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National and International Developments in Technology

Trends, Patterns and Implications for Policy

Declining R&D intensities at the national level coincide with growing international technological links. In this context a number of questions arise: Do companies research in the same field of technology abroad as they do at home? 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?

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 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 government 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 government 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 inter-

vention 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 spillovers 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:

The overall R&D intensity in the business enterprise

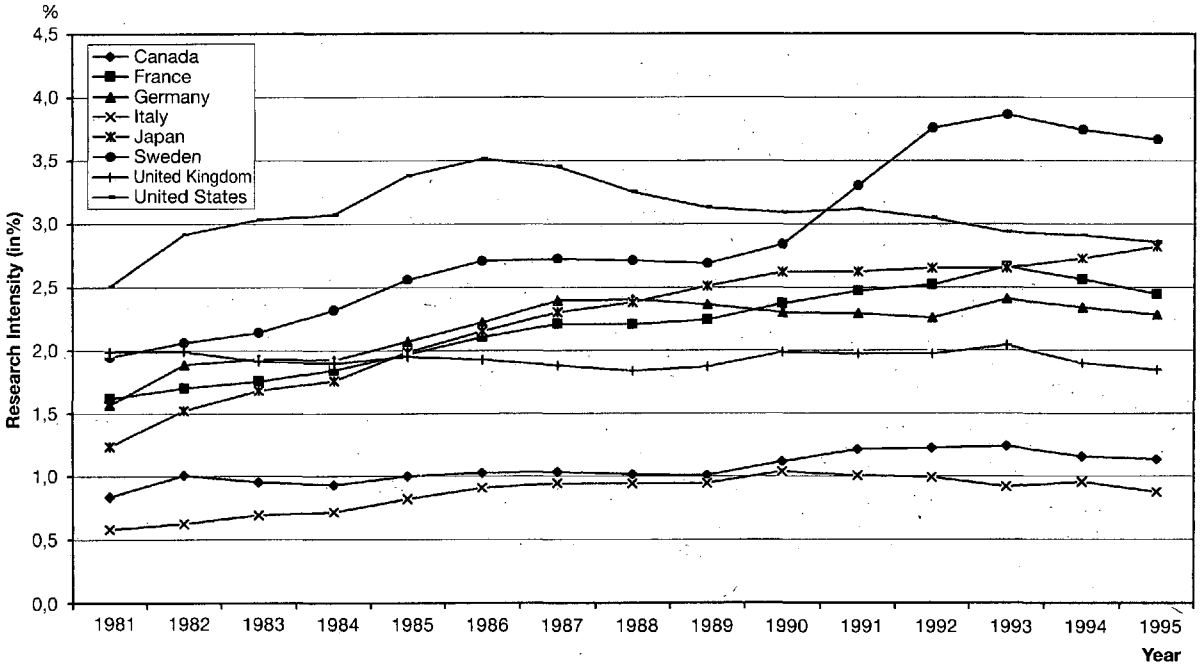
¹ R&D is a (partially) public good in that it is non-rival and non-excludable. Furthermore, R&D often displays positive externalities for production and future research that are not taken into account by researchers even in the presence of patents. However, R&D can also be accompanied by negative externalities because it frequently renders existing technology obsolete or less profitable (cf. Philippe Aghion, Peter Howitt: A Model of Growth Through Creative Destruction, in: *Econometrica*, Vol. 60, March 1992; Gene M. Grossman, Elhanan Helpman: Innovation and Growth in the Global Economy, Cambridge (Mass.) 1991; Paul M. Romer: Endogenous Technological Change, in: *Journal of Political Economy*, Vol. 98, October 1990).

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Figure 1

Research Intensities¹ in the Manufacturing Sectors of the G7 Countries and Sweden, 1981-1995



¹ R&D Expenditures as a share of gross production.

Sources: OECD ANBERD and STAN databasis.

sector as well as in the economy as a whole 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 worldwide 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 the 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?

