DISKUSSIONSPAPIER

National and International Developments in Technology – Trends, Patterns and Implications for Policy

Georg Koopmann
Felix Münnich

HWWA-Diskussionspapier

76

HWWA-Institut für Wirtschaftsforschung-Hamburg
1999
ISSN 1432-4458

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Georg Koopmann
Felix Münnich

HWWA-Institut für Wirtschaftsforschung-Hamburg
Öffentlichkeitsarbeit
Neuer Jungfernstieg 21 • 20347 Hamburg
Telefon: 040/3562-355
Telefax: 040/35 19 00
e-mail: hwwa@hwwa.de
Internet: http://www.hwwa.de/

Georg Koopmann
Telefon: 040/428 34 302
e-mail: koopmann@hwwa.de

Felix Münnich
e-mail: fmuennich@bigfoot.com

Contents

List of Tables

List of Graphs

Abstract

Declining R&D intensities at the national level coincide with growing international technological links. Deviations of individual OECD countries from the average R&D intensity reflect differences in industry structure as well as in sectoral R&D intensity. At the same time, the sectoral distribution of R&D expenditure varies substantially less across countries than do the respective growth rates. Foreign direct investment (FDI) is the most important vehicle for the exploitation of “home-grown” technology abroad. FDI frequently also entails the generation of knowledge abroad in own R&D facilities the nature of which increasingly shifts from adaptation to innovation development and knowledge-seeking. In addition, international technological collaboration via in- and outsourcing and inter-company alliances is gaining growing significance. The policy challenges posed by technological internationalisation include the provision of better market access, more effective patent protection and competitive regimes, as well as the promotion of clustering and networking and international cooperation.

Zusammenfassung

Sinkende FuE-Intensitäten auf der nationalen Ebene gehen mit einer wachsenden internationalen Technologieverflechtung einher. In den Abweichungen einzelner OECD-Länder von der durchschnittlichen FuE-Intensität spiegeln sich Unterschiede in der Industriestruktur und in der sektoralen FuE-Intensität wider. Gleichzeitig unterscheiden sich die Länder weniger in der sektoralen Verteilung der FuE-Ausgaben als in den Zuwachsraten. Direktinvestitionen sind das bedeutendste Vehikel der Verwertung inländischer Technologie im Ausland. Sie führen häufig auch zur Erzeugung neuen Wissens in ausländischen FuE-Einrichtungen, die verstärkt eigene FuE statt reiner Anpassungsentwicklung betreiben und ausländisches Wissen suchen. Neben Verwertung und Erzeugung gewinnt die internationale technologische Kooperation via In- und Outsourcing und Allianzen zwischen Unternehmen wachsende Bedeutung. Die politischen Herausforderungen der technologischen Internationalisierung schließen einen verbesserten Marktzugang, effizienteren Patent- und Wettbewerbsschutz sowie die Förderung der Cluster- und Netzwerkbildung und internationalen Kooperation ein.

1. Introduction

Technology is a fundamental determinant of growth in an open economy as it shapes international trade as well as foreign direct investment and thereby enhances economic interdependence among countries. Changes in the stock of technology and hence changes in a country's performance, absolute and relative, are linked to research and development (R&D). A country's R&D is conducted either within the public sector (education /universities) or by private companies. Because the private incentives for research are often considered insufficient[1], R&D is frequently viewed as one of the prototypical areas in which the public hand should play a prominent role.

If R&D does indeed determine national growth and if the incentives of non-governmental actors to engage in R&D are indeed sub-optimal, then governmental intervention could be employed to improve the situation. However, too much or the wrong kind of meddling by the government can be counterproductive. While the above reasoning applies regardless of the degree of openness of an economy, further arguments for government intervention on a national and international level apply when a country engages in international trade. For example:

- R&D influences a country's competitiveness and comparative advantage. Here, government intervention in the R&D sector at a national level may enhance competitiveness and may be imperative if other countries already engage in such practices.
- In the presence of international spill-overs of knowledge, co-operation between governments on an international level may be required to counter free rider problems, to reduce the danger of duplication of research and to safeguard incentives through patent protection.

In order to design the appropriate policies, it is important to understand the structure and trends of a country's research and development efforts and consider these in their proper international context. To this end, we shall concentrate on describing major features of R&D activities at the country and company level. In particular, two broad developments will provide the main routes along which this paper will develop:

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1 R&D is a (partially) public good in that it is non-rival and non-excludable. Furthermore, R&D often displays positive externalities on production and future research that is not taken into account by researchers even in the presence of patents. However, R&D can also be accompanied by negative externalities because it frequently renders existing technology obsolete or less profitable (Aghion, Howitt 1992; Grossman, Helpman 1991; Romer 1990).

- The overall R&D intensity in the business enterprise sector as well as in the whole economy has decreased in most of the industrialised countries since the early 1990s.
- At the same time, R&D has been increasingly “internationalised”. Multinational companies (MNEs) account for the lion’s share of world-wide business R&D[2], while more and more R&D is undertaken outside the companies’ home-country.

The two tendencies together entail possible conflicts between countries as governments compete to attract R&D activities of foreign firms. In this context, a number of questions arise, some of which will be addressed below. Do companies research in the same fields of technology abroad as they do domestically? Are the fields of technology in which R&D is concentrated within a country those in which it has a comparative advantage? What drives the process of the internationalisation of technology? What are the implications for host countries and home countries? What are the implications for policy, on a national and an international level?

2. R&D Intensities in the Manufacturing Sector of OECD Countries: Decomposing the Deviations

The first of the above trends, namely that of falling R&D intensities, is summarised in Graph 1, which displays R&D intensities in the manufacturing sector for the G7 countries as well as Sweden over the period 1981-95.[3] The 1980s, in particular the first half, display a remarkable rise in the intensity of R&D expenditure for all countries except the United Kingdom. However, every country has experienced a falling R&D intensity for at least the last few years under consideration, with the exception of Japan, although the severity and starting point of this downturn vary considerably. Thus, the USA has exhibited a decreasing R&D intensity since 1986 with an overall reduction of nearly 20%. In contrast, R&D intensities in France, Germany, Sweden, the UK and Canada have been falling only since 1993 and much less severely.

