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New perspectives on the innovation strategies of multinational enterprises: lessons for technology policy in Europe

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Abstract

The aim of this contribution is to learn more about changes in the innovation strategies of large multinational corporations, whereby one focus is on internationalization aspects. As sources for our analyses we reviewed the main empirical studies and gathered information and insights from 21 corporations. Our results show, firstly, that the internationalization of research and technology is still characterized by 'Triadization' involving companies from the US, the European Union and Japan. Secondly, qualitative motives are increasingly driving R&D location decisions, like learning from technological excellence and lead markets and dynamic interactions within the value chain. Thirdly, the process of internationalization in research and technology has been accompanied by an increasingly selective focus on a very few locations and the concentration of innovation activities on worldwide centers of excellence. We conclude that these changes in the innovation strategies of large multinational companies put several topics on the agenda for technology policy in Europe: (1) a stronger focus on extra-European collaboration and mobility, (2) strengthening the attractiveness of the European Union to foreign R&D investment and (3) the absorptive capacities of R&D organizations in Europe, (4) a stronger integration of different policy areas and of indirect policy measures (5) as well as the establishment of a transparent and global framework for policy coordination and priority-setting worldwide. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Internationalization of research and technology is a major topic within the business community, as well as for academic researchers and decision-makers in government. Since the early 1980s, the international generation of innovation has increased, and affected the internationalization of research and development (R&D). During earlier periods of international expansion (the 1960s and 1970s), multinational corporations first built up their sales, distribution and assembly operations in foreign countries. In later phases (late 1970s/early 1980s), efforts were then

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directed towards supporting foreign subsidiaries with corresponding capacities in application engineering and applied R&D. Although initially the tasks of development departments abroad were limited to adapting product and process technologies from the home country to local production and market requirements, there was a clearly recognizable trend, since the late 1980s, towards strengthening R&D in foreign countries and extending the global competence portfolio. Increasingly, research became established at a high level in foreign locations.

The internationalization of research and technology is one key constituent of the globalization of trade and business, with potentially major impacts on patterns of economic development and public policies worldwide. Although certain aspects of this internationalization trend are well documented, and some effects can be quantified, the overall processes are extremely complex and the outcomes/impacts are highly uncertain. The existence of the phenomenon is generally accepted, but its importance and the trends are currently the topic of a lively debate. This contribution will describe the changes in the innovation strategies of multinational corporations (with a strong focus on internationalization aspects) on the basis of the review of empirical studies, quantitative data and own qualitative research in 21 multinational corporations [2] and will assess the consequences for technology policy in Europe.

The promotion of research and technology by the state is always based on premises on the behaviour of enterprises performing R&D. Our study has revealed a number of new trends which require changes in the approaches used until now by technology policy. Building on analyses of the changes taking place in R&D management, this paper indicates important issues and options for the shaping of technology policy in Europe. Many of the consequences and our conclusions concern the level of the European Union (EU), as well as national and regional policies. Therefore, it seems to be appropriate to refer to technology policy *in Europe* (meaning EU, national and regional). The term 'European S&T policy' is used when the European Union is specifically concerned.

This paper concentrates on the innovation strategies of large, multinational, technology-intensive corporations. The reasons are twofold. Firstly, these companies play a key role in the international generation and diffusion of technological knowledge, and thus in the competitive positioning of different regions in the world economy. [3] Secondly, large R&D-intensive companies are of great importance for the allocation of R&D resources, economic development and employment. [4] A consideration of the role of small and medium-sized enterprises (SMEs), or of the links between SMEs and large firms, is not included and could be the object of further research.

In Section 2 the methodology and the selected corporations are described. In Section 3 a summary of the main changes in industrial innovation strategies is given, and our results are reflected with further empirical research in this field. The consequences for technology policy in Europe and new policy issues are discussed in Section 4. The central thoughts of this contribution are summed up in Section 5.

2. Methodology and selected corporations

The aim of this contribution is to learn more about changes in the innovation strategies of internationally active corporations; a focus is hereby on the internationalization of research and technology. As

[2] This study on the innovation strategies of multinational corporations was carried out jointly by the Fraunhofer Institute ISI in Karlsruhe, the University of St. Gallen and the University of Hohenheim (see Gerybadze et al., 1997).

[3] See e.g., Patel and Pavitt (1991), Cantwell (1994), Nonaka and Takeuchi (1995), Roberts (1995a,b).

[4] In Japan the 'Top 50' innovative corporations have a share of 63% of the total Japanese R&D expenditures (1992); in the United States this share amounts to 35%; and in the European Union to 45% of the total EU R&D expenditures (cf. Gerybadze et al., 1997, p. 38). Global Fortune Top 500 companies in aerospace, motor vehicles, and pharmaceuticals account for 65%, nearly 60% and 82% of employment in their respective sectors (cf. Commission of the European Communities, 1997).

Table 1
R&D intensities and the degree of internationalization of R&D within our sample

Rank	Company	R&D intensity 1993 (%)	Share of foreign R&D 1993 (%)	Degree of internationalization R&D	Industry
1	Siemens	9.2	28	**	Electrical engineering
2	IBM	7.1	55	***	Computers
3	Hitachi	6.7	2	*	Electrical engineering
4	Matsushita Elec.	5.7	12	**	Consumer electronics
5	ABB	8.0	90	***	Electrical engineering
6	NEC	7.8	3	*	Telecommunications
7	Philips	6.2	55	***	Electrical engineering
8	Hoechst	6.2	42	***	Chemical/Pharmaceuticals
9	Sony	5.8	6	**	Consumer electronics
10	Ciba-Geigy	10.6	54	***	Chemical/Pharmaceuticals
11	Bosch	6.7	9	**	Electrical engineering
12	Roche	15.4	60	***	Chemical/Pharmaceuticals
13	Mitsubishi Elec.	5.2	4	*	Electrical engineering
14	BASF	4.5	20	**	Chemical/Pharmaceuticals
15	UTC	5.4	5	*	Engineering/Aeroengines
16	Sandoz	10.4	50	***	Chemical/Pharmaceuticals
17	Sharp	7.0	6	*	Consumer electronics
18	Kao	4.6	13	**	Chemical/Cosmetics
19	Eisaj	13.2	50	**	Chemical/Pharmaceuticals
20	Sulzer	3.4	27	**	Advanced engineering
21	MTU	~ 25	–	*	Engineering/Aeroengines

Evaluation of the ‘Degree of Internationalization of R&D’

***	Internationalization of R&D very advanced
**	Above-average internationalization of R&D
*	Relatively low internationalization of R&D

Source: Database on International R&D Investment Statistics (INTERIS) and ISI Database on International Research and Innovation Activities (ISI-DORIA).

sources for our analyses we reviewed the main empirical studies [5] and gathered information and insights from ‘trend-setting’ corporations and decision-makers. We conducted a total of 120 semi-structured expert interviews on three levels (board member, head of research, project leader) in 21 internationally active corporations. The results of the interviews were presented, at three workshops, to representatives from enterprises and to policy-makers, and were intensively discussed. The precise stipulations and comments elaborated at these workshops were incorporated into the final report of our study.

The empirical sample consisted of 21 multinational corporations, most of which are engaged in electronics and information technology, in the chemical and pharmaceutical industry, as well as in machinery and advanced engineering (e.g., turbines and

[5] See, for instance, the empirical studies conducted by Ronstadt (1977, 1978), Warrant (1991), Patel and Pavitt (1991), Granstrand et al. (1992), Pearce and Singh (1992), Molero and Buesa (1993), Cantwell (1994, 1995), Archibugi and Michie (1995), Dalton and Serapio (1995), Florida (1995, 1997), Molero et al. (1995), Odagiri and Yasuda (1996), Dunning (1997), Gerybadze et al. (1997), Molero (1997), Pavitt (1997), Patel and Vega (1997), Soete (1997), Sölvell (1997), Archibugi et al. (1998), Meyer-Krahmer (1999), Reger et al. (1999). The OECD (OECD, 1995, 1996, 1997a,b, 1998) and the European Commission (Commission of the European Communities, 1997, 1998) both have on-going activities monitoring the internationalization of research and technology.

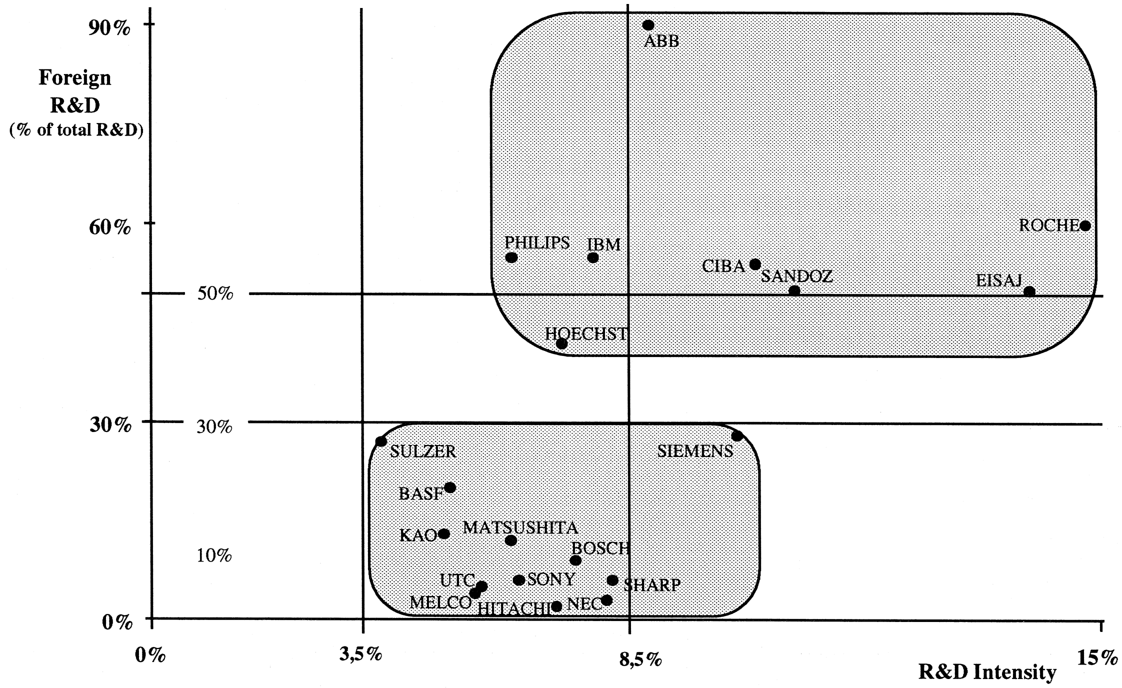

Fig. 1. R&D intensity and proportion of R&D conducted abroad in the enterprises analyzed.

aeroengines). Table 1 gives an overview of the corporations studied. Eleven enterprises were included from western Europe, eight from Japan and two from the United States. We concentrated our investigations on corporations from western Europe (Germany, Switzerland, the Netherlands) and Japan. The 21 selected enterprises are among the leading R&D-performing industrial firms worldwide. Many of them are technology leaders in their specific business, and are very far advanced in terms of the degree of R&D internationalization.