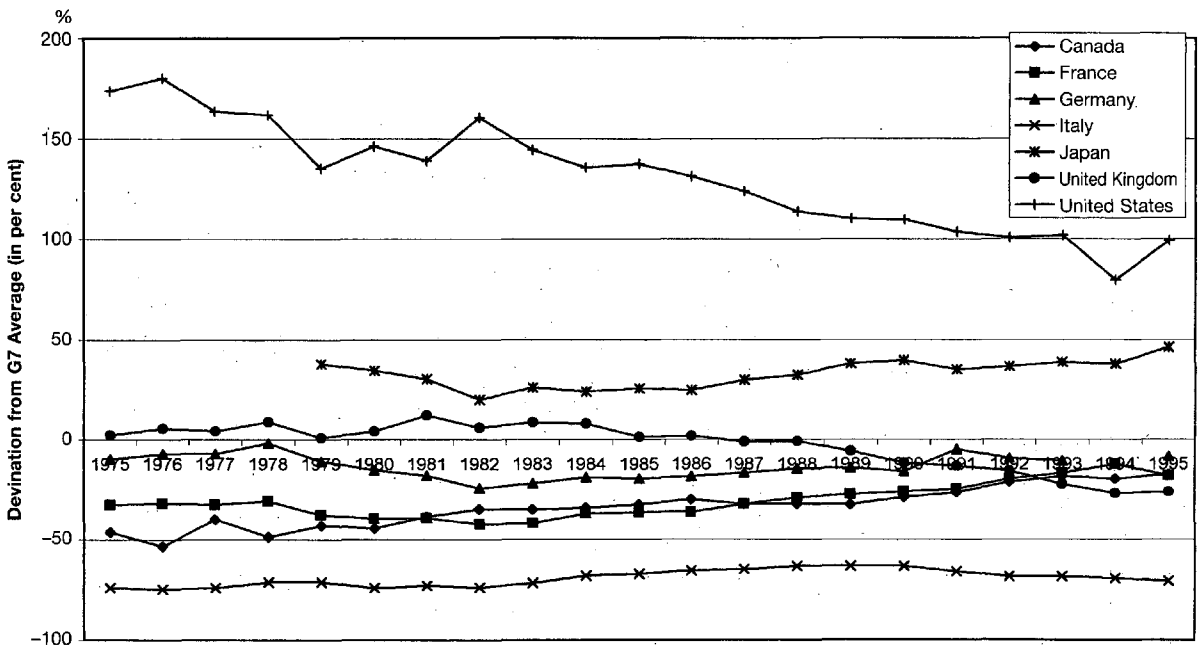
Declining and Deviating R&D Intensities

The first of the above trends, namely that of falling R&D intensities, is summarised in Figure 1, which displays R&D intensities in the manufacturing sector for the G7 countries as well as Sweden over the period 1981-95. R&D intensity, as used in this paragraph, reflects R&D expenditures as a share of gross production. An equivalent measure, which is applied subsequently, relates R&D employment to total employment. The 1980s, in particular the first half, display a 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.

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

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'.

Figure 2
Relative R&D Intensities in OECD Countries 1975-1995



Sources: OECD ANBERD and STAN databases.

$$\tau_i - \tau_w = \underbrace{\sum_{j=1}^n (\sigma_{ji} - \sigma_{jw}) \tau_{ji}}_A + \underbrace{\sum_{j=1}^n (\tau_{ji} - \tau_{jw}) \sigma_{jw}}_B + \underbrace{\sum_{j=1}^n (\sigma_{ji} - \sigma_{jw}) (\tau_{ji} - \tau_{jw})}_C$$

Here, τ_i and τ_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. τ_{ji} represents sector j 's research intensity in country i , σ_{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.³

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

□ Relative R&D intensities vary substantially from year to year in all countries. Most of these variations

