EUROPEAN COMMISSION

Brussels, 28.10.2010
SEC(2010) 1276 final
VOLUME III

COMMISSION STAFF WORKING DOCUMENT

European Competitiveness Report 2010

Accompanying document to the

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

An integrated Industrial Policy for the Globalisation Era
Putting Competitiveness and Sustainability at Front Stage

{COM(2010) 614}
{SEC(2010) 1272}

COMMISSION STAFF WORKING DOCUMENT

European Competitiveness Report 2010

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3. FOREIGN CORPORATE R&D AND INNOVATION IN THE EUROPEAN UNION

3.1. Introduction

The internationalisation or globalisation of economic activity is one of the most significant changes the world economy has experienced over the last thirty years. Firms have considerably expanded their business by exports and foreign direct investment (FDI). A strong impetus for this expansion came from the opening of new markets in China, India and other emerging economies and the economic integration of the former communist countries in Central and Eastern Europe into the world economy.

Globalisation does not only change trade and FDI flows. It also opens up access to new knowledge, and it shapes and transforms the innovation processes of firms. It poses new requirements in terms of the knowledge needed to compete on domestic and international markets. To meet these requirements, an increasing number of firms, in particular large multinational enterprises (MNEs), locate research, development and innovation activities outside their home countries. This is what has become known as the internationalisation of corporate R&D and innovation (Narula and Zanfei 2005; OECD 2008; Dunning and Lundan 2009).

The aim of this chapter is to study the internationalisation of R&D and innovation for the European Union. Section 2 of the chapter gives a brief overview of the motives of firms when they internationalise R&D and innovation. Section 3 looks at R&D and innovation activities of foreign-owned firms in the EU by sector, country and technology. Section 4 examines the activities of EU firms outside the European Union. Sections 5 and 6 investigate whether — and how — foreign-owned and domestically owned firms differ in their innovation behaviour. Section 7 investigates how both groups transform innovation into productivity and employment growth. Section 8 draws conclusions from the analysis.

3.2. Motives of firms when they internationalise R&D and innovation activities

The decision of a firm to go abroad with R&D and other innovation activities is a trade-off between the benefits of doing R&D and innovation at various locations and the costs associated with the decentralised organisation of R&D and innovation.

Benefits of doing R&D and innovation abroad are related to the generation and acquisition of new knowledge which is not available in the home country. The literature describes two principal strategies which emerge from this knowledge motive (von Zedtwitz and Gassmann 2002; Cantwell and Mudambi 2005; Narula and Zanfei 2005): first, overseas R&D and innovation seek to create localised, market-oriented knowledge which helps firms to adapt existing technologies and products to foreign markets and to boost the overall revenue they generate from these assets (‘*asset-exploiting*’ strategy). R&D and innovation often follow other economic activity, in particular production and sales, to locations abroad and are in most cases an extension of existing overseas production and marketing activities. As a result, countries with strong economic ties in foreign trade and FDI are also integrated in corporate R&D and innovation. Second, R&D and innovation activities of MNEs abroad focus on creating the kind of technological and scientific knowledge that may find application in the whole enterprise group. This is known as the ‘*asset-augmenting*’ strategy. Research suggests that asset-exploiting strategies still prevail, although asset-augmenting is gaining in importance (le Bas and Sierra 2002).

Another important motive for overseas R&D and innovation activities — besides a lack of knowledge — are capacity bottlenecks in the home country. In a number of cases, firms move abroad because they cannot find enough research staff at their headquarters location. The internationalisation of R&D and innovation has also been fuelled by cross-border mergers and acquisitions.

Cost differences between countries, in contrast, seem to be less important for R&D and innovation than for production, and only relevant for certain locations. Evidence from innovation surveys and econometric studies shows cost advantages having only a modest influence compared to other locational advantages (Thursby and Thursby 2006; Kinkel and Maloca 2008; Belderbos et al. 2009; European Commission JRC IPTS 2009b).