Four of the ten enterprises with the highest R&D expenditures in the world were included in the survey (Siemens, IBM, Hitachi and Matsushita). Approximately one-third of the 50 most important corporations with the highest R&D expenditure were included. Sixteen of the 21 enterprises spend more, some considerably more, than US$1 billion on R&D annually. The analyzed enterprises have an above-average intensity of R&D (R&D expenditure as a proportion of turnover) of 8.3%. Most of them are characterized by a high R&D intensity at the corporate level, or at least one of their business units is very R&D intensive. [6]

In addition to presenting the R&D intensity and the share of foreign R&D, Table 1 includes a qualitative evaluation of how far the R&D internationalization process has advanced in the corporations in our sample. This qualitative assessment of the extent of internationalization cannot alone be compared with the parameter of the share of R&D performed abroad. The former also considers the extent of worldwide distribution of R&D and innovation activities, the internationalization of management and corporate

[6] Examples for a very high R&D-intensity at the corporate level are Roche (15%), Eisaj (13%) and Ciba-Geigy (11%). Several other firms spend less than 10% of turnover for R&D at the *corporate* level, but display very high R&D intensities at the *business* level. As an example, SulzerMedica invests more than 10% of its turnover for R&D, while the average ratio for the Sulzer corporation is only 3.4%.

culture, and the type of cross-border coordination and interaction. If the average values for R&D intensity and the share of foreign R&D are compared at the level of the corporation, two clusters can be distinguished (cf. Fig. 1):

(1) A group of corporations with a strong international orientation, which have a strong R&D presence abroad (close to 50%, or even above that rate); these include ABB, Ciba-Geigy, Eisaj, IBM, Hoechst, Philips, Roche and Sandoz.

(2) There is a second group of enterprises which are not so far advanced in building up R&D functions abroad. A few of these enterprises have a share of foreign R&D of 20 to 30% (e.g., BASF, Siemens and Sulzer); however, the majority of enterprises in this group have a less international orientation in R&D.

3. Main changes in the innovation strategies of multinational enterprises

3.1. Technology alliances and the merging of paradigms: towards an internationally learning company

If the situation up to the end of the 1970s was largely characterized by the dominance of a world center for research and innovation (the United States in many important fields of technology, and western Europe in individual fields, such as chemistry), it is now true to say that, for the important fields, two to three centers are crystallizing out within the Triad countries. These are in fierce competition with one another, and from time to time very rapid changes in ranking take place. Because of this development, enterprises which are leading performers of R&D have to demonstrate a presence in several locations at the same time, establish sufficiently competent and extensive structures there, and react as quickly as possible to dynamic changes in relative location advantages.

For this reason, R&D centers and product development capacities were established within the same corporation at several different Triad locations as a part of entrepreneurial integration strategies. At the same time, attempts are being made, through R&D cooperations and strategic technology alliances, to form networks as fast and as flexibly as possible between institutionally and regionally scattered centers of competence. Empirical evidence has shown that since the 1980s the number of newly established strategic technology alliances has increased considerably, [7] especially in the most dynamic technology fields such as biotechnology, new materials and, above all, information technologies. Strategic technology alliances are here understood as those interfirm agreements that contain arrangements among firms for joint R&D or technology transfer. Agreements across borders constitute by now almost 60% of the ones [8] registered in the MERIT/CATI database. [9] It is significant that the number of newly established *intraregional* alliances have lost relevance in Europe and Japan (see Fig. 2). By contrast, *interregional* alliances with industrial partnerships between Japan–US and Europe–US have gained importance: new alliances which contain at least one Japanese and one US partner have grown from 186 (1980–1984) to 213 (1990–1994). Especially newly established Europe–US technology alliances have increased from 221 to 457 in the same time span. Europe–US alliances have grown most in the biotechnology area.

There are widespread benefits for a region which manages to be the ‘junction’ of technological knowhow, including strategic agreements. Countries with greater inflows and outflows of technological knowledge are able to exploit them for economic develop-

[7] See Hagedoorn and Schakenraad (1990, 1993).

[8] This is confirmed by other reports. Amongst members of the EU the number of purely national alliances is very small (only 8%). Alliances between member states account for 24% of the total and interregional alliances between EU members and nonmembers for 68% (see Commission of the European Communities, 1997). These interregional alliances differ from sector to sector: in the aerospace industry, only 49% of the alliances with at least one EU partner are interregional (1984–1995). By contrast, the share of interregional agreements is much higher in computers (86%), pharmaceuticals (86%), instruments (80%), chemicals (78%) or electronics (75%).

[9] The MERIT/CATI databank is a relational database which contains information on nearly 10,000 cooperative agreements involving some 3500 different parent companies. For more detailed information, see Narula and Hagedoorn (1997).

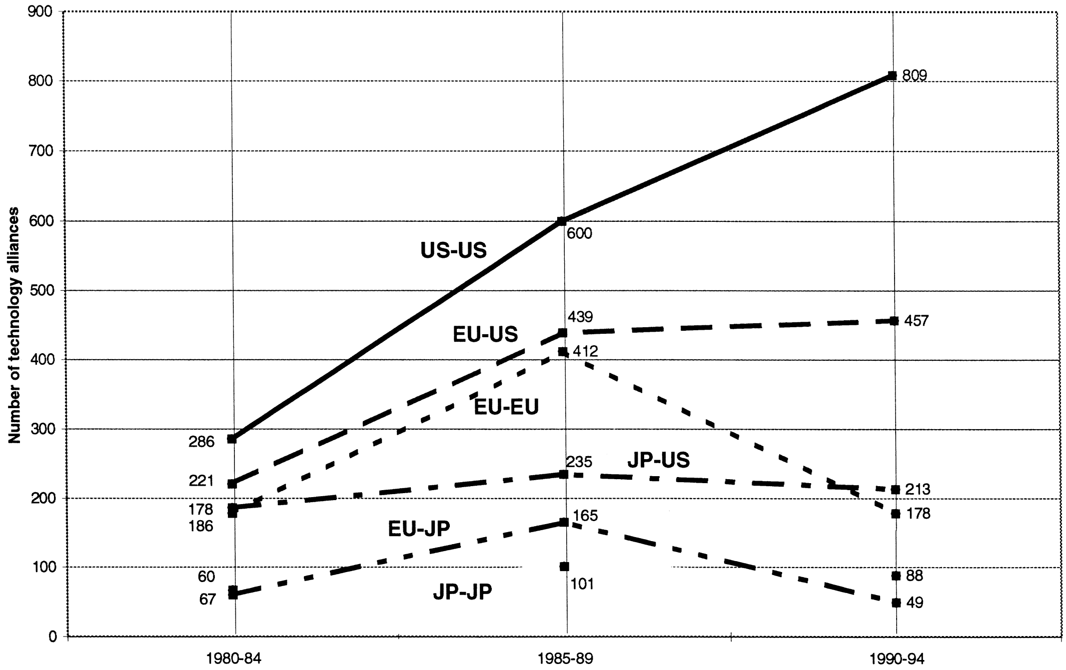

Fig. 2. Number of newly established strategic technology alliances in the Triad (1980–1984, 1985–1990, 1990–1994). Source: CEC (1997) and data from the MERIT/CATI dataset (see Duysters and Hagedoorn, 1996; Narula and Hagedoorn, 1997; Narula, 1998); basis: nearly 10,000 cooperative agreements.

ment and welfare. Regions with a larger base of technological know-how or excellence in research will obviously be more interesting for firms searching for partners. However, the data show that the United States are much more a junction of technical exchange, on both the Atlantic and the Pacific sides, than Europe. The strategic alliances between companies from the European Union and Japan is still small, compared with the strong position of the US.

This trend towards R&D cooperation and alliances is linked with the fiscal consolidation of R&D, observed in almost all OECD countries. Both public institutions and private firms are increasingly coming up against the limits of ‘financeability’ of R&D. In the highly developed, industrialized countries a value of 3% of R&D expenditure of the GDP represents a sort of ‘sound barrier’. In some of the leading industrialized countries this value has even been reduced again in the last few years: in Germany, the share of R&D expenditure in the gross domestic product went down from 2.88% (1987) to 2.48% in 1993, and in the USA from 2.84% (1987) to 2.72% (1993). Corporations performing leading R&D are also reporting extreme problems in financing, on a private economic basis, certain parameters forced upon them by international competitors (e.g., expenditure on R&D amounting to well over 10% of turnover).