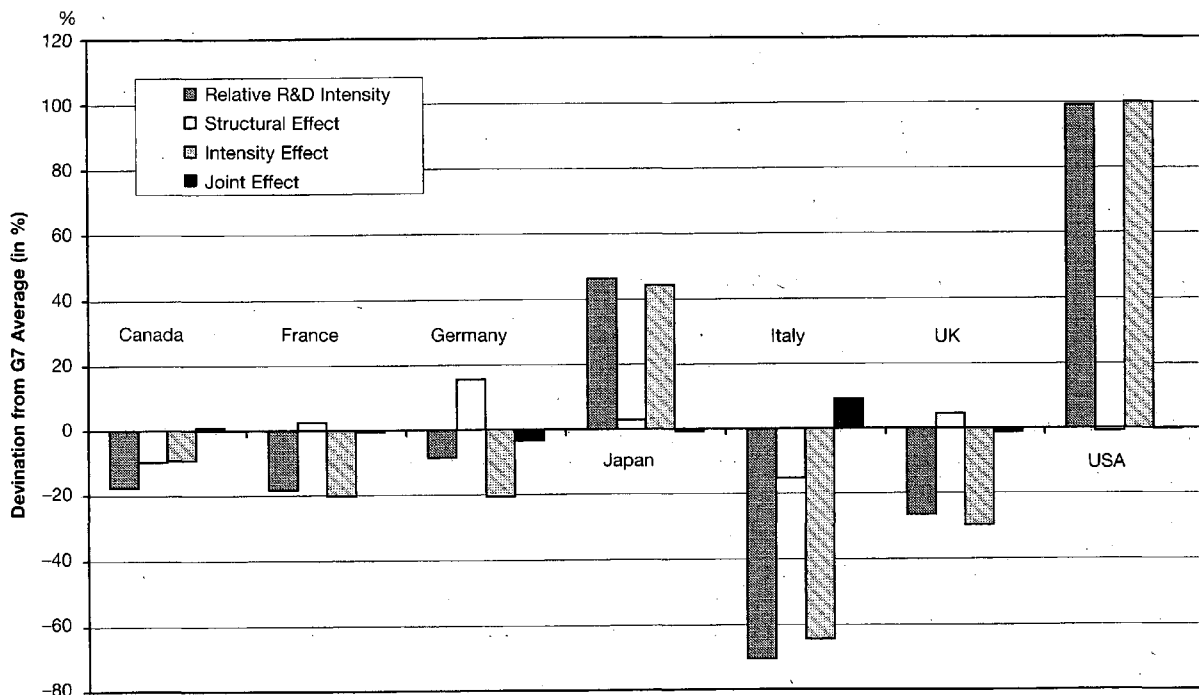
in the deviation of the individual countries' R&D intensities from the mean is driven by the intensity effect, while the structural and joint effects contribute relatively little. Hence, R&D employment proves far more variable than overall employment in the industries concerned. Moreover, the joint effect 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 (cf. Figure 2).

□ 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. The structural effects in both countries are small, as is also the case in 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, in Canada and Italy the structural and intensity effects are both negative (cf. Figure 3).

³ Eaton et al. refer to this effect as the 'interaction effect' (cf. Jonathan Eaton, Eva Gutierrez, Samuel Kortum: European Technology Policy, in: Economic Policy, Vol. 27, October 1998, p. 411).

Figure 3
Decomposition of Relative R&D Intensities¹ in G7 Countries, 1995



¹ R&D intensity measured by R&D employment as a share of total employment.

Sources: OECD ANBERD and STAN databases.

Sectoral Patterns

When the composition of relative R&D intensities is analysed separately for high and medium technology sectors,⁴ 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.

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 2). However, in both categories, the relative R&D intensities of the USA have been falling, initially in the medium and subsequently in the high technology sectors. Again, as with the decomposition 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 USA.

