual units (e.g. Beckmann and Fischer, 1994; De Meyer and Mizushima, 1989; Gassmann and von Zedtwitz, 1996; Håkanson and Zander, 1988; Carnegie Bosch Institute, 1994; Krubasik and Schrader, 1990; von Boehmer et al., 1992), we have summarized these factors and concentrated on two principal external drivers that affect the development of the R&D organization as a whole.

But what are other possible explanations for the observed R&D archetypes? The behavior of companies is to a large degree determined by corporate culture and the ethnic/cultural background of their decision makers. We shall therefore first consider differences by geographical–cultural origin. Then business and industry environments may necessitate a competitive behavior influencing the organization of international R&D. We thus look into differences of industry by industry. However, we believe our strongest argument is given by the differences between scientific and engineering work, which not only account for different patterns between individual companies but also the observed global distribution of R&D sites.

5.2. Differences by geographical–cultural origin

European, American, and Japanese companies have shown different patterns in the way they approached the establishment of foreign R&D operations. Perrino and Tipping (1989, pp. 14–15) argued that European companies have been most aggressive in establishing foreign R&D outposts, often through the acquisition of entire firms. Japanese companies have relied on home development, licensing, and listening posts to acquire technology rather than expanding R&D overseas. American companies have tended to support new business opportunities by setting up overseas R&D units staffed with American researchers. Brockhoff (1998, p. 42) noted differences between companies from Japan and other countries in their acquisition of foreign R&D units.

We may be able to refine the patterns of R&D internationalization for multinational companies by discerning differences between research and development and their specific location drivers. Due to their large home markets and their strength in domestic research, many American and Japanese companies have been found to adhere to the 'national treasure' paradigm. European companies are characterized by the 'market-driven' model mostly because of their small domestic markets and relative ease of establishing development units within the European continent. Based on our study of 1021 R&D locations, we observed a substantial amount of intra-European internationalization.[2] Of a total of 352 R&D locations in Europe, no less than 133 R&D sites were owned by companies from other European countries. If they were not considered as international R&D sites, Europe would be left with 30 research sites from extra-European companies, and 95 development sites, or just about half of their previous rate of internationalization.[3]

Recently, many American companies have assumed a 'market-driven' configuration because of the rising relative importance of foreign markets. Japanese companies are following suit. Due to their relative weakness in domestic research, they have located research units in Europe and North America. However, instead of having R&D follow production, many Japanese companies have chosen to internationalize research first in order to prepare the ground for local development and manufacturing. This constitutes the 'technology-driven' paradigm. With the relatively strong emphasis on technology implementation in Japanese companies, cultural and social factors like tight personal networks and narrowly-meshed company interdependencies have made it difficult for them to establish productive development centers outside Japan.

Similar regional attributions for 'global' companies are difficult to make. Only few Japanese companies so far have established significant overseas presence in both research and development. A number of European and US companies have spread research and development evenly in dominant regions around the globe. 'Global' R&D is thus less likely determined by geographic provenience but rather by maturity of an internationally-dispersed R&D organization.

[2] The OECD estimates that about one-half of EC investment goes into other EC countries (OECD, 1996, p. 32, citing Thomsen and Woolcock, 1993). Only the UK has stronger ties to the US as measured by inward and outward investment.

[3] The remaining 94 locations (38 research, 58 development) are R&D sites established by companies in their home counties.

5.3. Differences by industry

A breakdown by industry neglects national, cultural, and company-specific factors. The available data and examples suggest that pharmaceutical and some IT/electrical companies prefer the 'global' R&D organization, probably due to particular location advantages in centers of excellence for research with global development networks to adapt or test products locally.

The 'market-driven' paradigm is the most prevalent and obvious way of R&D internationalization. It is pursued in almost all industries, and particularly strongly in electrical, machinery, and chemical companies. In these cases, technology platforms developed at home are the bases for local product development. There appears to be little need for elaborate international research networks.

Internationalization of development occurs more naturally as a consequence of internationalization of sales and local market support. Therefore, there are relatively few examples where research is more decentralized than development. It appears that some pharmaceutical and electrical companies internationalize research before development, following trend 1. The pharmaceutical industry appears to be the most internationalized in research: it operates about one foreign research site for every foreign development unit. Companies of more traditional business such as automobiles, heavy industry, and oil exploration concentrate their R&D resources in the home country.