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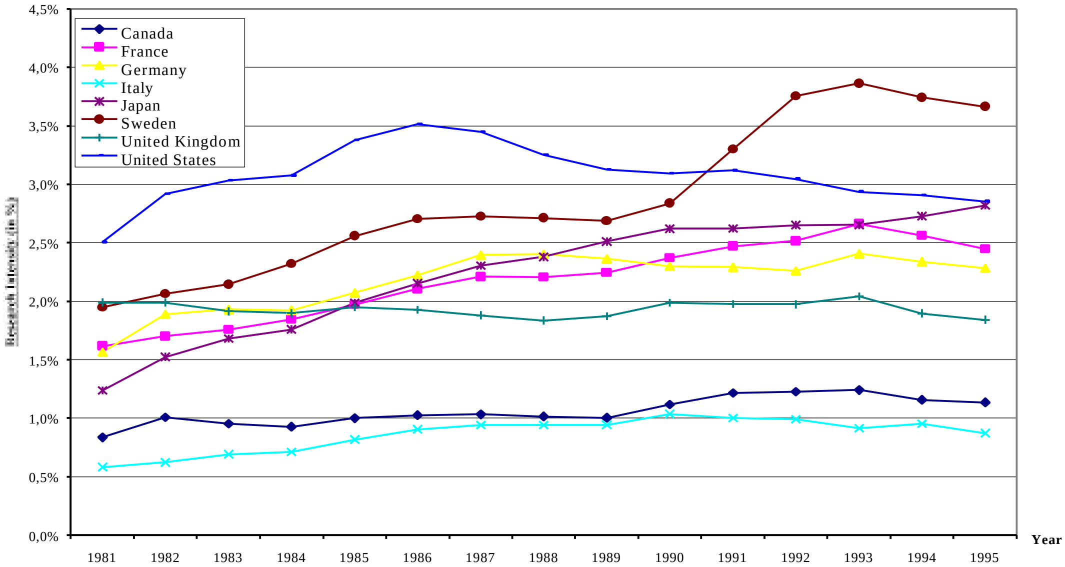
2 Cf. R&D Scoreboard of the UK Department of Industry, in: Financial Times of 25.6.1999: “US Powers Ahead as Competition Drives Investment”.

3 Here, R&D intensity is measured by R&D expenditures as a share of gross production.

Graph 1: Research Intensities (a) in the Manufacturing Sector of OECD Coutnries, 1981-1995



(a) R&D expenditures as a share of gross production
Source: OECD ANBERD and STAN databases

Persisting – sizeable – inter-country differences in overall R&D intensities can be traced back to three factors:

$$t_i - t_w = \underbrace{\sum_{j=1}^{n} (s_{ji} - s_{jw}) t_{jw}}_{A} + \underbrace{\sum_{j=1}^{n} (t_{ji} - t_{jw}) s_{jw}}_{B} + \underbrace{\sum_{j=1}^{n} (s_{ji} - s_{jw})(t_{ji} - t_{jw})}_{C}$$

Here, t_i and t_w denote the research intensity in country *i* and in the average G7 economy, respectively. Their difference is thus a measure of country i's relative research intensity. t_{ji} represents sector *j*'s research intensity in country *i*, s_{ji} represents sector *j*'s share of total manufacturing in country *i* and *n* stands for the number of sectors.

Factor A measures the weight of R&D intensive sectors in a country with respect to the international average (structural effect), while factor B captures the difference in R&D intensity (intensity effect) and factor C is a combination of A and B (joint effect) indicating to what degree a country's industrial structure is characterised by sectors that are disproportionately R&D intensive in this country compared to the rest.[4]

The decomposition of relative R&D intensities in the manufacturing sector of the G7 countries for the period 1975-95 reveals three main characteristics.[5]

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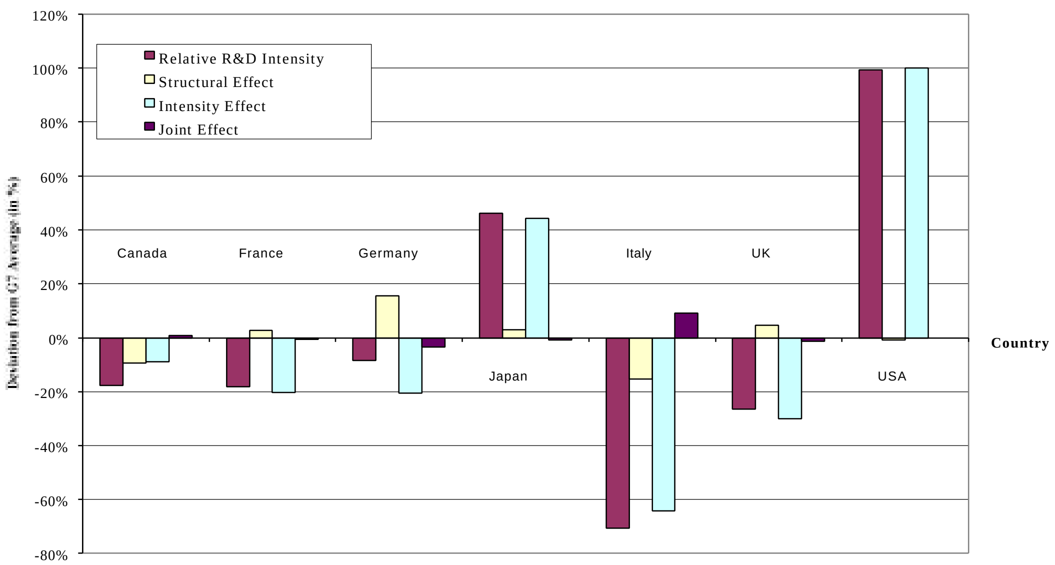
4 Eaton et al. (1998, p. 411) refer to this effect as the "interaction effect".
5 In the following, R&D intensity is measured by R&D employment as a share of total employment.