The above analysis refers to 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 contracted the most in terms of R&D expenditure were 'aerospace', 'shipbuilding', 'petroleum refining', 'electrical machinery' and 'ferrous metals'.⁵ In contrast, the five most dynamic sectors were 'pharmaceuticals', 'instruments', 'motor

⁴ 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).

⁵ 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.

Table 1
Decomposition of Relative R&D Intensities in the High and Medium Technology Sectors in Germany and the USA, 1975, 1985, 1995

(in %)

		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

Sources: OECD ANRSE and STAN databases.

vehicles', 'non-electrical machinery' and 'office machinery & computers'.⁶ The five largest sectors over the period under consideration were 'electronic equipment and components', 'motor vehicles', 'industrial chemicals', 'aerospace' and 'pharmaceuticals'.⁷

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 USA, the UK and Canada⁸ whereas all other countries show only small negative changes or even positive values.⁹ With regard to the sectoral distribution of R&D spending and its dynamics, we can compare countries using the following equation:

$$R_i = \sum_{j=1}^n \bar{\omega}_j (\gamma_{ij} - \bar{\gamma}_j)$$

where indices *i* and *j* denote country and sector, respectively, $\bar{\omega}_j$ is the weight of sector *j* in the average G7-economy,¹⁰ γ_{ij} denotes the variable under investigation (size or growth rate) for sector *j* in country *i* and $\bar{\gamma}_j$ 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.

⁶ Their respective growth rates were 74%, 59%, 15%, 12% and 9%.

⁷ Their respective shares of total R&D expenditure were 13%, 10%, 9%, 8% and 8%.

⁸ Growth rates of the share of R&D spending in manufacturing industry over the period 1973-1995 were -18%, -14% and -26%, respectively.

Table 3 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 particular sectors,¹¹ 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.

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 not a generalised phenomenon common to all countries, industries and companies to

⁹ The respective growth rates were -5% (France), +2% (Germany), -0.4% (Italy) and +1% (Japan).

¹⁰ As measured by the sector's share of R&D spending over the period 1993-95.

¹¹ High technology and medium technology industries are defined as in footnote 4; for large, dynamic and shrinking industries cf. the preceding paragraphs.

Table 2
Sectoral Foreign Trade according to Technology Intensities, 1976-78 and 1992-94
 (in %)

		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 GDP.

- Import Penetration defined as Import Share of Domestic Consumption (=GDP+Import-Export).

- Specialisation defined as $(X_i/M_i)/(X/M)$ where X=exports, M=imports and i=sector index.

Source: OECD STAN Database.

a similar degree. Even within one industry and among the biggest global players, firms can be observed which have spread their R&D laboratories all over the globe as well as those which have centralised these activities.¹² Among the world's largest 359 firms, wide-ranging differences exist in the degree of R&D internationalisation according to nationality and industry.¹³ 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 goods 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:¹⁴

□ *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 cooperation and alliances among independent companies, involving joint R&D projects, exchange of technical information, strategic moves etc.

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 share of sales amounting to at least 3½%, are indeed the dynamic element in world trade. Their share of total OECD trade increased from 36.2% in 1989 to 38.9% in 1996. The distinction between medium technology

¹² Cf. Klaus Brockhoff: Internationalization of Research and Development, Berlin 1998, p. 1.

¹³ Here, R&D internationalisation is measured as the share of foreign-origin patents in a company's total patents (cf. Guido Reger, Marian Beise, Heike Belitz: Innovationsstandorte multinationaler Unternehmen: Internationalisierung technologischer Kompetenzen in der Pharmazutik, Halbleiter- und Telekommunikationstechnik, Heidelberg 1999, p. 4).

¹⁴ Archibugi and Iammarino refer to international knowledge spillovers, 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. Cf. Daniele Archibugi, Simona Iammarino: Innovation and Globalisation: Evidence and Implications, Reading, February 1998, p. 5 f.

goods and high technology goods¹⁵ serves to clarify the trend towards increased trade in technology. While the share of total OECD trade of medium technology goods grew only from 22.7% to 23.0% from 1989 to 1996, trade in high technology goods expanded from 13.5% to 15.9%. Exports of technology as embodied in high technology goods have thus increased substantially.¹⁶

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 it 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 2).