The internationalisation of R&D and innovation can create advantages for enterprises; such advantages are not, however, cost-free. The costs of internationalisation (Gersbach and Schmutzler 2006; Sanna-Randaccio and Veugelers 2007) comprise first of all the foregone benefits of R&D centralisation, including economies of scale and scope from specialisation and a tighter control over core technologies. Second, additional costs arise from higher coordination efforts and the cost of transferring knowledge within the MNE. Despite its public-good characteristics, transferring knowledge is an expensive process because of its 'tacit', localised and context-related nature. Third, concentrating innovation activity in the home country is favoured by various linkages between the firm and the host country innovation system. Patel and Pavitt (1999) and Narula (2002) point out that many firms are strongly embedded in their home country innovation system, with ties that include formal R&D cooperation schemes with domestic universities and research centres, and informal networks that have grown from doing business together in the past. Informal networks between firms may also evolve from staff undergoing joint training at universities and research centres and from labour mobility.

It is also important to consider the influence of differences across technologies and sectors. The knowledge bases of technologies and sectors differ in their degree of tacitness, their cumulativeness, appropriability, spatial concentration, or the degree they draw on and refer to knowledge external to the firm (Marsili 2001; Malerba 2005a, b). These differences translate into different degrees of internationalisation of R&D and innovation at the sectoral and technology level. A high degree of tacitness, for example, makes it more difficult and expensive to transfer knowledge between the parent company and the affiliate. This may reduce intra-firm knowledge transfer, but may also call for a more decentralised organisation of R&D and innovation, because many tasks can only be done at the affiliate.

3.3. Mapping the internationalisation of R&D and innovation activities in the EU

3.3.1. Internationalisation at the EU-27 level

The analysis starts by examining the degree of internationalisation and characteristics of foreign-owned R&D and innovation activity in the EU Member States. R&D and innovation in firms is a multifaceted process that cannot really be described or measured by reference to a single data source. It is therefore important to look at a variety of data sources to capture different aspects of innovation behaviour (see Annex: Measuring the internationalisation of R&D and Innovation).

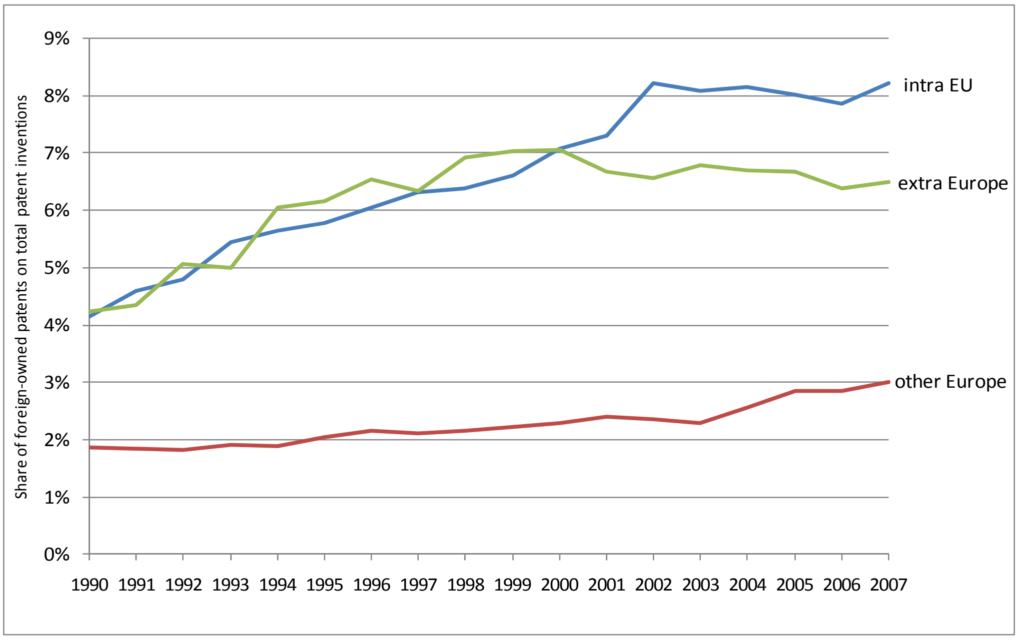
Patent data from the European Patent Office (EPO) is a rich source for surveying the innovation activities of foreign-owned firms in the EU as well as cross-border links between EU Member States and countries outside the EU. Patent documents include the location of the applicant and the location of the inventor of a particular patent. By comparing the two, one can derive a measure for the foreign ownership of patent inventions in a particular country. The share of foreign-owned patents in all patent applications of a country will be used as an indicator for the internationalisation of R&D and innovation in that country.