In public institutions and in enterprises, this fiscal consolidation leads initially to short-sighted approaches: a stronger application orientation and a corresponding reduction in long-term oriented research are observed. In many corporations this has led to a weakening of central research and to increasing ‘divisionalization’ of R&D. In universities and public research institutes, too, altered fiscal and policy priorities have not infrequently led to short-term pressure and the atrophying of long-term research competence.

A lack of equilibrium between strategic research and application-oriented development can have grave consequences, however, because in innovation-intensive fields that promise future growth the relationship of strategic research—development—innovation is fundamentally altered. Research centers and international enterprises are increasingly gaining their competitive advantages from a close, undistorted link between basic and applied knowledge. Integrated product development processes, simultaneous engineering and increasingly close links between R&D, production and marketing are progressively emerging as the principles that shape innovation management.

With regard to R&D activities, it is a fact that changes in structure are triggering decisive changes in linking the elements of the value chain, both within corporations (e.g., in the coordination of transdisciplinary topics) and between enterprises (adoption of very different forms of cooperation in R&D). More and more, a re-thinking of the traditional view of the international enterprise is taking place: interest is no longer focused on a production machine for optimization, seeking out its locations according to theoretical factor costs, but on the globally learning enterprise, gaining knowledge of options at the leading centers of intelligence and transferring them as rapidly as possible into marketable products.

On the one hand, this confirms other approaches that globalization follows *different paradigms in different entrepreneurial functions* (see Gordon, 1994): the internationalization of markets is determined by the search for markets with high income elasticities and low price elasticities of demand in conditions of free world trade, the transnationalization of production locations is driven by the regime of production possibilities (qualified workforce, supplier–producer networks, costs, other comparative advantages, closeness to market) and lastly, globalization is characterized by the pursuit of system competence through global 'R&D sourcing' and the orientation towards the excellence of (national) R&D systems and centers. [10] On the other hand, our results show that the 'three worlds' postulated in this 'three-different-paradigms' approach repeatedly impinge on one another, so that the various paradigms merge again to some extent.

This statement is supported by a recent study on determinants of location factors of the internationalization of research and development (see Reger et al., 1999): in different key technologies the three paradigms play varying roles. Differences between sectors regarding the degree of liberalization of international trade, the regulation of streams of direct investments, specific features of regional demand, economies of scale in production and the internationalization of technological knowledge, result in different levels of internationalization. The surveys in the three selected technology fields have shown that the internationalization of R&D is mainly influenced by three factors, namely:

- early linkage of R&D activity to leading, innovative clients ('lead users') or to the 'lead market',
- early coordination of the enterprises' own R&D with scientific excellence and the research system,
- close links between production and R&D.

Our analysis showed that internationally active enterprises think in terms of value-added chains and process chains. Consequently, the criteria for selecting a location for R&D include not only factors of supply, such as a well-developed research infrastructure, but also demand factors, which increasingly play a more important part in the decisions of enterprises. Only by linking various value-added chains can (relatively) non-transferable 'performance alliances' be created, establishing Germany internationally in selected fields as a location for competence centers which it would be difficult to transfer, or duplicate, elsewhere.

The importance of lead markets in anchoring existing industrial R&D activities and attracting new activities has increased. The market's function as a 'lead market' is decisive for innovations which only fully mature when they come into close contact with demanding, innovative customers. In fields of technology that are strongly science-based, it is the results of scientific research that constitute a driving force in the internationalization of innovation processes. In both cases, regional proximity to external partners such as customers, competitors and scientific institutions is an advantage. If there is a close

[10] In management theories these terms 'transnationalization' and 'globalization' are used the other way round (see, e.g., Bartlett and Ghoshal, 1989).

Table 2
Determinants of the internationalization of R&D in selected fields of technology

Importance of R&D link to	Pharmaceuticals		Semiconductor technology		Telecommunications technology	
	Pre-clinical	Clinical research	Process technology	Product development	Hardware	Software
Lead market	low	very high	low	very high	low	very high
Science/research system	very high	high	high	low	high	low
Production	low	low	high	low	high	low

Source: Reger et al. (1999).

interlinking of production and R&D activities, internationalization of R&D follows internationalization of production. The internationalization of production is then the main driving force behind the internationalization of R&D.

One central finding of this survey is that the determinants of internationalization in the three fields of technology considered are different (cf. Table 2). The dynamics of innovation in product development in semiconductors and in software in telecommunication technology is largely driven by lead markets.

In process technology in semiconductor technology and in hardware in telecommunications, the linkage of production with R&D is also a significant factor. In the pharmaceutical industry a clear distinction has to be made between pre-clinical and clinical research: the innovation dynamics in pre-clinical research are driven by scientific excellence, whereas in clinical research it is the lead market that is the driving force. The link of R&D to production is very loose in this case. The differences for the three technology fields are described more in detail in Reger et al. (1999).

3.2. Trends and motives for the international generation of innovation

The internationalization of research and technology consists of complex processes and encompasses three main types of activities. [11]

(1) The *international exploitation of technology produced on a national basis* includes exports, granting of licenses and patents, and foreign manufacturing of innovations generated in the home country.

(2) The *international techno-scientific collaboration* of partners in more than one country for the development of know-how and innovations, whereby each partner retains his own institutional identity and ownership remains unaltered. Actors here are enterprises as well as the academic world (universities, public R&D institutes).

(3) The *international generation of innovations* is mainly carried out by multinational enterprises, which develop R&D strategies to generate innovations across borders by building up internal research networks.

In the following, we have focused our analysis on the third type of activity, the international generation of innovations.

3.2.1. Trends in the international generation of innovation

The creation of technological knowledge in foreign countries has become an important part in the on-going trend towards internationalization. The international generation of innovations is mainly conducted by multinational enterprises, which develop R&D strategies to create innovations across borders. R&D and innovation activities which are carried out simultaneously in the home and host country, the acquisition of foreign R&D facilities and the establishment of new R&D institutions in the host countries, are all means to this end. In many cases, the company's R&D capacity at the home base does not decrease through the re-location of R&D abroad, but

[11] See Archibugi and Michie (1995).

through the dynamic growth of foreign R&D activities. [12]

The picture, however, is not unambiguous. The empirical evidence on the share and type of innovation activities conducted abroad and its significance to the home and the host country is still controversial, with researchers adopting different indicators, sources of information and analytical approaches. [13] Extensive research has been done on the geographical distribution of R&D expenditure and patenting, and the various types of overseas R&D laboratories. Certain research results are presented in this section, however, due to the lack of comparable data, it is not possible to draw a comprehensive picture.

There are empirical proofs that the internationalization of R&D is gaining in significance in a number of industrialized countries. Consider the trends in the US, which is the only country where time series on inward and outward R&D investment exist. Here, since the early 1980s, the extent of internationalization of R&D has slowly but surely increased, both in long-term research and industrial development. R&D investment of foreign firms in the US grew in real terms by 11.4% per year from 1980–1994, with a decrease in this growth rate since the beginning of the 1990s (1987–1993: 9.9% per year). R&D expenditures of foreign firms in the US are highest from the United Kingdom, Switzerland, Germany, Japan, France and the Netherlands, in that order (see Fig. 3). Hereby, foreign R&D in the US is heavily focused in some regional clusters, such as California's Silicon Valley (computer, semiconductors, software, biotechnology), Greater Los Angeles (diverse groups, auto design and styling centers), Princeton, NJ (drugs, chemicals, electronics, telecommunications), Research Triangle Park, NC (biotechnology), Boston area (computer, biotechnology), and Detroit (automotive industry). [14]

The growth and the extent of inward foreign investment in R&D varies considerably by country (see Fig. 4). In the US, R&D spending by foreign companies began to grow rapidly between 1987 and 1993, from US$6.5 billion to US$14.6 billion, reaching 15.3% of total industrial R&D expenditure. Other surveys show that in that same year (1993), the share of foreign R&D was almost similar for France, Germany and Sweden (15.2%, 15.9% and 14%, respectively), but was significantly higher in the UK, Spain and Ireland (25.8%, 50% and 68%). In Japan, only 1.3% of R&D was funded by foreign companies.

Several surveys have also produced data showing the extent to which firms invest in R&D abroad, and although they are not fully comparable (applying to different years or firm samples, for instance), the data show a rough similarity between inflows and outflows of corporate R&D investment for Japan and Germany (see Fig. 4). The US attracts more R&D investment from abroad. For Sweden, however, the outflow of R&D investment is roughly twice and for Finland three times the inflow. Swiss companies spend about half of their R&D budgets abroad, whereas approximately 7% of R&D in Switzerland is invested by foreign firms. On the

[12] An example of the stronger growth of foreign R&D activities is the German corporation Siemens. In 1993, Siemens' share of R&D personnel employed abroad amounted to 28%; in the period from 1989 to 1993, its number of R&D employees abroad went up by 60% and its R&D employees in Germany by 6% only (see Reger, 1997, p. 214).

[13] The generation of innovations in foreign countries can be roughly measured with R&D expenditures of companies abroad (input indicator) and the patents of companies first applied abroad (output indicator). Regarding the indicator R&D expenditure, the problem is that, with the exception of the USA, there are rarely data or time series available for each country. However, time series can be constructed by patent analysis. Each patent can be related to the country of invention (the inventor) and the home country of the corporation in which the inventor is employed. The main difficulty in using the primary data at the company level is that many patents are granted under the names of subsidiaries and divisions that are different from those of the parent companies, and are therefore listed separately. Generally speaking, the use of patents as indicators is subject to certain limitations, which have to be borne in mind when collecting information in the field of applied technological research and industrial development (on this aspect, see e.g., Schmoch, 1990; Grupp, 1997). Nevertheless, specialist analytical procedures can minimise the influence of undesirable effects of this kind. Over the last few years, so much positive experience has been gained with patent analyses worldwide that the OECD recommends patent indicators in one of their manuals as an important instrument in the analysis of research and development (OECD, 1994).