Based on our data, foreign R&D investment is more than twice as likely to be development oriented than domestic R&D investment (oil, machinery, automotive, chemicals, telecommunication, food, diversified products). The information technology and electrical industries have a moderate emphasis towards more domestic research. Only the pharmaceutical industry repeats its domestic R&D investment ratio abroad.

In some cases, we observed that research sites were established as precursors to development centers. For instance, Philips' corporate research center in Briarcliff Manor, New York, has recently spun off a development team to their digital video and television business groups. Xerox research center in Grenoble has dedicated a team to more product-oriented research. In general, however, the present data set is still too limited to provide strong indications for clear industrial preferences in the patterns of research and development internationalization.

5.4. Different drivers for sciences and engineering

In our understanding, neither geographical/cultural nor industrial analysis sufficiently explains the observed archetypes and trends, although it is possible to argue for certain correlations of geographical origin or industry with R&D archetypes. We have found too many counter-examples to warrant possible hypotheses like "pharmaceutical companies tend to establish 'global' R&D organizations". Disregarding R&D-external factors such as mergers and acquisitions, one could also expect the causal determinants of differences in R&D dispersions to be rooted in differences in the very constituents of R&D work, namely science and engineering.

Scientists aspire to find new phenomena and create new knowledge. Their time horizon is usually long: some scientists devote their entire career to the advancement of a very specialized subject. Scientists identify themselves stronger with their field than with the company they work for. Their main contacts are other scientists, although there is a strong tendency to work and obtain credit as an individual. Commercial objectives are often absent and their success uncertain, and it is a difficult task for the director of a research department to match thematical freedom with budgetary constraints.

Engineers develop new technology and products mostly by utilizing existing knowledge in a novel way. There is often a strong time pressure to meet technical, performance, and market targets. Almost exclusively, these goals require the close cooperation with other engineers as well as frequent contacts with suppliers and lead customers. Technical specifications and commercial objectives are defined or negotiated with production, marketing, or customers. Executing a development project is thus more a matter of process management than of people administration (Boutellier et al., 1997).

These R&D-internal demands help to explain the two principal motivations to establish R&D sites abroad.

1. Proximity to other corporate activities (e.g. manufacturing) and proximity to local customers, which favor the operation and productivity of engineering and local product development.
2. The quest for technical know-how and expertise available in only a few centers-of-excellence around the world, which favor the productivity of research and technology monitoring.

Since science has productivity requirements different from engineering, the internationalization of research follows a different rationale than the internationalization of development. The internationalization of research is driven by access to local science and absorption of know-how of global value (see Table 3).

Table 3
Location drivers for research and development

Reasons to locate 'research' in a particular location[a]	Reasons to establish 'development' in a particular location[b]
Proximity to local universities and research parks	Local market requirements
Tapping informal networks	Global customers request local support
Proximity to centers-of-innovation	Customer proximity and lead users
Limited domestic science base	Cooperation with local partners
Access to local specialists/recruiting	Market access
Dissipating risks among several research units	Local citizen image
Support of local development projects	Simultaneous product launching
Adhering local regulations	Use of different time zones
Local patenting issues	Country-specific cost advantages
Subsidies	Facilitating scale-up in manufacturing
Low acceptance of research in home country (e.g. genetics)	Process innovation and adaptation to local production
	National protection

[a] Science and technology drivers.
[b] Engineering and market drivers

In international development, understanding and reacting to the local market and the efficient cooperation with local customers (manufacturing, development partners) are important drivers.

New R&D units are rarely set up as fully-fledged R&D centers. Most of them are established as rather small units that have to prove their viability first. Because of different science and engineering orientation, their internal evolution towards more mature R&D sites may be quite different. In many cases for which we obtained historical data of individual R&D units, we observed that development units evolve from local market support units, while research units evolve from scanning and listening posts. For instance, Leica's product development unit in Singapore is based on their previous technical service expertise and local manufacturing cooperation, and Daimler's research center in Palo Alto was originally conceived as a listening post. Although, still largely uninvestigated, we believe that our principal external factors (customer and market demands as well as integration of local science and technology) are important determinants for the evolution of individual R&D laboratories.

6. Managerial implications

R&D is torn between the demands for scientific and commercial results. Research is geared towards discovery rather than invention, while development aims at invention rather than discovery. Since research differs from development, the management of research differs from the management of development. Coping with managerial and organizational distances between research and development are at least as challenging as coping with geographical distances. These distances explain why there are internal struggles about mission and leadership, time pressures, funding sources and financing, results and performance evaluation, structure and thematical freedom.