- Relative R&D intensities vary substantially from year to year in all countries. Most of these variations in the deviation of the individual countries' R&D intensities from the mean is driven by the intensity effect, while the structural and joint effects contribute relatively little. Hence, R&D employment proves far more variable than overall employment in the industries concerned. Moreover, the joint effect is of small absolute size in all countries.
- Countries develop differently with respect to their relative R&D intensities: Canada, France, Germany and the UK all converge towards a negative value. The USA and Japan also converge but at a positive level - with the US moving towards and Japan away from the mean -, while Italy displays no consistent change with regard to the mean and remains at a highly negative level.
- The composition of relative R&D intensities also differs among countries. The USA and Japan are the only countries to display positive intensity effects, which indicates that industries in these countries are more research-intensive than in other G7 economies. Both countries have structural effects of small size, which also holds in the case of France and the UK. Germany, on the other hand, has the largest positive structural effect, expressing the fact that Germany employs a large amount of R&D personnel in relatively R&D-intensive sectors. Finally, Canada's and Italy's structural and intensity effects are both negative (Graph 2).

Graph 2: De-composition of Relative R&D Intensities (a) in G7 Countries 1995



(a) R&D intensity measured by R&D employment as a share of total employment
Source: OECD ANRSE and STAN databases

3. Sectoral Patterns of R&D among Countries: High- and Medium-Technology, Large, Dynamic and Shrinking Industries

When the composition of relative R&D intensities is analysed separately for high- and medium-technology sectors[6], a more differentiated picture emerges (Table 1). The familiar story of Germany's strength at the medium-technology level (with the exception of the chemical industry) and weakness at the high-technology level (with the exception of the instrument sector) is confirmed and shown to hold over the last 20 years without too much change. Furthermore, consistent with the 'macro' picture, positive deviations from the G7 average are mainly a result of structural effects rather than intensity effects.

Table 1: Decomposition of Relative R&D Intensities for High- and Medium-Technology Sectors in Germany and the US 1975, 1985, 1995 (%)

		Germany				USA			
		Relative R&D Intensity	Structural Effect	Intensity Effect	Joint Effect	**Relative R&D Intensity**	Structural Effect	Intensity Effect	Joint Effect
1975	Overall	**-9.7**	11.0	-19.1	-1.6	**173.8**	1.7	168.6	3.5
	High-Technology Sectors	**-72.7**	-57.1	-47.2	31.6	**193.5**	44.5	105.6	43.4
	Medium-Technology Sectors	**-23.6**	-13.8	-33.1	23.3	**110.5**	-14.7	153.9	-28.6
1985	Overall	**-19.6**	13.9	-29.5	-4.0	**137.5**	3.5	128.8	5.2
	High-Technology Sectors	**-38.0**	-11.1	-25.0	-1.9	**190.2**	44.3	90.3	55.7
	Medium-Technology Sectors	**22.2**	34.6	-4.9	-7.5	**69.1**	-12.7	95.6	-13.8
1995	Overall	**-8.5**	15.5	-20.6	-3.4	**99.3**	-0.8	100.1	0.0
	High-Technology Sectors	**-45.2**	-11.7	-34.7	1.3	**77.3**	16.3	46.6	14.5
	Medium-Technology Sectors	**20.3**	32.0	-6.0	-5.8	**52.3**	-16.5	87.7	-18.8

Source: OECD ANRSE and STAN databases.

6 High-technology sectors comprise ISIC (Rev. 2) sectors 3522 (Pharmaceuticals), 3825 (Office Machinery & Computing), 3832 (Electronic Equipment and Components), 3845 (Aerospace) and 3850 (Instruments); medium-technology sectors consist of 35-3522-353-354 (Chemicals), 382-3825 (Non-electrical Machinery), 383-3832 (Electrical Machinery), 3843 Motor Vehicles and 3842+3844+3849 (Other Transport Equipment).

The United States, in contrast, is relatively R&D-intensive in both sector-groups, but more so in the high-technology sectors. As in the German case, this is consistent with the pattern of comparative advantages as reflected in RCA (Revealed Comparative Advantage) values (Table 3). However, in both categories, relative R&D intensities of the US have been falling, initially in the medium- and subsequently in the high-technology sectors. Again, as with the de-composition for the whole economy, much of this R&D competitiveness stems from high intensity effects in the relevant sectors, whereas the structural effects are low or negative for the US.

The above analysis, as indicated, refers to the manufacturing industry which receives by far the largest share of overall R&D expenditure in the G7 countries. However, this share has been falling steadily (from a high-point of 95% in 1974 to 86% in 1996) in favour of the services sector. Within the manufacturing sector, the five industries that shrank the most in terms of R&D expenditure were "Aerospace", "Shipbuilding", "Petroleum Refining", "Electrical Machinery" and "Ferrous Metals"[7] In contrast, the five most dynamic sectors were "Pharmaceuticals", "Instruments", "Motor Vehicles", "Non-Electrical Machinery" and "Office Machinery & Computers"[8], The five largest sectors over the period under consideration were "Electronic Equipment and Components", "Motor Vehicles", "Industrial Chemicals", "Aerospace" and "Pharmaceuticals"[9].

These characteristics of the average G7 economy are shared to varying degrees by the individual countries. For example, the trend of R&D spending away from manufacturing towards services is most pronounced in the US, the UK and Canada[10] whereas all other countries show only small negative changes or even positive values.[11] With regard to the sectoral distribution of R&D spending and its dynamics, we can compare countries based on the following algorithm:

$$R_i = \sum_{j=1}^{n} \overline{v_j}\,(g_{ij} - \overline{g_j})$$

7 Their respective growth rates were –55%, -48%, -40%, -31% and –29%. Rates were computed using the average share of total R&D expenditure over the periods 1973-1995 and 1993-1995 so as to minimise the influence of short-term fluctuations in the distribution of R&D expenditures. Data in this paragraph are from the OECD ANBERD database.