Table 3
Distribution and Growth of R&D Expenditure
across G7 Countries, 1973-95 R-indices

		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
Shrinking 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

Sources: OECD Anberd and STAN databases.

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 quarters of total receipts from patents, inventions and processes in 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.

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).

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 tell. 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

¹⁵ Medium technology and high technology goods are commonly defined as those with an R&D share of sales between 3 1/2% and 8 1/2% and above 8 1/2% respectively.

¹⁶ The database used here is the OECD International Commodity Trade Statistics.

Table 4
Technological Balance of Payments of US Companies and their Foreign Subsidiaries, 1982, 1989, 1994
(in %)

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

proprietary technology often is the main ownership-specific advantage which according to the standard theory of direct investment 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.¹⁷ 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.¹⁸ 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.¹⁹ 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.

Inward and Outward R&D Investments

In actual fact, R&D is still more a headquarters 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.²⁰ 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.²¹

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%

¹⁷ Cf. Ray Barrell, Nigel Pain: Foreign Direct Investment, Technological Change, and Economic Growth within Europe, in: *The Economic Journal*, Vol. 107, November 1997.

¹⁸ Cf. Edwin Mansfield: R&D and Innovation: Some Empirical Findings, in: Zvi Griliches (ed.): *R&D, Patents and Productivity*, Chicago and London 1984.

¹⁹ Cf. Gunnar Fors: Utilization of R&D Results in the Home and Foreign Plants of Multinationals, in: *The Journal of Industrial Economics*, Vol. 45, No. 2, June 1997.

²⁰ Cf. Klaus Brockhoff, op. cit., p. 1.

²¹ Cf. Robert Pearce: The Implications for Host-Country and Home-Country Competitiveness of the Internationalisation of R&D and Innovation in Multinationals, Reading, November 1995, p. 7.

Table 5
R&D Intensities¹ for MNEs across Industries 1994
 (in %)

	Manufacturing Industry	Food	Chemicals	Metal Products	Machinery	Electronics	Transport	Instruments	All Industries
US Companies with foreign Subsidiaries	3.7	0.5	6.4	0.9	6.3	4.5	4.0	6.0	2.0
US Subsidiaries of foreign Companies	2.5	0.6	4.8	0.5	2.0	3.9	1.0	4.3	1.1
US Subsidiaries of German Companies	3.2	0.5	4.6	0.9	-	-	3.0	3.9	1.7
Foreign Subsidiaries of US Companies	1.4	0.3	2.4	0.4	1.6	1.2	1.9	1.7	0.8
German Subsidiaries of US Companies	2.5	0.2	2.2	0.9	2.8	1.9	4.2	2.4	

¹ R&D expenditure as a share of value added.

Sources: US Department of Commerce: Benchmark Survey 'U. S. Direct Investment Abroad', 1994; US Department of Commerce: Annual Survey 'Foreign Direct Investment in the U.S.', 1994.

(1920-1924) to 19% (1987-1990).²² 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 manufacturing industry affiliates in foreign countries. The US data also display a relatively strong R&D performance by foreign-owned affiliates in the United States (Table 5).

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, delinked 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 the 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)²³ to be a significant influence on the level of R&D activities abroad.²⁴ 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 and compare company and country related technological specialisation indices²⁵ for two periods (1980-1986 and 1990-1996).²⁶ 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,²⁷ using a sample of 32 multinational companies²⁸

²² Cf. John Cantwell: The Globalisation of Technology: What Remains of the Product Cycle Model?, in: Cambridge Journal of Economics, Vol. 19, 1995.

²³ Measured as a country's share of worldwide R&D expenditures in a specific industry compared to its share of total R&D expenditures.