[14] See Dalton and Serapio (1995), p. 20.

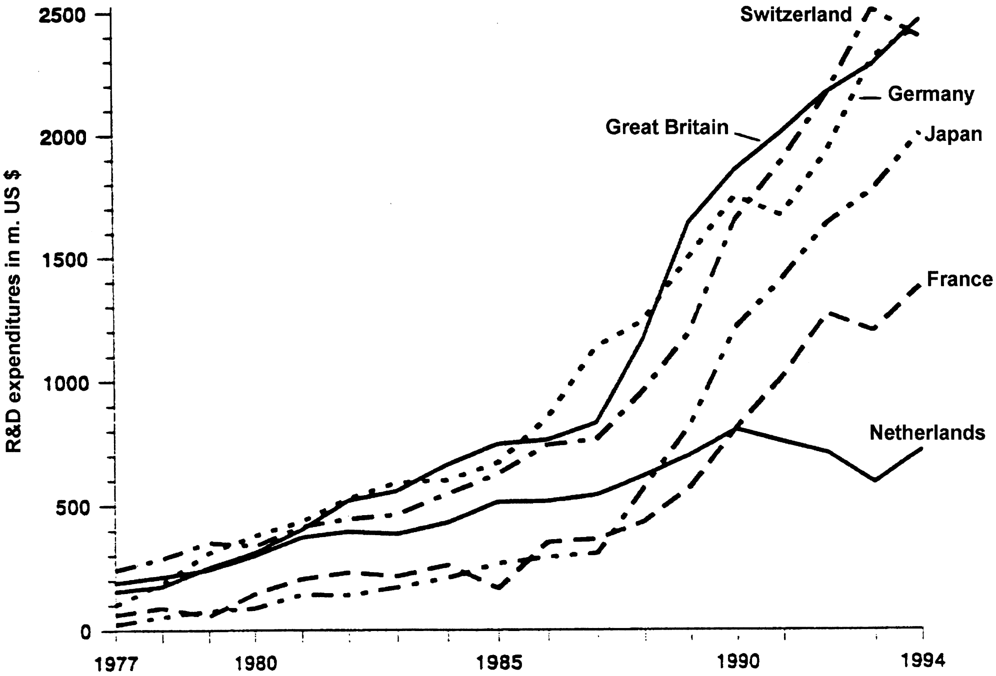

Fig. 3. R&D expenditures of foreign firms in the US, 1977–1994. Source: Beise and Belitz (1997) acc. to data from the US Department of Commerce.

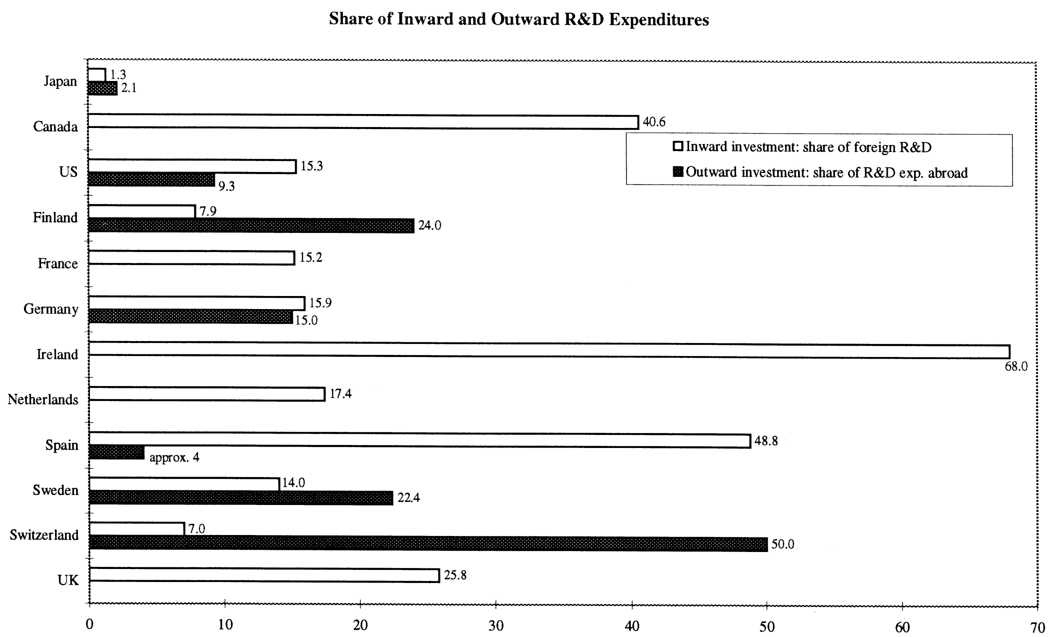

Fig. 4. Inward and outward R&D investment of selected countries. Source: Data from country surveys, see CEC (1998).

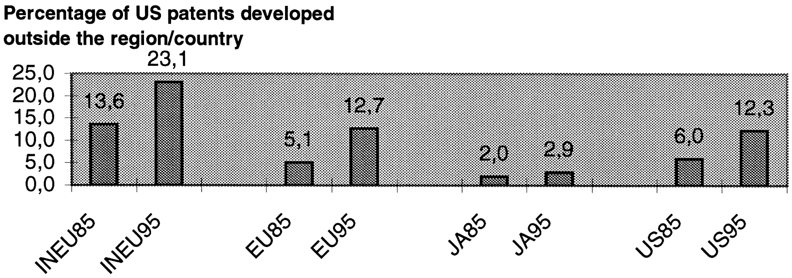

Fig. 5. Percentage of US patents developed outside the region or country. Source: CEC (1997).

other hand, in Spain, R&D activities of Spanish firms abroad are less developed (approx. 4%), whereas nearly 50% of industrial R&D in Spain is conducted by foreign-owned companies.

As the following Fig. 5 shows, regarding the Top 500 Global Fortune companies, there has been a dramatic increase in the number of US patents developed abroad, within Europe, and for each region of the Triad Europe, Japan and the US between 1985 and 1995. Perhaps the most significant aspect for Europe is the dramatic growth in European inventions that are developed outside Europe (growth rate of 149%) relative to intra-European development (70%). The growth of US patents applied abroad by either the US corporations (105%) or Japanese companies (45%) are lower for the same time period. [15] The imbalance of inventions, unfavourable for Europe (generated in the home country vs. abroad) indicates a pattern of inventions by large European companies being developed more and more outside the Community. The generation of *intra-European* innovations is losing importance for large EU firms, compared with the creation of *extra-European* innovations. At the forefront of this development are large companies from France, Germany and the UK (but also Italy, the Netherlands and Switzerland) which invest significantly more in innovation-generating activities in the US than in other European countries.

Although innovative activity is no longer restricted to the Triad, the generation of innovations is heavily concentrated in the three blocs US, EU and Japan. [16] Again, this confirms that internationalization or globalization is still a process of 'Triadization'. Despite the complexity of the internationalization processes, certain general characteristics can be discerned in corporate R&D internationalization in the Triad, results which are confirmed by our own interviews in 21 multinational corporations: [17]

- *Japanese firms* have the least 'internationalized' structure of R&D activities: only 2% of the US patents of the largest Japanese companies are applied for abroad. Corporations such as Sony, Sharp, Hitachi, NEC and Mitsubishi all spend less than 10% of their R&D budgets abroad, Kao and Matsushita Electric spend only slightly more than 10% of their R&D investment abroad.
- Large *US companies* also perform a high proportion of their R&D activities at home (more than 90%, measured in patenting). There are two distinct types of US enterprises. For instance, IBM is highly internationalized. UTC, on the other hand, is representative of the greater part of American firms, which are strongly domestic in their orientation. However, the United States is an important location for innovative activities for most large European firms.
- The R&D activities of the largest *European companies* are internationalized to the highest degree (22.4% abroad, measured in patenting), especially in

[15] These data on the Top 500 Global Fortune companies from the Second European Report on S&T Indicators (Commission of the European Communities, 1997) show that large European companies have developed 12.7% (EU 95) of their US patents outside the European Union, US firms 12.3% (US 95) and Japanese companies 2.9% (JA 95) in 1995.

[16] At an aggregate level, about 90% of the technological activities (measured by patents) are hosted by the US, Western Europe and Japan (see Cantwell, 1995; Patel and Vega, 1997).

[17] See Gerybadze et al. (1997), p. 34.

the consumer goods, chemicals and pharmaceuticals, process technology, and electronics sectors. Most of the R&D activities of these large European firms are located in the US.