The data reveal that the internationalisation of R&D and innovation has increased considerably in the EU. The share of foreign-owned patents in all patent inventions in the EU-27 at the EPO[1] climbed from about 10 % in 1990 to around 17 % in the years 2002 to 2007. This upward trend is even more striking in terms of absolute numbers: the total number of foreign-owned patents rose from 2 772 in 1990 to 9 677 in 2005, an increase of 249 %. Domestically owned patent inventions, by contrast, increased by 88 % in the same period.

Despite a rising degree of internationalisation, foreign-owned patents are still an exception. Patents owned by domestic applicants — individuals, firms, universities or other organisations — still account for the bulk of R&D and innovation in the EU. The data give no indication of any substitution or crowding-out of domestic by foreign-based activity.

Figure 3.1 further distinguishes between patent inventions owned by applicants located in EU-27 countries (intra EU), in other European countries (other Europe) and in countries outside Europe (extra Europe in Figure 3.1). Between 1990 and 1998, internationalisation increased steadily in all three groups. Since 1998, there has been a diverging development between the three groups: i) the share of foreign-owned patent inventions with applicants from outside Europe stagnated at between 6% and 7%; ii) the share of 'other Europe' and in particular intra-EU ownership continued to increase, at least until 2002, reflecting R&D and innovation integration and exploitation of Single Market opportunities as well as efforts to support the emergence of a European Research Area.

Figure 3.1: Share of foreign-owned patents in all domestic patent inventions in the EU-27 by country groups, 1990-2007, EPO.



Source: European Patent Office, ZEW/AIT calculations.

[1] Data provided by the EPO PATSTATS database, edition October 2009.

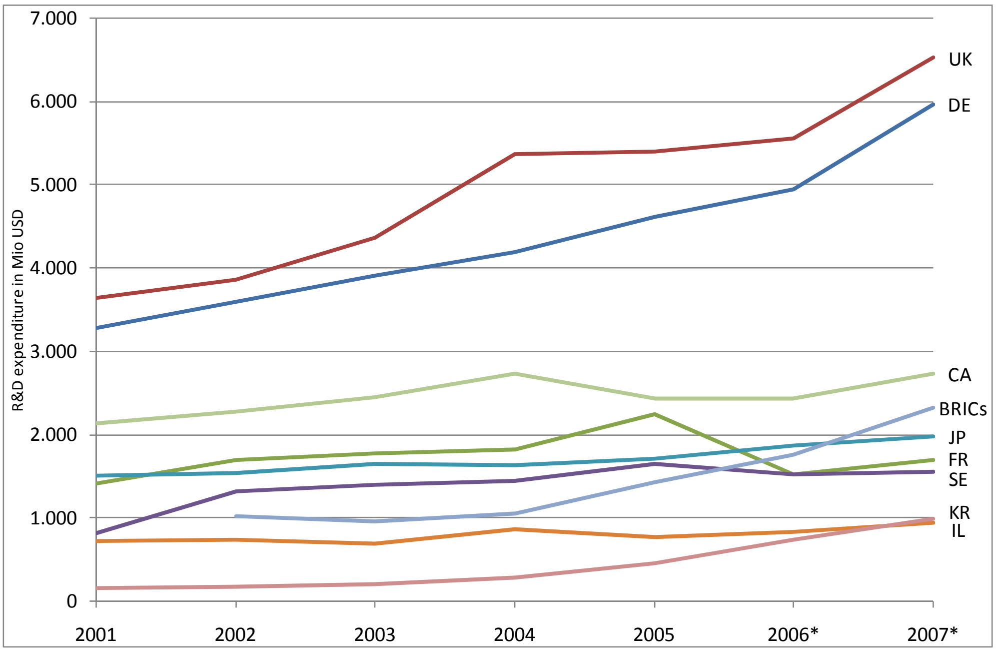
Later, around 2002 (after peaking at almost half of all foreign-owned patents invented in the EU-27), the share of intra-EU applicants began to lose ground. As a consequence, the overall degree of internationalisation of innovation and R&D in the European Union has remained fairly stable over more recent years, as measured by cross-border patent ownership.