At the same time, it is often argued that a re-integration of the two disciplines would improve overall innovation efficiency (e.g. Iansiti, 1998; Dimanescu and Dwenger, 1996). Detz (1996, p. 31) states that "the isolation of this (research) function in separate units, often physically separated from a company's other technology activities, and remote geographically and strategically from the needs of the company's businesses ··· made technology transfer exceedingly difficult". Asking for 'seamless integration' of R&D processes, authors with a focus on efficient project management expect shorter development times, improved technology transfer and project handover, higher customer orientation, and reduced overall costs.

We are therefore confronted with a fundamental tension between centrifugal forces that try to establish distance between research and development for greater R&D effectiveness, and centripetal forces that try to integrate research and development for stronger customer orientation and higher economic efficiency.

The current trend towards shorter time-to-market certainly favors the quality and intensity of communication and collaboration which are achieved by frequent face-to-face contact, physical collocation (see especially Allen, 1977), and modern information and communication technology. However, we believe that physical and organizational separation between research and development has also the following advantages:

- research and advanced development teams can better evaluate radical new technologies 'off-line';
- mid- and long-term platform teams are not just extended capacity resources for time critical projects;
- pilots with visionary lead users can be developed separately; this enables solutions that are more innovative than the average *existing* customer's requirement, which is normally the base for business cases.

Thus, at the possibly high costs from inefficient communication and long-distance collaboration processes, research needs to be conducted in places where scientific input can be maximized and where the environment is more conducive to carry out research. A calm environment is needed to cultivate 'new buds', including separate performance evaluation criteria and a more focused and specialized research infrastructure. Removed from distracting short-term concerns of development managers and corporate administration, these teams are more likely to pursue radical ideas, possibly leading to breakthrough innovations. The installation of research teams in scientific hot-spots like Silicon Valley, science clusters such as Route 128 near Boston, Massachusetts, and research parks allows the emergence of such a creative dynamic.

'Seamless integration' must not lead to tearing down all walls between research and development. Research must be organized according to the task at hand, not the function! This may well mean that the entire innovation process must bridge geographical distances, synchronize different technologies, and overcome organizational reservations. Two fundamentally different attitudes in R&D must be aligned or even merged. Thus, the dilemma between well-separated research and development and an efficient knowledge transfer needs specific managerial attention. Management of dispersed research must address technology and knowledge transfer between remote locations, the ivory-tower syndrome, and the guidance of colorful and individualistic personalities.

7. Conclusion

International R&D does not necessarily mean a globally integrated approach to R&D. International R&D dispersion is often a result of non-R&D-related merger and acquisitions of parent companies. The analysis of 1021 R&D units, each distinguished by its main orientation towards either research or development work, has revealed that research is concentrated in five regions worldwide, while development is more dispersed globally than research.

The establishment of new R&D units is influenced by two principal factors: access and support of local markets, and access to local science and technology. They give rise to four archetypical forms of R&D organization in which research and development are not necessarily collocated. Four generic trends describe the evolution of R&D organizations from one archetype into another. More than geographic origin or industry, the relative importance of science and engineering appears to influence the direction of R&D internationalization. Spatial and functional distances make the research-to-development interface more difficult to handle. Particular in fulfilling its role as a facilitator of inter-unit knowledge and technology transfer, R&D management becomes more complex due to limitations in knowledge mode conversion, side effects of cultural, linguistic and behavioral diversity, and project-internal communication impediments.

We expect that advances in information and communication technologies will further facilitate the dispersion of R&D. At the same time, multinational companies will establish talent pools of managers who are experienced in conducting multi-site R&D projects. With increased global presence, companies will be able to draw more easily on local science and technology. We do not expect, however, that international R&D alone will improve a company's ability to innovate. It will remain necessary to manage the communication flows and innovation processes that are at the core of the integrated R&D network.

References

Allen, T.J., 1977. Managing the Flow of Technology—Technology Transfer and the Dissemination of Technological Information within the R&D Organization. MIT Press, Cambridge.

Bartlett, C.A., 1986. Building and managing the transnational: the new organizational challenge. In: Porter, M.E. (Ed.), Competition in Global Industries. HBS Press, Boston, pp. 367–401.