8 Their respective growth rates were 74%, 59%, 15%, 12% and 9%.

9 Their respective shares of total R&D expenditure were 13%, 10%, 9%, 8% and 8%.

10 Growth rates of the share of R&D spending in the manufacturing industry over the period 1973-1995 were –18%, -14% and –26%, respectively.

11 The respective growth rates were –5% (France), +2% (Germany), -0.4% (Italy) and +1% (Japan).

where indices *i* and *j* denote country and sector, respectively, $\overline{v_j}$ is the weight of sector j in the average G7-economy[12], g_{ij} denotes the variable under investigation (size or growth rate) for sector j in country i and $\overline{g_j}$ its value in the average G7 economy. An R-index of zero expresses the fact that a particular country does not deviate from the average G7 economy with respect to the chosen variable. A positive R-index implies that sectors are either bigger or have grown faster/shrunk less quickly than the G7 average.

Table 2 lists the R-indices for the composition of expenditure in 1993-95 and for growth rates between 1973 and 1995. Strikingly, R-indices for overall growth are negative for all countries except the United States. Differences in distribution, on the other hand, are much less widely dispersed, with Canada's and Britain's deviations explained by their pronounced shift to R&D expenditure in service industries. When the analysis is concentrated on sectors of interest[13], several noteworthy trends emerge. The distribution of R&D expenditure varies substantially less across countries than do the respective growth rates. A clear contrast emerges between the high-technology industries with generally positive but highly dispersed R-indices for growth, and the medium-technology sector where negative values predominate while Germany stands out as the "champion". Germany (and Japan) also exhibits relatively high values in the dynamic industries, whereas Italy seems to be bucking the trend by growing strongly in large and shrinking industries.

Table 2: Distribution and Growth of R&D Expenditure across G7 Countries 1973-95 (%)

		Canada	France	Germany	Italy	Japan	United Kingdom	United States
All Industries	**Growth**	**-8.5**	**-15.3**	**-0.9**	**-12.3**	**-19.6**	**-9.6**	**35.6**
	Distribution	-8.5	0.7	5.0	1.1	1.0	-7.4	-1.0
High-Technology Industries	**Growth**	**7.9**	**-5.8**	**3.3**	**43.5**	**16.5**	**23.3**	**0.6**
	Distribution	0.7	0.8	-0.9	0.4	-0.4	2.9	0.0
Medium Technology Industries	**Growth**	**-18.0**	**1.4**	**49.6**	**5.5**	**-2.5**	**-9.9**	**-9.0**
	Distribution	-3.4	0.1	1.9	0.1	0.7	0.5	-1.0
Large Industries	**Growth**	**-0.9**	**4.5**	**-0.6**	**30.7**	**-3.8**	**-**	**-1.1**
	Distribution	-0.6	1.5	0.9	0.9	-0.3	2.9	-0.6
Dynamic Industries	**Growth**	**0.0**	**-7.6**	**12.6**	**-4.8**	**10.7**	**-3.1**	**0.7**
	Distribution	-2.0	-0.5	0.8	0.2	0.1	-0.6	-0.1
Stagnant Industries	**Growth**	**0.3**	**2.3**	**2.9**	**54.6**	**3.4**	**3.3**	**-**
	Distribution	-0.2	0.3	0.1	0.0	-0.3	0.1	0.1
Source: OECD ANBERD and STAN databases.								

12 As measured by the sector's share of R&D spending over the period 1993-95.

13 High-technology and medium-technology industries are defined as in footnote 6; for large, dynamic and shrinking industries cf. the preceding paragraphs.

4. Dimensions of Technological Internationalisation

With regard to the second broad development indicated above – the growing internationalisation of technology -, it is worth noting at the outset that R&D internationalisation is no generalised phenomenon common to all countries, industries and companies in a similar degree. Even within one industry and among the biggest global players, one can observe firms which have spread their R&D laboratories all over the globe as well as those which have centralised these activities (Brockhoff 1998, p. 1). Among the world's largest 359 firms, wide-ranging differences exist in the degree of R&D internationalisation according to nationality and industry.[14] European companies, in particular firms from smaller countries, are much more internationalised in this regard than US and Japanese corporations. The same is true for consumer good industries in comparison with the engineering sector.

Conducting R&D activities in various countries is, however, not the sole form of technological internationalisation which can be depicted as consisting of three basic components:[15]

- *Exploitation* – the results of domestically conducted R&D are used abroad by means of exporting ("embodied R&D"), licensing ("disembodied R&D") or producing at foreign locations.
- *Generation* – knowledge is generated abroad through the foundation of new or acquisition of existing research facilities and the funding of independent research.
- *Collaboration* – R&D is conducted through international co-operation and alliances among independent companies which involves joint R&D projects, exchange of technical information, strategic moves etc.

4.1 Exploiting Domestic R & D Abroad

Exporting is the most conventional means of exploiting technological knowledge abroad. It serves to extend the markets for goods incorporating the results of R&D. This in turn is necessary for realising the economies of scale typically associated with (sunk) R&D costs. Technology-intensive goods, conventionally defined as goods with an R&D

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14 Here, R&D internationalisation is measured as the share of foreign-origin patents in a company's total patents (Reger et al. 1999, p. 4).

15 Archibugi and Iammarino refer to international knowledge spill-overs, and the corresponding use of external sources of technology, as a fourth category of the globalisation of technology but consider it almost impossible to gather evidence on the significance of the autonomous diffusion of innovation (Archibugi, Iammarino 1998, p. 5f.).

share of sales amounting to at least 3½%, are indeed the dynamic element in world trade. Its share of total OECD trade increased from 36.2% in 1989 to 38.9% in 1996. The distinction between medium-technology goods and high-technology goods[16] serves to clarify the trend towards increased trade in technology. While the share of total OECD trade of medium-technology goods only grew from 22.7% to 23.0% over the same period, trade in high-technology goods expanded from 13.5% to 15.9%. Exporting technology as embodied in high-technology goods thus has increased substantially.[17]

At the industry level, the degree of openness (of the domestic market and of foreign markets) to international trade, as measured by the import penetration ratio and export intensity, is significantly higher in technology-intensive industries than in the manufacturing sector as a whole. This is particularly true for high-technology industries, but in most cases also holds for the medium-tech sector. Over the years, the degree of openness has also quickly increased in technology-intensive industries and typically much faster than in other industries.