Within Europe, the degree of internationalization varies considerably. To a great extent, the participation of the Community in the internationalization of research and technology is an uneven process, because there are considerable differences among member states. Thus, both the role as a home for international expansion and as a host of foreign R&D labs are mostly concentrated in a few countries—mainly Germany, France and the United Kingdom. According to Warrant (1991), these three nations account for 77% of European R&D labs outside Europe and for 60% of foreign labs established in Europe (nearly 70%, including the Netherlands). On the contrary, in this study Spain and Portugal had no R&D establishment abroad [18] and accounted for only 2% of those operating in Europe (5.3% including Italy). Within the Community, three main clusters of countries—which are related to the companies' strategies—can be identified:

- *Small, highly developed European countries* like Belgium, Sweden or the Netherlands (also Switzerland), where global players perform up to more than half of their R&D activities outside their home country. These countries have a relatively small pool of domestic R&D resources; firms therefore invest heavily in the international generation of innovations (for instance, Philips from the Netherlands, Solvay from Belgium, ABB, Nestlé, Novartis or Hoffmann LaRoche from Switzerland). One notable exception are large Austrian firms, which conduct only 14% of their technological activities abroad.
- *Large European countries* with large technology bases and markets, like Italy, Germany, France and where 'their' multinationals perform between one-fifth to one-third of their R&D activities abroad. Still, many large enterprises in these large European countries, particularly in the machinery, transportation, and electrical engineering sector, tend to concentrate a significant part of their research in the country of origin (e.g., Bosch, Daimler-Benz, Siemens). Large British firms can be considered an exception to this pattern, with nearly 50% of their R&D activities abroad. Another exception is the pharmaceutical sector, in which firms are investing heavily in foreign R&D (e.g., Hoechst Marion Roussel, Bayer, Rhône-Poulenc Rorer, Glaxo Wellcome).
- *'Intermediate countries'* like Spain, Portugal or Ireland participate somehow differently in the new international division of labour. These countries lack well-equipped technological infrastructures and resources and are characterized by high foreign inward R&D investment and very low outward R&D investment. On the one side, multinationals contribute to a quantitatively and qualitatively high extent to the technological efforts of these countries. On the other side, there is, firstly, a considerable number of innovative domestic companies which do not internationalize (neither via exports nor FDI). Secondly, most domestic firms operating in international contexts use exports as the basic and almost unique way of internationalization.

3.2.2. Motives for the international generation of innovation

The motives for establishing R&D units abroad and the main factors in selecting locations have been examined in various empirical surveys. [19] These emerge mainly as market characteristics (size/attractiveness of foreign market, combined with the need to adapt product variants to country-specific situations) and specific location determinants (desire to access a local talent pool). Most of these studies, however, are driven by factor cost and availability considerations related to the R&D function. Our interviews and more recently published papers emphasize the knowledge- and innovation-generating capacities of particular locations, and the dynamic interaction between R&D, lead markets and advanced manufacturing. When deciding to establish or expand R&D abroad, firms are motivated by the wish to gain access to highly sophisticated resources

[18] However, these data have to be interpreted with care: Warrant's study deals only with the largest 151 industrial groups of the world, in which only one Spanish group is included.

[19] On this aspect, see particularly the overview in Cheng and Bolon (1993) and also Teece (1976), Ronstadt (1977), Mansfield et al. (1979), Lall (1980) and Kogut and Zander (1993).

which cannot be found anywhere else, and to learn about specific customer requirements, market and production constellations on the spot. In our survey, the following motives for the on-going international generation of innovation and foreign R&D investment were given particularly often:

1. access to leading research results and talents,
2. presence on-the-spot, learning in lead markets and adaptation to sophisticated customer needs,
3. initiation and strengthening of R&D at locations where the effects of greatest usefulness can be expected and the highest cash flow is generated,
4. monitoring and taking advantage of regulations and standardizations,
5. support of production and sales on-the-spot by local R&D capacities.

Thus the primary motive and aim of the internationalization of R&D is not—as it has been in the past—the simultaneous maintaining of several globally 'dislocated' R&D units, but the internationalization of learning processes along the whole of the value-added chain (research, development, production, marketing/sales, service relations, embedding in supply and logistic networks). The decisive parameter for the intensity of transnational learning and innovation processes is the proportion of value added within the corporation constituted by the generation of knowledge.

In areas where the dynamics of technological change are weak and/or where there are no substantial synergies between product- and production-related knowledge, R&D locations and production locations may well become disassociated. On the other hand, for certain types of strategies—particularly in highly dynamic fields—the close linkage of both locations is important. Under certain conditions, all three functions (market, production, R&D) may even coincide in one location. In the latter case, both from the viewpoint of the investing enterprise and of the location being invested in, only those projects and development strategies can have a sustained and really positive impact, in which functioning high performance units are established along the whole length of the value chain. Under these conditions, R&D laboratories are set up primarily where the best conditions are to be found worldwide, both for research and also for the transfer of its results. These R&D units are part of a functioning cycle in the host country, and at the same time are embedded in a highly effective network of transnational learning.

3.3. The new logic of internationalization of R&D

3.3.1. Establishing worldwide centers of competence in R&D

Whereas the 1980s were a period during which the internationalization of R&D was associated with decentralization and the 'dislocation' of activities, the 1990s are characterized by a continuing trend towards internationalization, accompanied by concentration, focusing and strategic emphasis. International enterprises that are leading performers of R&D are pursuing the strategy of a presence with R&D and product development at precisely those locations where the best conditions prevail, worldwide, for innovation and the generation of knowledge in their product segment or field of technology. They are no longer satisfied with locations which 'just about keep up' with the global technology race; they deliberately seek out the unique centers of excellence.

Although the majority of large international enterprises performing R&D are still following the strategy of keeping the competence base for their core technologies in their country of origin, processes of re-thinking are in progress. The dynamics of change in this context are dependent on global technology strategy on the one hand and, on the other, on the size and the resource base of the country of origin. The largest Swiss chemical firms internationalized their R&D earlier, and to a much greater extent, than for instance, the German ones. Thus within a branch or product segment, a broad distinction can be made between two patterns: in corporations with a strong research and market base in their country of origin, units abroad mostly continue to have only scanning and exploration functions as well as tasks of applications development (this is true particularly of enterprises originating in Japan, in the USA, and in Germany with the exception of chemicals/pharmaceuticals). Compared with these, corporations with a less developed research and market base in their country of origin have come to occupy a 'vanguard' role in internationalization. In corporations with their headquarters in Sweden, the Netherlands or Switzerland, and also in some individual enterprises from the large industrialized countries, R&D activities are increasingly being shifted to centers of excellence abroad, and the idea of concentrating ‘core technologies’ in centers of competence abroad is also definitely being considered.

Even in large international corporations, this worldwide focusing strategy and formation of centers is associated with considerable adaptation measures in organization and management. The absorptive capabilities of an organization, which enable it to draw sustained benefit from centers of excellence abroad, depend on whether the enterprise itself has concentrated enough competence on the spot, and whether it provides support from headquarters in the form of resources and decision-making competence. Despite their growing importance in terms of R&D expenditure, R&D units abroad in many enterprises still do not receive sufficiently strong strategic support and are sometimes inadequately coordinated. In the 1980s, the linking of internationalization with decentralization led to duplication of tasks, to R&D units lacking the ‘critical mass’ of resources and capacities, and to disputes about competency. From these experiences, transnationally oriented enterprises are now going over to consistent, cross-corporate technology management (e.g., ABB, Philips, Hoffmann-LaRoche, Hoechst). This generally also implies that the core activities of their R&D are concentrated as far as possible in one place and assigned as clearly as possible to responsible groups and locations.

The outcome is that this development leads to the fixing of just one center as a ‘leading house’ for one specific product group or technology within a corporation, as far as possible. In view of this, the competition between national innovation systems will increase. For allocation decisions in R&D, this change of direction implies that excellence of a national research system, although a necessary prerequisite for these decisions, is not in itself a sufficient condition. Conditions that have to be satisfied include particularly the presence of lead markets, in the case of radical innovations (cf. Table 3). With incremental innovations, it is mainly a case of building up local R&D capacities for the support of production and sales.

Table 3
Orientation of R&D according to degree of innovation

R&D	Incremental innovation	Radical innovation
Global	Development of equal parts	Centers of excellence and lead markets
Local	Adaptations to local/national conditions	Dissemination of start-ups

Source: Gerybadze et al. (1997).

3.3.2. Need for the use of different types of coordination mechanisms

Following an initial phase of over-enthusiastic decentralization of R&D in the 1980s, growing problems of coordination led to disillusion and the increasing formation of centers in a global context. At present, many multinational enterprises are experimenting with various mechanisms for steering and integration, with the aim of creating synergies worldwide and avoiding the duplication of tasks. It can be regarded as certain that, to coordinate geographically dispersed R&D activities, an intelligent set of mechanisms is needed which must be combined as effectively as possible. Whereas the Japanese enterprises investigated place the emphasis on personal contacts, informal communication and socialization, combined with a centrally dominated decision-making process, the western European enterprises in the survey mainly rely on contract research for the divisions and daughter companies as a coordination mechanism (see Reger, 1997, 1999 for a detailed analysis). The importance of informal instruments and the formation of a corporate culture is often underestimated, especially in the western European enterprises investigated.

Particular importance is attached to the use of ‘hybrid’ coordination mechanisms (such as multifunctional, interdisciplinary projects, strategic projects, technology platforms, core programmes and core projects). The novel aspects of these coordination mechanisms are that they cut across—or overlay—organizational and hierarchical structures, and that they foster direct communication between people involved in the innovation process. These ‘hybrid’ coordination mechanisms are often used for the simultaneous coordination of several different aspects—for instance, the integration of R&D strategy with the business strategies, integration of the business functions of R&D, production and marketing, as well as ensuring synergies between various areas of technology.

Manifold requirements for coordination also exist in public research systems. In this context, it can be observed in several countries that the development of new, flexible types of coordination mechanisms is not nearly so advanced in the public research systems as it is in the enterprises investigated. Several approaches, some of them newly developed and some already tried and tested, can also be transferred in adapted form to meet new networking needs in the public research system. This particularly applies to hybrid and informal coordination instruments, which can be used to form networks between various different levels and types of actors.