Beckmann, C., Fischer, J., 1994. Einflussfaktoren auf die Internationalisierung von Forschung und Entwicklung in der Chemischen und Pharmazeutischen Industrie. Zeitschrift für Betriebswirtschaftliche Forschung 46 (7/8), 630–657.

Behrmann, J.N., Fischer, W.A., 1980. Transnational corporations: market orientations and R&D abroad. Columbia Journal of World Business 15 (3), 55–59.

Boutellier, R., Gassmann, O., von Zedtwitz, M., 1997. Innovation and phases in transnational R&D. In: Hirasawa, R. (Ed.), Proceedings of the 7th International Forum on Technology Management on Challenges for the 21th Century—Networking East and West, Kyoto, Japan, 3–7 November, pp. 481–488.

Boutellier, R., Gassmann, O., von Zedtwitz, M., 2000. Managing Global Innovation. 2nd Revised Edition, Springer, Berlin.

Brockhoff, K., 1997. Industrial Research for Future Competitiveness. Springer, Berlin.

Brockhoff, K., 1998. Internationalization of Research and Development. Springer, Berlin.

Buderi, R., Weber, J., Hoots, C., Neff, R., 1991. A Tighter Focus for R&D. Business Week, Vol. 2, December, pp. 80–84.

Cantwell, J., 1995. The globalisation of technology: what remains of the product cycle model? Cambridge Journal of Economics 19, 155–174.

Cantwell, J., Janne, O., 2000. The role of multinational corporations and national states in the globalization of innovatory capacity: the European perspective. Technology Analysis and Strategic Management 12 (2), 243–262.

Carnegie Bosch Institute, 1994. Managing International Research and Development. Working Paper 94–98, International Executive Forum of the Carnegie Bosch Institute, Pittsburgh, 1993.

Chiesa, V., 1996. Managing the internationalization of R&D activities. IEEE Transactions on Engineering Management 43 (1), 7–23.

Daimler-Benz, 1997. Producing the goods. Daimler-Benz High Tech Report'97. Daimler-Benz, Stuttgart, pp. 12–15.

Dalton, D.H., Serapio, M.G., 1995. Globalizing Industrial Research and Development. US Department of Commerce, Washington, DC.

De Meyer, A., Mizushima, A., 1989. Global R&D management. R&D Management 19 (2), 135–146.

Detz, C.M., 1996. Corporate-supported research in a reengineered technology organization. Research Technology Management 39 (4), 30–32.

Dimanescu, D., Dwenger, K., 1996. World-Class New Product Development. Amacom, New York.

Eldred, E., McGrath, M., 1997a. Commercializing new technology - I. Research Technology Management 40 (1), 41–47.

Eldred, E., McGrath, M., 1997b. Commercializing new technology - II. Research Technology Management 40 (2), 29–33.

Gassmann, O., 1997. Internationales F&E-Management. Potentiale und Gestaltungskonzepte transnationaler F&E-Projekte. Oldenbourg, München.

Gassmann, O., von Zedtwitz, M., 1996. Ein Referenzrahmen für das Internationale Innovationsmanagement. In: Gassmann, O., von Zedtwitz, M. (Eds.), Internationales Innovationsmanagement. Vahlen, München, pp. 3–15.

Gassmann, O., von Zedtwitz, M., 1998. Organization of industrial R&D on a global scale. R&D Management 28 (3), 147–161.

Gassmann, O., von Zedtwitz, M., 1999a. New concepts and trends in international R&D organization. Research Policy 28, 231–250.

Gassmann, O., von Zedtwitz, M., 1999b. Organizing virtual R&D teams: towards a contingency approach. In: Kocaoglu, D.F. (Ed.), Proceedings of the Portland International Conference on Management of Engineering and Technology (PICMET) on Technology and Innovation Management—Setting the Pace for the Third Millennium, Portland, July, pp. 25–29.

Gates, S., 1995. The Changing Global Role of the Research and Development Function. Report No. 1123-95-RR, The Conference Board, New York.

Granstrand, O., Håkanson, L., Sjölander, S. (Eds.), 1992. Technology Management and International Business: Internationalization of R&D and Technology. Wiley, Chichester.

Håkanson, L., Nobel, R., 1993. Foreign research and development in Swedish multinationals. Research Policy 22, 373–396.

Håkanson, L., Zander, U., 1988. International management of R&D: the Swedish experience. R&D Management 18 (3), 217–226.