Germany may serve as an example in this context. Here, imports have risen from 27% (1976-78) to 47% (1992-94) of the domestic market in high-technology industries and from 17% to 27% in total manufacturing. During the same period, the export intensity of high-tech manufacturing (total manufacturing) in Germany grew from 34% (24%) to 46% (31%). In the medium-tech sector, Germany's stronghold in international competition, the development has been less dramatic but still impressive, with export intensity increasing from 34% to 40% and import penetration from 16% to 26% (Table 3).

The disembodied export of knowledge generated "at home" is partly reflected in a country's *technological balance of payments* where receipts from license fees and royalties (export of technology) are counted against payments made for the use of innovations (import of technology). Multinational enterprises (MNEs) account for the bulk of these technology flows in both directions. In the case of Germany, for instance, German companies with foreign subsidiaries in 1997 covered about three fourths of total receipts from patents, inventions and processes in the manufacturing industry while nearly half of the corresponding payments were met by foreign-controlled firms in Germany. In some industries such as electronics the dominance of multinational corporations was almost complete.

16 Medium-technology and high-technology goods are commonly defined as those with a R&D share of sales between 3½% and 8½% and above 8½%, respectively.

17 The database used in this paragraph is the OECD International Commodity Trade Statistics.

Table 3: Sectoral Foreign Trade Links according to Technology Intensity 1976-78 and 1992-94 (%)

		Germany		France		UK		USA		Japan	
		1976-78	**1992-94**	**1976-78**	**1992-94**	**1976-78**	**1992-94**	**1976-78**	**1992-94**	**1976-78**	**1992-94**
High-Technology Industries	Export Share	10.7	**15.0**	10.1	**18.6**	14.5	**26.3**	21.7	**32.1**	17.6	**29.5**
	Import Share	11.6	**18.8**	11.6	**19.2**	13.1	**23.3**	12.4	**25.1**	12.2	**19.5**
	Export Intensity	34.3	**46.1**	25.0	**41.4**	38.6	**58.5**	15.3	**24.2**	25.3	**24.4**
	Import Penetration	27.3	**46.7**	25.0	**41.1**	34.8	**58.4**	9.8	**24.8**	7.3	**9.2**
	Specialisation (RCA)	91.9	**79.9**	86.9	**96.8**	110.7	**113.0**	174.8	**128.1**	144.1	**151.8**
Medium-Technology Industries	Export Share	54.6	**54.8**	44.6	**43.6**	44.5	**40.2**	50.1	**42.0**	42.9	**53.8**
	Import Share	29.4	**36.6**	37.1	**39.4**	31.3	**37.8**	35.8	**39.0**	19.2	**22.9**
	Export Intensity	34.3	**39.6**	32.5	**43.1**	31.4	**37.7**	12.3	**17.7**	16.6	**18.6**
	Import Penetration	15.7	**26.4**	25.8	**39.6**	23.3	**39.1**	9.5	**20.9**	2.9	**4.5**
	Specialisation (RCA)	185.9	**149.7**	120.1	**110.4**	142.1	**106.4**	139.9	**107.7**	223.4	**234.5**
Other Industries	Export Share	34.7	**30.2**	45.3	**37.8**	41.0	**33.5**	28.2	**25.9**	39.5	**16.7**
	Import Share	59.0	**44.6**	51.2	**41.3**	55.6	**38.9**	51.8	**35.9**	68.6	**57.6**
	Export Intensity	15.3	**19.4**	15.5	**21.3**	15.0	**18.8**	3.5	**6.2**	7.5	**4.1**
	Import Penetration	16.9	**22.6**	15.3	**22.0**	18.3	**23.3**	6.5	**10.9**	4.4	**6.7**
	Specialisation (RCA)	58.9	**67.7**	88.4	**91.6**	73.8	**86.0**	54.4	**72.0**	57.6	**29.0**
Manufacturing Sector	Export Intensity	24.0	**30.6**	21.3	**30.9**	22.1	**30.3**	7.4	**12.7**	11.7	**12.3**
	Import Penetration	17.3	**26.6**	19.0	**29.9**	21.1	**33.0**	7.7	**16.2**	4.2	**6.3**

Notes:
- Export intensity defined as export share of gross production
- Import penetrattion defined as import share of domestic consumption (=gross production + import-export)
- Specialisation defined as (Xi/Mi)/(X/M) where X=export, M=import and i=sector index

Source: OECD STAN Database.

Data for US-based MNEs allow us a closer look into the structure of international technology flows. The figures show a striking asymmetry between parent companies and foreign affiliates in that the formers' receipts from technology exports to the latter exceed the reverse flows by a factor of 45 (data for 1994). However, the affiliates' share of their parents' technology exports declined significantly between 1989 and 1994 (from 80.3% to 51.7%) while their import share more than doubled during the same period (from 6.2% to 13.3%) which suggests a tendency towards a more balanced relationship and enhanced R&D activity with the affiliates proper (Table 4).