²⁴ Cf. Gunnar Fors: Locating R&D Abroad: The Role of Adaptation and Knowledge-Seeking, in: Pontus Braunerhjelm, Karolina Ekholm, (eds.): The Geography of Multinational Firms, Boston etc. 1998, p. 129.

²⁵ Share of patents in a particular field of technology related to the share in all fields.

²⁶ Cf. Parimal Patel, Modesto Vega: Patterns of Internationalisation of Corporate Technology: Location vs. Home Country Advantages, in: Research Policy, Vol. 28, 1999.

²⁷ Cf. Walter Kuemmerle: Foreign Direct Investment in Industrial Research in the Pharmaceutical and Electronics Industries - Results from a Survey of Multinational Firms, in: Research Policy, Vol. 28, 1999.

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. 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.²⁹

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.³⁰ 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.³¹ This corresponds to the different patterns of technological specialisation displayed by the two regions.

External Technological Networks

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

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

²⁹ The survey is based on questionnaires and interviews. The sectors covered are pharmaceuticals and electronics. Home countries include the USA, Japan, Germany, France and the Netherlands.

³⁰ Cf. John Cantwell, Odile Janne: Technological Globalisation and Innovative Centres: The Role of Corporate Technological Leadership and Locational Hierarchy, in: Research Policy, Vol. 28, 1999.

³¹ According to Dunning, M&As account for more than half of all foreign direct investments and concentrate on knowledge and information intensive industries. Cf. John H. Dunning: Location and the Multinational Enterprise: a Neglected Factor?, in: Journal of International Business Studies, Vol. 29, No. 1, 1998, p. 50.

³² Cf. Pierre Buigues, Alexis Jacquemin: Structural Interdependence between the European Union and the United States: Technological Positions, in: Gavin Boyd, (ed.): The Struggle for World Markets. Competition and Cooperation between NAFTA and the European Union, Cheltenham (UK) and Northampton (Mass.) 1998, p. 47 f.

³³ Cf. Reinhold Veugelers: Internal R&D Expenditures and External Technology Sourcing, in: Research Policy, Vol. 26, 1997.

³⁴ Cf. John Hagedoorn: The Economics of Cooperation among High-Tech. Firms. Trends and Patterns in Strategic Technology Partnering since the Early Seventies, in: Georg Koopmann, Hans-Eckart Scharrer (eds.): The Economics of High-Technology Competition and Cooperation in Global Markets, Baden-Baden 1996.

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.³² 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 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.³³ They often also

Table 6
External R&D Links¹ of Industrial Companies
in Germany, 1979-95

	(in %)				
	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 Finance	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 \$ m.)	22,195.4	29,331.4	40,565.4	50,793.6	51,955.0

¹ External R&D as a share of internal R&D.

Source: Stifterverband für die Deutsche Wissenschaft: Forschung und Entwicklung in der Wirtschaft, various issues.

Table 7
Intraregional and Interregional Technological Alliances 1980-1994

(in numbers of alliances)

	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
Intraregional	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
Interregional	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

Source: National Science Board: Science & Engineering Indicators 1996, Washington, DC 1996, Appendix table 4-38.

serve 'non-technological' aims such as improved market access or ensuring better market control. However, it is in practice very difficult 'to separate the competitive pressures from the technological imperatives'.³⁴ 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).³⁵

While the majority of technology alliances are still national or regional (European) in outlook, international/interregional partnerships have gained in 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 has also been claimed, especially with regard to American-European partnerships, that the R&D content of these collaborations has been increasing at the expense of non-technological cooperation via joint production or joint marketing.³⁶

National and International Policy Challenges

In view of the decisive importance of R&D and technology for economic performance, technological internationalisation in the three dimensions discussed above is undoubtedly 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 the 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).³⁷

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,³⁸ while in the case of FDI a binding framework of common rules for investors, beyond the prohibition of some Trade-

³⁴ John Hagedoorn: Atlantic Strategic Technology Alliances, in: Gavin Boyd, (ed.): The Struggle for World Markets. Competition and Cooperation between NAFTA and the European Union, Cheltenham (UK) and Northampton (Mass.) 1998, p. 179.