3.3.3. Management of corporate research and new businesses

In the transition from the first generation of R&D management (dominance of central research) to the second generation (divisionalization, subordination of research to divisional interests), most large international enterprises substantially weakened their basic research in the course of the 1980s. At the beginning of the 1990s, the third generation of R&D management tried to achieve a kind of synthesis (simultaneity and equilibrium of group development and basic research, formation of portfolios). Our empirical investigations in the 21 enterprises show, however, that third generation management of R&D is causing problems in all the enterprises to a greater or lesser extent, and that up to now various models have been experimented with, all of which have to be regarded as 'second best'. Some examples here are:

- Linking corporate research through a high proportion of contract research (up to 90% of the budget of corporate research) and joint strategic technology planning to the business units.
- Full integration of parts of corporate research into the strongest division and 'spinning off' other parts as a 'contract research company' for external customers.
- Liquidating corporate research labs and full decentralization of R&D activities towards the responsibility of the divisions or business groups.
- 'Enrichment' of the internal research activities through partnering, R&D cooperation, technology alliances or contract research done by 'suppliers'.

Japanese corporations are particularly consistent in the way they open up promising future areas that require many years of preliminary research. A new research laboratory with a clear mission is set up in a foreign country, well-equipped in terms of staff and financial resources. As soon as a topic shows promise of becoming marketable, the laboratory is affiliated to an existing division; and the new technology is used for the expansion of existing fields of business. Alternatively, the laboratory forms the nucleus for a new division, if the enterprise has not previously been active in the relevant market. Several good examples of this establishing of research laboratories abroad, and the subsequent founding of 'spin-offs', can be found in Canon, Sony, Sharp or Matsushita Electric.

In any case, it can be stated that the enterprises questioned are trying to establish a balance between central research and development in divisions or business groups; no 'best practice' for this has been found so far. In the Japanese enterprises investigated, excellent use is made of basic research abroad as an instrument for opening up promising fields of business in the long term. This example does not only demonstrate the importance of 'worldwide technology sourcing', but also shows that judicious linking and embedding in the research systems of other countries is a necessary practice. Thus enterprises and research institutions, in their efforts to achieve a stronger international presence in this way, will necessarily enter the orbit of national or European technology policy.

4. Consequences and issues for technology policy in Europe

As a general result of this situation, the premise of national science and technology policy, encountered in many countries, that the main benefit from the public allocation of resources in this policy area flows into the national economy is progressively dissolving. Not only the know-how produced in the national innovation system, but also other public investments, for instance in training and education, are increasingly being swept into the stream of the international exchange of knowledge. This development enlarges the focus of policy: it is not simply the appropriation of nationally generated knowledge that is involved, but the strengthening of a generally beneficial, interactive transnational exchange of knowledge. It is possibly as important to absorb knowledge that has been generated worldwide, as it is to support the production of knowledge in one's own country. This statement is very important for technology policy on the national as well as the European level.

The main implications which we draw from the analysis of the changes of the innovation strategies of large multinational corporations are built around the following areas: [20]

- strengthening the European absorptive capacities and cooperating with non-European countries
- attracting innovative companies from non-European countries
- lead markets and learning for the mastery of complex innovations
- integrating different policies towards an innovation policy in Europe.

4.1. Strengthening European absorptive capacities and cooperating with non-European countries

The European Union is no longer (if it ever was) *the* knowledge-producing region; more and more knowledge is produced outside Europe. This concerns technical inventions and innovations, as well as best practices and innovative approaches to new organizational and managerial forms for the generation of innovation, production, diffusion, and exploitation. With the growth of new world centers of technological activities in other regions (especially in Asia), the economic and social welfare of the European Union will increasingly depend on the ability of the organizations in Europe to assimilate knowledge and techniques developed elsewhere in the world. In this respect, the absorptive capacities of large and small enterprises as well as of public R&D institutions within the Community are decisive for innovativeness and competitiveness. Further, it will be of growing importance not just to know what to do, but even to know how to do it. The assimilation of knowledge and techniques distributed worldwide should include all skills which are related to technology and innovation (e.g., education, vocational training, management, organization, financing).

Large and multinational companies have more resources and capabilities to realize these opportunities. In contrast, the absorptive capacity of SMEs is often regionally limited to the home country or the European market. However, looking to the Single Market will not be sufficient for the future. The structural differences between large multinationals and SMEs will grow. All in all, the absorptive capacities of the actors in the national innovation system is becoming more important, i.e., the ability and speed with which they can absorb knowledge produced worldwide and transfer it into innovations. The ability to open up fields and markets for the application of new knowledge and new technologies by rapid learning is decisive. This argument is in line with other research on the 'learning economy' (see Lundvall and Barras, 1997 and the TSER projects mentioned there).

Although it may be controversial whether public technology policy includes supporting internationally active firms in attaining these goals, it should be convincing to suggest that at least R&D institutions should be motivated and supported in their efforts to achieve a stronger presence and better integration into worldwide research networking and transfer. This implies that the 'absorptive capability' of national innovation systems is becoming more important, i.e., the ability and speed with which they can absorb knowledge produced worldwide and pass it on to enterprises. The ability to open up fields and markets for the application of new knowledge and new technologies by rapid learning is decisive.

As an example, the efforts of the German Fraunhofer Society (FhG) to become active 'on-the-spot' in other countries can be cited. Thus, for instance,

[20] See also the recommendations of the ETAN Working Group on 'Internationalisation of Research and Technology: Trends, Issues and Implications for S&T Policies in Europe' (Commission of the European Communities, 1998) to which the authors contributed as chairman (Frieder Meyer-Krahmer) and as rapporteur (Guido Reger).

the FhG is attempting to link up with the 'scientific community' in the United States in the area of graphic data processing—a field in which the US is the recognized world leader in research—where it is trying to achieve the position of a seriously regarded partner. By contrast, in the area of production technology, particularly lasers, the FhG is rather pursuing the aim of presence in a market which is of increasing global importance for FhG services. The FhG has now also intensified its activities in South East Asia, where it is treading new ground by taking on the role of an international 'broker' between technology supply and demand.

The statements made above refer to national innovation systems, but what do they mean in the context of European technology policy? R&D networking between different institutions in Europe has been supported by the European Framework Programme for Research and Technological Development (RTD) since the beginning of the 1980s. Until the early 1980s, science and technology policy in Europe was dominated by national programmes. The role of the European Commission in S&T was limited to nuclear research, supported by the Euratom Treaty of 1957. After the early 1980s, various Framework Programmes were set up and again given civil legal support by Title VI of the 1987 Single European Act. The focus of most of these research policies developed, implemented and monitored by the European Commission was primarily directed towards programmes to overcome the fragmented, national structure of European industry and markets. However, it is only fair to say that up until now no European 'national system of innovation' has really emerged. [21] On the contrary, the European policy measures were often simply added to existing national and regional institutions and instruments.

The so-called 'Impact Studies', which evaluated the Second Framework Programme in most member states at the beginning of the 1990s, concluded that in the highly industrialized EU members the Programme succeeded in integrating researchers in Europe to a certain extent across institutional, sectoral and national borders into a 'European science and research community'. However, the German impact study came to the conclusion that the European integration in S&T has developed so far in certain areas that an R&D cooperation with non-European countries is required. [22] This is true for industrial S&T cooperation: large German multinationals, especially in the electronics, information and communications sector had already succeeded in 'their' European integration at this time, and R&D cooperation with the US and Japan has gained more and more significance from their viewpoint.

Since the mid 1980s subsidiaries of non-European companies established and performing R&D in Europe can participate in the Framework Programmes on the same basis as European firms. For organizations without a Community base, nationality plays an important role. From the mid 1980s international cooperation (with third countries outside the Community) was built into the structure of the Framework Programme. The 4th Programme promoting international cooperation (INCO 1995–1998) has had a budget of 575 MECU, 86% of which was shared in cooperation with central and eastern European countries and developing countries. Organizations from countries which have a bilateral S&T cooperation agreement with the Community can participate in all programmes, provided that it is in the interest of Community policies. In 1995 and 1996 there were over a thousand reported new participations by third countries in short-listed proposals submitted to the Framework Programme (excluding cooperation in nuclear research programmes). According to sources of the CEC, over half of these participations were by researchers from Switzerland, while the US and Canada accounted for some 6%. While the S&T policy of the European Community is confirmed towards an international dimension, it has in the past focused de facto on western, central and eastern Europe.

[21] See Caracostas and Soete (1997).

[22] 'Community policy in future will have to promote not only R&D cooperations within Europe, as it has done until now, but will have to specifically envisage the support of cooperation with partners in the 'Triad' (USA, Japan) and with developing regions' (Reger and Kuhlmann, 1995, p. 183).

If one considers the dramatically increased needs and possibilities for rapid and international cooperation and information exchange, this de facto *intra-European* focus needs a more extended complementary extra-European focus than was developed in the past. This is especially necessary in areas where other countries are much more advanced in leading-edge research and in lead markets (like e.g., in pharma/biotechnology, where Europe is lagging behind the US) or in areas where a global collaboration is required (e.g., sustainable development, environmental protection). [23]

However, the support for *intra-European* S&T networks is still essential for those areas where European competences are strong or can be combined to a unique worldwide center of competence. Further, participation in the RTD Framework Programme is still of great value for locally rooted organizations (esp. SMEs), for which this is very often the first step towards cross-border technology-related cooperation. This argument is even stronger if these actors are from less developed or intermediate countries.