Table 4: Technological Balance of Payments of U.S. Companies and their Foreign Subsidiaries 1982, 1989, 1994 (%)

		US Parent Companies			German Subsidiaries			World-wide Subsidiaries		
		1982	1989	1994	1982	1989	1994	1982	1989	1994
Import (in mn$)		**457**	**978**	**2,929**	**533**	**1,380**	**3,427**	**3,954**	**12,472**	**22,039**
Internal	**Total**	**13.6**	**6.2**	**13.3**	**91.9**	**93.9**	**-**	**92.6**	**90.8**	**87.8**
	From Parent	-	-	-	85.6	84.5	0.6	83.7	78.9	76.0
	From Sub-sidiaries	13.6	6.2	13.3	6.4	9.4	-	9.0	11.9	11.9
External	**Total**	**86.7**	**93.8**	**86.7**	**8.1**	**6.1**	**-**	**7.4**	**9.2**	**12.2**
	From the US	-	-	-	3.6	2.9	-	2.6	5.3	9.7
	From other Countries	-	-	-	4.5	3.2	-	4.8	3.9	2.5
Export (in mn $)		**5,151**	**12,800**	**33,957**	**33**	**124**	**440**	**435**	**1,461**	**2,581**
Internal	**Total**	**70.5**	**80.3**	**51.7**	**51.5**	**41.1**	**81.1**	**52.6**	**48.6**	**56.7**
	To US Parent Companies	-	-	-	12.1	4.8	9.8	8.3	3.7	14.3
	To Subsidi-aries	70.5	80.3	51.7	36.4	35.5	71.4	44.4	44.9	42.5
External	**Total**	**29.5**	**19.7**	**48.3**	**48.5**	**59.7**	**18.9**	**47.4**	**51.3**	**43.2**
	To the US	-	-	-	6.1	0.0	9.5	6.0	6.6	15.0
	To other Countries	-	-	-	42.4	59.7	931.8	41.4	44.8	28.3

Source: U.S. Department of Commerce, Benchmark Surveys "U.S. Direct Investment Abroad" 1982, 1989, 1994.

US subsidiaries in Germany lessened their dependence on technology imports from the parent company much faster than other affiliates while sharply – and over-proportionately - increasing intra-company technology exports. These were, however, overwhelmingly directed towards "sister companies" in other (mostly European) countries rather than towards the parent company. Whether this is an indicator of growing technological "networking" or simply a "one-shot" development is difficult to decide. In any case, the European subsidiaries of US multinationals, in Germany as well as in other European countries, are a more important source of technology for each other than for their US parents.

Probably the most important vehicle for the utilisation of "home-grown" technology in foreign countries *is foreign direct investment.* Disposal of proprietary technology often is the main ownership-specific advantage which according to the eclectic theory of Dunning is a *conditio sine qua non* for FDI. Empirical analysis confirms the critical role of technological capabilities in promoting foreign direct investment. Barrell and Pain, for instance, find a significant (positive) influence of technical knowledge (measured by cumulative patent applications) on the level of German direct investment in the United States (Barrell, Pain 1997). FDI, like international trade, also tends to increase with the technology intensity of the industry in which it originates.

In a case study on international activities of US companies, Mansfield found that 70% of the reviewed firms' innovations were exploited abroad through FDI but just 20% through exports (Mansfield 1984). According to a survey of Swedish firms, parent companies are the prime users of the R&D which they undertake in Sweden but also send substantial flows of technology to their foreign subsidiaries. Reverse flows from affiliates to parents, on the other hand, were found to be insignificant (Fors 1997). This might be seen as an indication that own R&D by affiliates abroad is still in its infancy or primarily geared towards the peculiarities of individual host country markets.

4.2 Inward and Outward R & D Investments

In actual fact, R&D is still more a headquarter function than e.g. investment, employment, production or distribution, as it is often firmly rooted in the corresponding national system of innovation. Besides the conventional forces working in favour of R&D centralisation (economies of scale, avoidance of high communication and co-ordination costs, close control of the R&D portfolio, proprietary information), the exploitation of firm-specific technological advantages offered by public research institutions in the home market is an important reason why R&D lags behind in the internationalisation process (Brockhoff 1998, p. 1). In this model, R&D activities of foreign subsidiaries are at the bottom of the innovation hierarchy, largely confined to "adaptation development", which is aimed at peripheral adjustments of products and processes to local conditions, technical support of the production process and promoting the transfer of technology within the company (Pearce 1995, p. 7).

However, in the R&D field too, decentralising influences are clearly gaining importance. It has been shown, on the basis of patent data for European and American-based companies, that in the long run, the foreign share of R&D activities has grown from 4% in 1920-1924 to 19% in 1987-1990 (Cantwell 1995). R&D expenditures of foreign subsidiaries have also grown more rapidly than sales. Even so, R&D intensities abroad are still a far cry from those at home which is most obvious in the case of US affiliates in foreign countries. The US data also display a relatively strong R&D performance of foreign-owned affiliates in the United States (Table 5).

Table 5: R&D Intensities[a] for MNEs across Industries 1994 (%)

	Manu-facturing Industry	Food	Chemicals	Metal Products	Machi-nery	Elec-tronics	Trans-port	Instru-ments	All Industries
U.S. companies with foreign subsidiaries	**3.7**	0.5	6.4	0.9	6.3	4.5	4.0	6.0	**2.0**
U.S. subsidiar-ies of foreign companies	**2.5**	0.6	4.8	0.5	2.0	3.9	1.0	4.3	**1.1**
U.S. subsidiar-ies of German companies	**3.2**	0.5	4.6	0.9	-	-	3.0	3.9	**1.7**
Foreign sub-sidiaries of US companies	**1.4**	0.3	2.4	0.4	1.6	1.2	1.9	1.7	**0.8**
German sub-sidiaries of US companies	**2.5**	0.2	2.2	0.9	2.8	1.9	4.2	2.4	**1.8**

a R&D expenditure as a share of value added
Sources: U.S. Department of Commerce: Benchmark Survey “U. S. Direct Investment Abroad”, 1994.
U:S. Dpartment of Commerce: Annual Survey “Foreign Direct Investment in the U.S.”, 1994.

In addition to adaptation development, foreign subsidiaries increasingly undertake “innovation development” where new products are developed for the local/regional or even global market. “Stand-alone” research units are also being established abroad, de-linked from production, which maintain close communication with research institutions in the host country and/or with research units of the same company in other countries. These tendencies reflect a new evaluation of locational factors in R&D, in particular the cost of research and availability of human resources, as well as a desire to monitor foreign scientific and technological developments (“state-of-the-art” technologies) and enjoy the external economies of scale or knowledge spill-overs available in foreign “centres of excellence”.