³⁵ Cf. Daniele Archibugi, Simona Iammarino, op. cit., p. 13. For European companies, Buigues and Jacquemin find a positive correlation between R&D intensity and alliance intensity. Cf. Pierre Buigues, Alexis Jacquemin, op. cit., p. 49. For a similar result concerning US companies, cf. Varghese P. George: Globalization through Interfirm Cooperation: Technological Anchors and Temporal Nature of Alliances Across Geographical Boundaries, in: International Journal of Technology Management, Vol. 10, No. 1, 1995.

³⁶ Cf. John Hagedoorn: Atlantic Strategic Technology Alliances, op. cit.

³⁷ 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 (cf. Raymond E. Vickery Jr.: Semiconductors and Information Technology. A Better Way, in: Journal of World Trade, Vol. 33, No. 2, 1999, p. 93).

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.³⁹

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.⁴⁰ 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 disciplines, and in the final analysis a supranational competition authority, would seem to be the right solution to the problem.⁴¹

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.⁴² 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.⁴³ Ideas range from a 'hands-off' approach to schemes of (temporary) 'infant-innovation system' protection.⁴⁴ Financial investment incentives apparently have little influence on where to locate which R&D units.⁴⁵ 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'.⁴⁶ It should also further international cooperation in technology, including the participation of foreign companies (or institutions) in national (or regional) technology programmes.

⁴² 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 (cf. Robert Pearce, *op. cit.*, p. 25 f.)

⁴³ Cf. OECD: *Science, Technology and Industry Outlook*, Paris 1998, p. 78 ff.

⁴⁴ Cf. Ove Granstrand, Lars Hakanson, Sören Sjölander: *Internationalization of R&D – a Survey of Some Recent Research*, in: *Research Policy*, Vol. 22, 1993, p. 425 f.

⁴⁵ This has been shown, for instance, in a regression analysis for the British Midlands (cf. John Cantwell, Ram Mudambi: *The Location of MNE R&D activity: The Role of Investment Incentives*, Reading, May 1998.)

⁴⁶ 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 (cf. Patries Boekholt, Ben Thuriaux: *Public Policies to Facilitate Clusters: Background, Rationale and Policy Practices in International Perspective*, in: OECD (ed.): *Boosting Innovation: the Cluster Approach*, Paris 1999, p. 405.

³⁸ Cf. Harald Grossmann, Georg Koopmann, Christine Borrmann, Konstanze Kinne, Elke Kottmann: *Handel und Wettbewerb – Auswirkungen von Wettbewerbsbeschränkungen zwischen Unternehmen auf die internationale Arbeitsteilung*, Baden-Baden 1998, p. 213. Eaton et al. assert a strong positive influence of improved patent protection on research activities in the European Union (cf. Jonathan Eaton et al., *op. cit.*).

³⁹ Cf. Rolf Langhammer: *The WTO and the Millennium Round: Between Standstill and Leapfrog*, Kiel Discussion Papers, No. 352, August 1999, p. 12 ff.

⁴⁰ The competitive impact of these restrictions of competition is, however, complex. For the case of R&D cooperation cf. for instance Pauline Ruitsaert: *To Promote R&D Cooperation: A Strategic Trade Policy?* Maastricht, April (1994). Von Weizsäcker points to increased R&D activities cum reduced price competition in certain take-over constellations (cf. Carl-Christian von Weizsäcker: *Keine Angst vor Fusionen*, in: *Frankfurter Allgemeine Zeitung* of 24. 4. 1999.

⁴¹ For a deeper discussion cf. Harald Grossmann, Georg Koopmann et al., *op. cit.*, p. 239 ff.