In this respect, strengthening absorptive capacities and cooperating with non-European countries means for European technology policy to support the international activities of public R&D institutions and enterprises and to foster *extra-European* R&D cooperation and knowledge exchange in areas with a clear global perspective. The following instruments may be useful to fulfil this task of extra-European collaboration and exchange:

- monitoring/screening: identifying areas with a need for extra-European collaboration and knowledge exchange, monitoring R&D and innovation strategies of firms and networks/consortia
- supporting the 'brokerage function' of public research institutions, to support the international exchange of technology supply and demand
- establishing international training/education and research programmes
- fostering the international mobility of students and scientists as well as encouraging researchers and students from abroad to come to Europe
- supporting the presence of public R&D institutes in non-European countries (joint ventures with other R&D establishments, research teams or 'virtual institutes' on a temporary basis)
- supporting enterprises in their efforts towards a stronger global presence in R&D (including the acceptance of this strategy)
- promoting transnational R&D projects with participants from European and non-European countries
- fostering transnational cooperation based on 'option-sharing'. [24]

4.2. Attracting innovative companies from non-European countries

The discussion on regional locations is often suggestive of the notion of defending a European or national fortress (the stronghold of the nation or Europe as a location for industry) while extending, in a one-way process, the possibilities of its industrial subjects to conduct their business in other, non-European countries. However, internationalization is forcing the course of events in another direction: it implies a mutual opening-up and 'penetrability' of

[23] Our conclusion is confirmed by a recent paper which aims at transferring insights of seven on-going TSER projects (Lundvall and Barras, 1997, p. 6): ''... given the high rate of change, networks that are geographically closed may, in the long run, hamper rather than stimulate innovation. (...) The experiences from ESPRIT and the general weak state of the European electronics industry point to the need for extra-European networking. Industrial districts may need stronger interaction with external parties in order to avoid lock-in into stagnating product areas. This implies a role for public policy in promoting the internationalisation of firms and the positioning of big European firms in global networks.''

[24] The notion of Kodama (1997) may be of interest here: Since technological development may follow a particular trajectory, all or most R&D activities may focus on one class of technologies and no attention is paid to other classes of technologies. A national innovation system might be locked into paths that are not globally optimal. In order to break up this lock-in, international cooperation can divide up the investments and responsibilities for pursuing each possible scientific or technological option. In this respect, option-sharing might give the opportunity to pursue all potential options through global cooperation. In areas with high R&D investments this cannot be done by a single country.

legal and economic frontiers, of science and research systems, mobility of people, cultures, organization and management systems. A pro-active European technology policy will therefore also open up to enterprises and (public) R&D institutes from non-European countries.

A considerable number of foreign enterprises are actively performing research and development in the European Union—some of them in their own R&D laboratories. The idea of the science system being opened up to foreign enterprises, or foreign research establishments being set up, is frequently associated with the fear that antennae are simply being installed to 'siphon off' accumulated knowledge of the Community. These enterprises and establishments are considered with reservation, since there are fears of a one-sided drain of science and technology to headquarters abroad. It is feared that the 'knowledge and technology drain' may take place without there being any positive impacts for Europe, and that in the long term it will serve only to enhance the innovativeness and competitiveness of foreign rivals. However, it is not so much the geographical situation of the parent enterprise that is decisive for the impacts, as what type of R&D activities, which production capacities and services are located in the host country (e.g., autonomous research versus local antenna, highly skilled manufacturing as opposed to the 'extended workbench').

There is still a lack of clarity regarding the impacts of foreign R&D units on the European, national or regional location. However, the decisive factor is probably not the ownership situation so much as the willingness of foreign enterprises to establish the whole value chain, including research and development. A few US studies have shown that the R&D performed within a national economy is increasingly exploited worldwide, so that the idea that European (or national) technology policy primarily causes positive effects in Europe (or in the nation) is no longer applicable. A stronger inclusion of foreign enterprises into European technology policy is thus inevitable in the end, and the issue at stake is to shape this process as usefully as possible. Japan, for instance, supports the presence of industrial R&D in its own country. 'Useful' in this context implies the generating of as many spill-over effects as possible within the region. The involvement of Sony, for example, in regional DAB (Digital Audio Broadcasting) pilot projects in Germany is leading to a build-up of high-grade R&D capacities around already established production facilities.

With the help of a matrix, the R&D activities at the location can be subjected to a first evaluation (cf. Fig. 6). If both the autonomy and the competence of the local R&D are low, it can be described as a 'local antenna'. Local antennae monitor the newest technological and market trends and transfer information to the corporation's country of origin; such transfer is *one-way* (Case 1). If autonomy is low, but competence is high, the R&D management is characterized by centralization of the decision-making process (Case 2). Although R&D activities are carried out autonomously, the appreciable domestic spill-over effects will probably be only moderate, due to the centralized decision-making. If autonomy from headquarters is high, but competence is low, knowledge tends to be exploited on-the-spot (Case 3). This type of R&D is usually associated with production-supportive technology centers and the exploiting of local market chances. If the competence and freedom of decision of the local R&D unit are both high, the unit is a center of R&D competence which also contributes to integrated transnational R&D activities. In this case (Case 4), it may definitely prove useful to include it more strongly in European (or national) technology policy. With regard to cases (2) and (3), the advantages and disadvantages more or less balance out; in case (3), at least, gains in competence can lead to positive development into a real, leading R&D center within the corporation, which is also beneficial for the location.

Two reports were submitted recently to the Federal Ministry of Economics, in the course of regular reporting on the structure of industry. The study by the HWWA-Institut für Wirtschaftsforschung (1995) comes to the conclusion that the internationalization of German industry (primarily with regard to production) implies a growing importance for industrial policy. With the internationalization of production increasing, improving the quality of locations would mainly mean improving the qualification and flexibility of the workforce, promoting investment and accelerating public decision-making. According to this report, the financial support for domestic enterprises (i.e., enterprises with their headquarters in

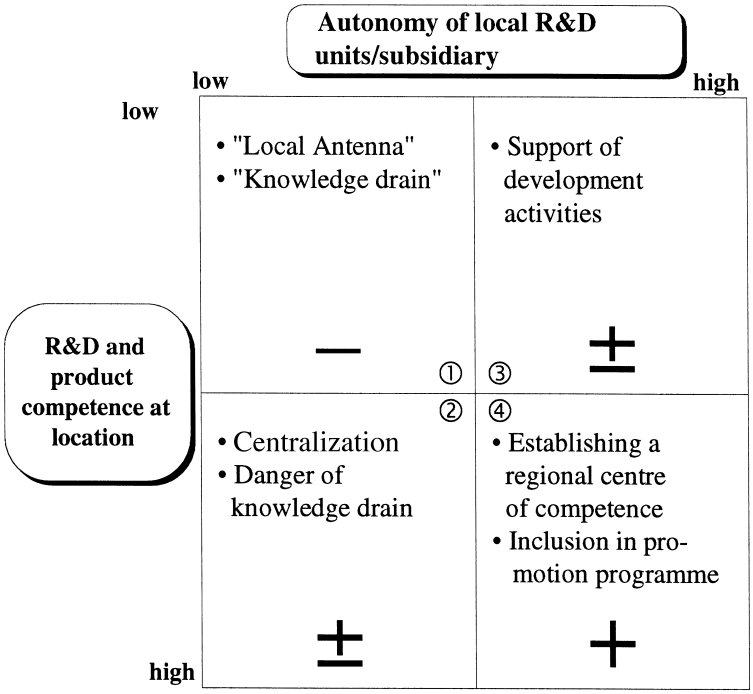

Fig. 6. Matrix for evaluating local R&D units.

Germany), including the public promotion of technology, are increasingly missing the mark, since it is not certain whether these measures will generate income in the national or regional locations.

With regard to this question of whether or not traditional technology policy is 'on target', our investigation reaches similar conclusions (e.g., on the subsidizing of R&D). However, it is precisely this circumstance which leads us to plead the case for a re-formulated concept of technology promotion, namely: to support both European R&D institutions and enterprises on their path towards internationalization and, at the same time, to gain foreign R&D institutions and enterprises for the European Union and, in both cases, to attain synergy effects and spill-over effects beneficial to the location. The fact that, on its own, technology policy will fall into an 'inadequacy trap' under these altered circumstances needs to be emphasized again and again. Technology policy is a strategic, interdisciplinary task, and the effectiveness and success of this policy will depend to a great extent upon whether it proves possible to establish internal networking in this field between policy areas which have previously been fragmented.

4.3. Shift from technology to market: the case of lead markets

Analysis of the innovation activity of transnational enterprises shows that they are increasingly thinking in terms of integrated process chains, and are not primarily transferring their value-added to places which provide the best conditions for research only. The demand side obviously plays a more important role in R&D allocation decisions than supply factors do. From a macroeconomic viewpoint, the central question is rather: 'Where will income be generated, where will benefits be felt and where will new resources be created?' than: 'Where will costs be created and where will existing resources be consumed?' In their transnational investment activities, enterprises are acting according to the following decision patterns: 'Where are the attractive, future-oriented markets in which users can be learned from, and which generate a sufficiently high return-on-investment for costly product development? Where can these markets be best served by highly developed production, logistic and supply structures? Where would it therefore be worthwhile to build up value-added in *one* place? In what countries do attractive markets, highly developed production structures and excellent research conditions coincide, so that innovative core activities can be concentrated there?'

In view of the strategic decision processes in transnational enterprises, the determinants and motives we have identified raise the following questions for technology policy in Europe:

(1) In what end-user markets is the country or Europe regarded as a trendsetter internationally?

(2) In what regions are production structures and supply networks so highly developed that high value-added can be secured as a location in the long term?

(3) What areas of research and technological development in the country or in Europe are at a leading level worldwide and can also induce effects of strengthening lead markets and production structures?

(4) Where is influence being exerted (through participation in research and standardization alliances, or in complex learning processes) on 'dominant technological designs' for innovations, which will subsequently bring lead advantages in the global innovation competition?

(5) What are the relative strategic importance of the country or Europe as a market, and as a production location, from the viewpoint of enterprises worldwide?

By creating effective links with these fields of competence and building up 'forward–backward linkages', it may prove possible to create high performance units with low transferability which are unique by world standards. Only by combining excellence in research with highly developed European lead markets, or by combining research with highly developed production structures, can the Community position itself as a location for core competences that are not readily internationally transferable.