A growing number of surveys and statistical analyses present evidence of a shift in focus towards innovation development and knowledge seeking. In a regression analysis based on international R&D and production data for Swedish companies, Fors finds both foreign production (reflecting the adaptation motive) and technological specialisation of the host country (as a proxy for knowledge-seeking)[18] to be a significant influence on the level of R&D activities abroad (Fors 1998, p. 129). Patel and Vega employ patent data for the 220 technologically most internationalised firms in the world (in terms of their patenting outside the home country) and for the respective host countries

18 Measured as a country’s share of world-wide R&D expenditures in a specific industry compared to its share of R&D expenditures in all industries.

and compare company- and country- related technological specialisation indices[19] for the periods 1980-1986 and 1990-1996 (Patel, Vega 1999). In most of the cases, the companies conducted R&D abroad in those fields where they are strong at home while in a growing number of cases the comparative advantages of firms and countries were complementary. This would be consistent with an increased importance of knowledge-seeking or home-base augmenting (as compared to home-base exploiting) R&D in foreign countries. Kuemmerle, using a sample of 32 multinational companies[20] demonstrates the growing significance of home-base augmenting R&D activities abroad though home-base exploiting investments still predominate in the survey. The survey also shows a tendency for "exploiting" units to be located near production facilities, whereas "augmenting" typically takes place in the proximity of universities or public laboratories (Kuemmerle 1999). According to Cantwell and Janne knowledge-seeking is a particularly strong motive for technological internationalisation in the case of companies emanating from the most important locations in their industry (Cantwell, Janne 1999).

Knowledge-seeking is also a major determinant of cross-border mergers and acquisitions (M&As) the frequency of which is closely related to the technology intensity of the industry concerned.[21] The respective companies often look for complementary technological competencies in the "target countries". M&As of European companies in the United States, for instance, concentrate on high-technology industries, whereas US M&As in Europe mostly occur in industries that are classified as medium-technology (Buigues, Jacquemin 1998). This corresponds to the different patterns of technological specialisation displayed by the two regions.

4.3 External Technological Networks

The third component of technological internationalisation – international technological collaboration – involves both

- an intensified technological division-of-labour via in- and outsourcing of R&D activities, and
- a growing significance of technologically-oriented inter-company alliances.

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19 Share of patents in a particular field of technology related to the share in all fields.

20 The survey is based on questionnaires and interviews. The sectors covered are pharmaceuticals and electronics. Home countries include the US, Japan, Germany, France and the Netherlands.

21 According to Dunning, M&As account for more than half of all foreign direct investments and concentrate on knowledge and information intensive industries (Dunning 1998, p. 50).

Table 6: External R&D Links[a] of Industrial Companies in Germany 1979-95 (%)

	1979	1983	1987	1991	1995
External R&D Expenditure	**5.1**	**10.8**	**9.2**	**10.9**	**11.3**
Domestic Suppliers	4.5	9.7	8.1	9.1	9.5
Industry	3.7	7.8	6.3	7.0	7.0
Government	0.9	1.9	1.8	2.0	2.5
Foreign Suppliers	0.6	1.1	1.1	1.8	1.8
External R&D Financing	**20.0**	**23.2**	**18.5**	**19.2**	**17.2**
Domestic Sources	17.6	21.4	16.8	16.3	14.8
Industry	3.7	7.8	6.3	7.0	7.0
Government	13.9	13.6	10.5	9.2	7.9
Foreign Sources	2.4	1.7	1.7	2.9	2.4
Internal R&D Expenditure (in mn$)	**22,195.4**	**29,331.4**	**40,565.4**	**50,793.6**	**51,955.0**

a External R&D as a share of internal R&D.
Source: Stifterverband für die Deutsche Wissenschaft: Forschung und Entwicklung in der Wirtschaft, various issues.

In the field of R&D, in-house activities aimed at developing new products and processes for the company's own needs, increasingly give way to the use of specialised external R&D sources (outsourcing/external expenditures) as well as to the external provision of specialised R&D services (insourcing/external financing). There is also a significant positive influence of R&D contracted out on internal R&D provided the companies have absorptive capacity in the form of a full-time staffed R&D department, as Veugelers has shown for a sample of Flemish companies (Veugelers 1997). Data for industrial companies in Germany demonstrate a strong increase of external vis-à-vis internal R&D expenditures as well as a growing significance (albeit at a low level) of foreign sources. External financing, on the other hand, has developed less dynamically, since contracts from the government have declined since the mid-1980s. On the whole, the technological division-of-labour through out-contracting and in-contracting has clearly intensified in the German case while foreign involvement in this development is still rather modest (Table 6).

Over and above these one-way technological relationships, two-way arrangements in the form of technological *alliances* have developed quickly in the 1990s. They shall allow participants to take advantage of technological complementarities, to move more quickly downwards on the learning curve and to shorten the span between the invention of a product and its introduction into the market (Hagedoorn 1996). They often also serve "non-technological" aims such as improved market access or to ensure a better market control. However, it is in practice very difficult "to separate the competitive pressures from the technological imperatives" (Hagedoorn 1998, p. 179). Technologically-oriented alliances concentrate on those industries in which technological change has been more intense and where the risks connected to innovation are higher (Table 7).[22]

Table 7: Intra- and Interregional Technological Alliances 1980-1994[a]

	Biotechnology			Information Technology			New Materials			Total		
	1980-84	1985-89	1990-94	1980-84	1985-89	1990-94	1980-84	1985-89	1990-94	1980-84	1985-89	1990-94
Intra-regional	184	348	232	288	651	706	52	178	98	524	1177	1036
Europe	47	118	52	105	251	97	26	43	29	178	412	178
USA	126	191	176	145	354	569	15	55	64	286	600	809
Japan	11	39	4	38	46	40	11	80	5	60	165	49
Inter-regional	109	223	209	313	446	471	52	106	78	474	775	758
Europe-USA	60	140	168	140	256	242	21	43	47	221	439	457
Europe-Japan	5	21	14	47	57	61	15	23	13	67	101	88
USA-Japan	44	62	27	126	133	168	16	40	18	186	235	213
Total	293	571	441	601	1097	1177	104	284	176	998	1952	1794

a In numbers of alliances.
Source: National Science Board: Science & Engineering Indicators 1996, Washington, DC 1996, Appendix table 4-38.