Hirschey, R.C., Caves, R.E., 1981. Internationalisation of research and development by multinational enterprises. Oxford Bulletin of Economics and Statistics 42 (2), 115–130.

Howells, J., 1990. The location and organisation of research and development: new horizons. Research Policy 19, 133–146.

Iansiti, M., 1998. Technology Integration: Making Critical Choices in a Dynamic World. Harvard Business Press, Boston.

Krubasik, E.G., Schrader, J., 1990. Globale Forschungs- und Entwicklungsaktivitäten. In: Welge, M.K. (Ed.), Globales Management. Schaetfer-Poeschel, Stuttgart, pp. 17–27.

Kuemmerle, W., 1997. Building effective R&D capabilities abroad. Harvard Business Review 3/4, 61–70.

Kumar, N., 1995. Intellectual Property Protection, Market Orientation and Location of Overseas R&D by Multinational Enterprises. UNU/INTECH Discussion Papers, March.

Leifer, R., Triscari, T., 1987. Research versus development: differences and similarities. IEEE Transactions on Engineering Management EM-34 (2), 71–78.

Medcof, J.W., 1997. A taxonomy of internationally dispersed technology units and its application to management issues. R&D Management 27 (4), 301–318.

Myers, M., Smith, K., 1999. Xerox: the global market and technology innovator. In: Boutellier, R., Gassmann, O., von Zedtwitz, M. (Eds.), Managing Global Innovation. Springer, Berlin, pp. 299–315.

National Science Board, 1991. Why US technology leadership is eroding. Research Technology Management 34 (2), 36–42.

Odagiri, H., Yasuda, H., 1996. The determinants of overseas R&D by Japanese firms: an empirical study at the industry and company levels. Research Policy 25, 1059–1079.

OECD, 1996. Science, Technology and Industry Outlook 1996. OECD, Paris.

Patel, P., 1995. Localised production of technology in global markets. Cambridge Journal of Economy 19, 141–153.

Patel, P., Pavitt, K., 1992. Large firms in the production of the world's technology: an important case of non-globalisation. In: Granstrand, O., Håkanson, L., Sjölander, S. (Eds.), Technology Management and International Business: Internationalization of R&D and Technology. Wiley, Chichester, pp. 53–73.

Pausenberger, E., Volkmann, B., 1981. Forschung und Entwicklung in internationalen Unternehmungen. In: Moll, H.H., Warnecke, H.J. (Eds.), RKW-Handbuch Forschung, Entwicklung, Konstruktion (F&E). Bd. 3, Stand: Okt. 1990 (19. Lfg.), Kennzahl 8400, Berlin.

Pavitt, K., 1984. Sectional patterns of technical change: towards a taxonomy and a theory. Research Policy 13, 343–374.

Pearce, R.D., 1989. The Internationalisation of Research and Development by Multinational Enterprises. Macmillan, Basingstroke, UK.

Pearson, A., 1990. Innovation strategy. Technovation 10 (3), 185–192.

Perlmutter, H.V., 1969. The tortuous evolution of the multinational corporation. Columbia Journal of World Business 4, 9–18.

Perrino, A.C., Tipping, J.W., 1989. Global management of technology. Research Technology Management 32 (3), 12–19.

Roberts, E.B., 1995. Benchmarking the strategic management of technology I. Research Technology Management 38 (1), 44–56.

Ronstadt, R.C., 1977. Research and Development Abroad by US Multinationals. Praeger, New York.

Ronstadt, R.C., 1978. International R&D: the establishment and evolution of research and development abroad by seven US multinationals. Journal for International Business Studies 9, 7–24.

Rubenstein, A.H., 1989. Managing Technology in the Decentralized Firm. Wiley, New York.

Serapio, M., Dalton, D., 1993. Foreign R&D facilities in the United States. Research Technology Management 36 (6), 33–39.

Thomsen, S., Woolcock, S., 1993. Direct Investment and European Integration: Competition among Firms and Governments. Catham, London.

von Boehmer, A., Brockhoff, K., Pearson, A.W., 1992. The management of international research and development. In: Buckley, P.J., Brooke, M.Z. (Eds.), International Business Studies. Oxford University Press, Oxford, pp. 495–509.

Woodall, B., Yoshikawa, A., 1997. Japan's Failure in Pharmaceuticals: Why is the World Saying No to Japanese Drugs? CIBER Working Paper.