An important new item of knowledge to emerge from our survey is the *significance of so-called lead markets*. But what are the characteristics of lead markets? They match one or more of the following criteria:

1. a demand situation characterized by high income elasticity and low price elasticity or a high per capita income
2. a demand with high quality requirements, great readiness to adopt innovations, curiosity concerning innovations and a high acceptance of technology
3. good frame conditions for rapid learning processes by suppliers
4. authorization standards that are 'setting standards' for permit authorization in other countries (e.g., pharmaceuticals in the US),
5. a functioning system of exploratory marketing ('lead user' principles)
6. specific, problem-driven pressure to innovate
7. open, innovation-oriented regulation and frame conditions.

The attractiveness of a country or Europe from this perspective is determined not so much by comparative, static competition factors such as costs and wages, as by its 'dynamic efficiency'.[25] This is largely dependent on the extent of social and organizational intelligence in the finding and acceptance of new structures and markets. Will complex system innovations be elaborated in Europe which will be used worldwide? Offensive learning through numerous field trials and pilot schemes for the finding of technical, economic, legislative and social solutions is important. Learning processes of this kind often take years. The system that first succeeds in mastering these complex solutions gives participating enterprises competitive advantages, and appears more attractive to foreign investors. The stipulation, fostering and organization of this European-wide learning process in the area of complex innovations (such as road pricing systems, closed-cycle economic concepts, European standards or platforms in I/C technologies, mobility/transportation) is one of the most prominent tasks of European technology policy. In

[25] Economic theory differentiates between static efficiency—relating to one point in time—and dynamic efficiency—relating to a long-term development. It is quite possible for static and dynamic efficiency to conflict with one another.

these cases the European 'value-added' will be extremely high.

4.4. Integrating different policies towards an innovation policy in Europe

All in all, it can be stated that internationalization is forcing European technology policy to re-focus technology promotion, orienting it towards the initiation of complex innovations with far-reaching effects in economic, legislative, social and societal domains. Here, too, it is the pace of learning and the mastery of new solutions that count. Not only leading-edge research, but the opening-up of new (lead) markets by anticipatory, future-oriented pilot projects is decisive for the international attractiveness of the Community ('keeping ahead in the learning race'). The target group for this European technology policy has altered: research-driven enterprises are engaging in a change of strategy and are giving more consideration to the conditions of lead markets and production networks. Technology policy will scarcely be able to avoid following this change.

For this reason, successful R&D locations have particularly good chances of inducing economically positive impacts, e.g., on employment, if they coincide with production and market locations. Technology policy *on its own* cannot constitute a policy strategy promising success, this is an inherent dilemma. Thus the results of our study underline the necessity—much called for, but not as yet fulfilled—for better networking between different policy areas. Insofar as they influence science and technology, these include:

1. fiscal framework conditions for the formation of venture capital
2. phasing-out of subsidies that preserve the status quo
3. public investment and procurement
4. regulation and approval procedures that relate to specific results and not to specific techniques
5. active policy to promote competitiveness (e.g., creating less regulated, more competitive markets, strengthening competition law)
6. improvement of corporate governance, i.e., the relations among firms and their various resource suppliers (corporate law, securities and investment rules, stock market regulations, accounting standards and tax regimes)
7. case-by-case coordination with specialized departmental policies, where appropriate, such as transport, health, environment, etc.
8. integration of policies such as education and training, labor relations and mobility, foreign trade, economic and industry policy.

To match the ever-increasing international demand for complex innovative and high performance units or networks, lateral structures essential for their formation have also to be called for in policy. Examples for this at the European level are the task forces initiated two years ago under the 4th Framework Programme, industrial platforms in life sciences or joint calls for proposals between programmes.

Experiences from companies and national or European policy-making can be used to develop these organizational forms further when generating and shaping new policy structures. In large companies, different forms are used to coordinate various business functions, different areas of technology and corporate strategies or sub-strategies. One example is the use of strategic projects to establish, at a European level, networks of non-transferable tasks, involving task-sharing by firms and institutions from each of the three steps of the value chain (R&D, production, lead market or final use). Strategic lead projects organized at a public level can help to attain the necessary 'critical mass' and build up promising new networks of competences. Difficulties in applying these coordination mechanisms lie in the details. Policy-makers of the European Commission should carefully evaluate own experiences (e.g., 'Inter-programme Coordination Group' or the 'Task Forces') and definitely draw on the experiences of large corporations in the use of these instruments. The following examples, drawn from the wide-ranging set of coordination instruments, illustrate possible applications.

(1) Interdepartmental 'core projects' offer, like 'task forces', a means of focusing EU funds on specific trans-disciplinary topics that cut across technology-specific units/departments and the technology-specific programme lines of the RTD Framework Programme.

(2) Qualitatively improved networking between policy, industry and science can be achieved through

systematic 'job rotation' of personnel in these three areas, offering career incentives.

(3) Strategic lead projects or technology/innovation platforms can serve for the selective, temporary integration of various Directorates General, companies and public R&D institutions in topics that are strategically important for the European Union.

Lateral structures reflect the holistic, learning view of the (international) innovation process. The advantages are their temporary limitation, direct communication across functional, departmental or institutional borders, integration of relevant persons, problem-solving orientation, and the creation of direct responsibilities. [26]

5. Summary: need for a change in technology policies in Europe

Due to the complexity and heterogeneity of the field, this contribution is necessarily selective and limited. Further research and analysis is needed, but nevertheless, in summing up our analysis, we can conclude the following.

Firstly, the internationalization of research and technology is still characterized by 'Triadization' involving companies from the US, the European Union and Japan. Companies from other countries, especially from South East Asia, are becoming slowly yet increasingly involved in this process. European firms are highly internationalized in research and technology, and interested in an increase of international technology alliances and international generation of innovation beyond intra-European limitations.

Secondly, qualitative factors and dynamic up-stream and down-stream interactions are increasingly driving R&D location decisions. Thus the motives and aims underlying the international generation of innovation do not relate primarily to exploiting the cost advantages of globally distributed R&D units, but emphasize more the value-added effects of transnational learning processes along the whole value-added chain (research, development, production, integration into supply chains and logistic networks, marketing/sales and services relationships). The motives for establishing R&D units abroad are very much driven by learning from technological excellence *and* lead markets *and* dynamic interactions between R&D, marketing and advanced manufacturing. The attractiveness of the European Union will be more and more determined by 'dynamic efficiency', the ability to support learning processes in complex system innovations, and the interaction of specific institutions (firms, R&D institutes, universities, policy administration).

Thirdly, R&D-intensive companies are undertaking far-reaching transformations of their R&D activities. For many of these companies, the process of internationalization in research, product development and market introduction has been accompanied by an increasingly selective focus on a very few R&D locations and the concentration of innovation activities at so-called first-class centers. Following this argument, the intensification of global competition increases the importance of the role of regional conditions. At the same time, an increasing need for international solutions is necessary in 'global' problem fields. This affects the emerging and appropriate division of labor in policy and strategy at the regional, national, European and international level.

Regarding *general* impacts on public technology policy, we conclude, firstly, that technology policy as a single measure will no longer be a successful policy strategy; this is a 'cross-functional' task and various policy areas have to be combined to form an integrated innovation policy. The efficiency and effectiveness of administrative processes in policy-making and the establishment of lateral structures and coordination mechanisms between the different policy areas are becoming decisive factors for the 'absorptive capacity'. Secondly, as well as modern methods of networking and coordination, business approaches to international R&D management also clearly show how strongly innovation processes are influenced by non-technical determinants. The necessity for a change of perspective in technology policy is apparent in other contexts, too—a change away from technical aspects and towards 'soft' innovation

[26] Most of the literature in this field is related to companies and business administration (see e.g., Galbraith, 1994; Mueller, 1995; Reger, 1997, 1999 and the literature cited therein). However, an interesting field for research can be opened up regarding the efficacy of lateral structures for policy administration and public policy-making.

factors, such as organization, qualification, management mentality, communication and styles of behavior. This is not only true for the area of R&D management, but also applies, for instance, to new production concepts, energy-saving, the use of environmental technologies, and to communication technology (cf. Meyer-Krahmer, 1996). The promotion of technology can be complemented by support in the 'management of change'. The growing importance of these innovation factors will bring with it an analogous change in the approach of technology policy at the European and national level.

Regarding impacts specifically for technology policy on the *level of the European Community*, we came to the following main conclusions.

Firstly, although intra-European technology-related cooperation is still useful in many areas, it has to be complemented more and more by extra-European collaboration and mobility. Public R&D institutions and enterprises should be more explicitly supported in their path towards internationalization.

Secondly, the attractiveness of the European Union to foreign R&D investment and international players has to be increased, not just from the science and technology side, but also from the side of markets, regulations and public decision-making processes. Special attention should be paid to the early identification of European-based lead markets based on specific socio-economic needs.

Thirdly, with the growth of new world centers of technological activities, the economic and social welfare of the European Union will increasingly depend on the ability of European organizations to acquire and assimilate knowledge and techniques developed elsewhere in the world. The absorptive capacities of large and especially small enterprises, as well as of public R&D institutions within the Community are decisive for innovativeness and competitiveness.

Fourthly, in responding to the challenges, the technology policy of the Community (i.e., the RTD Framework Programme) alone will clearly be overloaded. The integration of different policy areas and the use of indirect policy measures (e.g., competition, standards, or labor market defragmentation) towards a European innovation policy should be at the top of the policy agenda.

Fifthly, in a number of 'global' problems there is a need for more intra-European policy coordination, (not only) in the field of research and technology, as well as a political debate on the international level. This, together with the establishment of a necessary, transparent and global framework for policy coordination and priority-setting world-wide, will have to become important political priorities in the next century.

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