While the majority of technology alliances still is national or regional (European) in outlook, international/interregional partnerships have gained importance in the first half of the 1990s. This was most conspicuous in Europe and is mainly due to a sustained expansion of transatlantic alliances in certain high-technology areas like biotechnology, in particular, whereas the number of intra-European alliances fell dramatically. Hence a divergence has developed in the technological networking strategies of European companies between European-centred intra-company ("internal") networks, on the one hand, and alliance-based ("external") networks with a trans-European focus, on the other. It is also held, especially with regard to American-European partnerships, that the R&D content of these collaborations have been increasing at the expense of non-technological co-operation via joint production or joint marketing (Hagedoorn 1998).

5. Implications for National and International Policy

In view of the decisive importance of R&D and technology for economic performance, technological internationalisation in the three dimensions discussed above is undoubt-

22 Cf. Archibuigi, Iammarino 1995, p. 13. For European companies, Buigues, Jacquemin find a positive correlation between R&D intensity and alliance intensity (Buigues, Jacquemin 1998, p. 49). For a similar result concerning US companies, cf. George 1995.

edly an area of legitimate policy concern for national governments as well as for supranational policy-making bodies. With regard to the foreign *exploitation* of domestically-generated knowledge, it is imperative to further improve market access abroad, ensure a more effective protection of intellectual property and remove obstacles to foreign direct investment. A useful model in this context is the multilateral Information Technology Agreement (ITA) negotiated under the aegis of the World Trade Organisation (WTO) which provides for the elimination of tariffs on a broad range of information technology products. A follow-up agreement (ITA II), apart from further extending the product coverage, would in particular have to address non-tariff barriers to trade (NTBs).[23]

The WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) could be amended, too, in order to strengthen patent rights as well as to prevent their anti-competitive use (Großmann, Koopmann et al. 1998, p. 213),[24] while in the case of FDI a binding framework of common rules for investors, beyond the prohibition of some Trade-Related Investment Measures (TRIMs), would still have to be created in the first place. One argument in favour of a Multilateral Agreement on Investment (MAI) derives from a closer link between FDI and trade as discriminating investment regulations could undermine trade liberalisation. Another argument could be the public-good character of an MAI, e.g. in containing bidding competition among countries by means of fiscal and financial incentives, even though the public-good case for multilateral investment policies is not unequivocal and the trade-investment link might be dealt with more effectively in existing WTO agreements (Langhammer 1999, p. 12ff.).

Furthermore, multilateral competition rules might be needed to cope with the competitive implications of border-crossing technological alliances and M&As (international technological *collaboration*). Competition policy must prevent technologically-oriented alliances from turning into straightforward cartels that reduce variety, slow technological progress and keep prices high. M&As could have similar effects.[25] Governments of the involved countries might feel little incentive to intervene, however, or even encourage the anti-competitive conduct of “their” firms, if third countries were likely to bear most of the associated economic costs. In this situation, establishing multilateral disci-

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23 NTBs in this context comprise, *inter alia*, forced technology transfer requirements, purchases by State-invested or State-controlled enterprises, and software classification and electronic commerce taxation (Vickery 1999, p. 93).

24 Eaton et al. (1998) assert a strong positive influence of improved patent protection on research activities in the European Union.

25 The competitive impact of these restrictions of competition is, however, complex. For the case of R&D co-operation cf. for instance Ruitsaert (1994). Von Weizsäcker points to increased R&D activities *cum* reduced price competition in certain take-over constellations (Von Weizsäcker 1999).

plines, and in the final analysis a supranational competition authority, would seem to be the right solution to the problem.[26]

The policy implications of the growing geographical diversification of R&D expenditures (international *generation* of knowledge) largely depend on the type of R&D activities conducted by "home" firms abroad or "foreign" companies at home and their significance for the national system of innovation and the national economy as a whole. "Outward" R&D investments of the pure adaptation-development type have little impact on the domestic economy while the corresponding "inward" flows also produce limited (positive) effects. Foreign-located R&D activities that are geared to innovation development, on the other hand, may lead to a "new technological division of labour" between parent companies and foreign subsidiaries with substantial beneficial effects for both home countries and host countries.[27] Knowledge-seeking R&D activities abroad, finally, may enhance efficiency at home, in production as well as in R&D proper, through the transfer of "tacit" knowledge which is typically "localised" in nature.

According to the OECD, policies to capture the benefits from both inward and outward R&D investment are still in a state of flux (OECD 1998, p. 78ff.). Ideas range from a "hands-off" approach to schemes of (temporary) "infant-innovation system" protection (Granstrand et al. 1993, p. 425f.). Financial investment incentives apparently have little influence on where to locate which R&D units.[28] In order to attract internationally mobile R&D activities and to secure national access to the "global pool of knowledge", policy should concentrate on upgrading the local technology base and strengthening links between the various actors in the innovation system (companies, universities, research institutes, venture capital funds, technology transfer units, government agencies at different levels, etc.), i.e. support technological "clustering" and "networking".[29] It should also further international cooperation in technology, including the participation of foreign companies (or institutions) in national (or regional) technology programmes.

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26 For a deeper discussion cf. Großmann, Koopmann et al. 1998, p. 239ff.

27 According to Pearce, home countries of MNEs have little reason to fear for the competitiveness of their own industrial sector when domestic companies increase their commitment to overseas R&D and adopt a more globalised perspective on technology and innovation as this might result in a concentration of home-country research on the country's areas of greatest scientific ability (Pearce 1995, p. 25f.).

28 This has been shown, for instance in a regression analysis for the British Midlands (Cantwell, Mudambi 1998).

29 Typical instruments of a cluster-oriented technology policy include financial support of cooperative R&D, promotion of "start-up firms" and provision of "strategic" information about scientific and technological developments in certain sectors (Boekholt, Thuriaux 1999, p. 405).

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