3.3.2. Trends at the country level

The increasing internationalisation of R&D and innovation is also reflected in R&D expenditure. Figure 3.2 shows — as an example — R&D expenditure by overseas subsidiaries of US multinationals in Mio USD for the period 2001 to 2007.

US MNEs devote substantial resources to R&D activities abroad, particularly in the EU-27. Expenditure has increased considerably since 2001 in all EU countries depicted in Figure 3.2 (except for France, for which there is a relative stagnation in that period). The EU and its single market consistently attracted more than 60% of all US overseas R&D expenditure from 2001 to 2007, followed by Canada (with a much smaller share of around 10%). R&D expenditure of US MNEs in Brazil, Russia, India, and China (referred to as BRICs) is still at a low level, but is growing fast. R&D in Japan and Korea, by contrast, is stagnating or increasing only slightly.

Figure 3.2: R&D expenditure of overseas subsidiaries of US multinational firms, 2001-2007, Mio USD



* only majority-owned affiliates; KR: Korea; IL: Israel; CA: Canada; BRICs: Brazil, Russia, India, China.

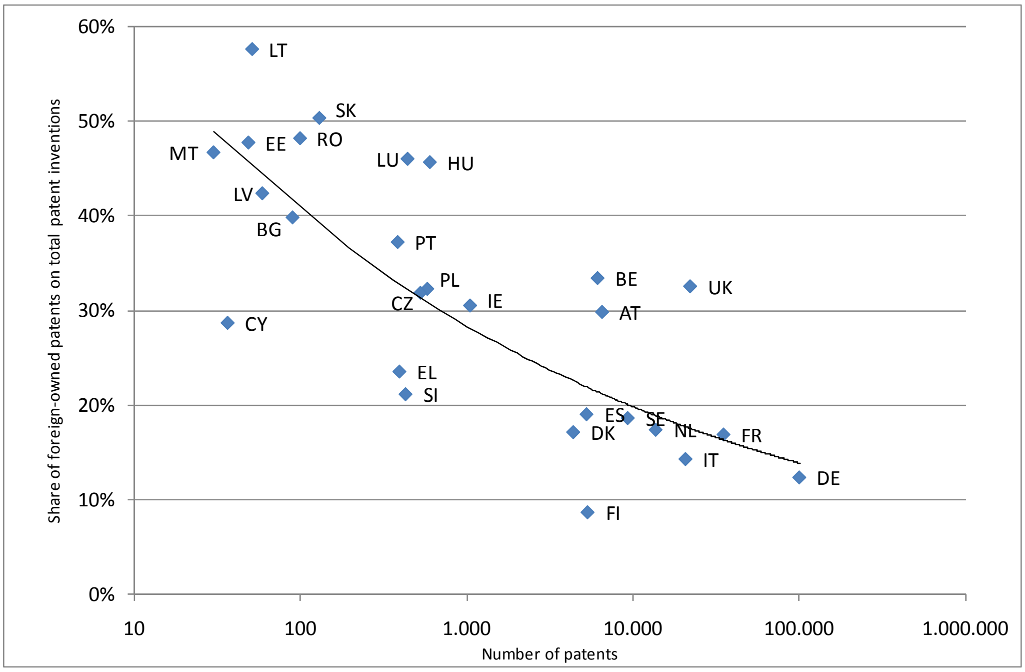
Source: OECD FATS database, US Department of Commerce, ZEW/AIT calculations.

The upward internationalisation trends can also be observed in data on R&D expenditure by foreign-owned affiliates, provided by the OECD FATS database and EUROSTAT. Sweden is the country with the longest time series in these databases. The share of foreign-owned affiliates in the Swedish manufacturing sector increased from 14.5% (1990) to 40% in 2007. The share of foreign-owned affiliates in manufacturing sector R&D expenditure also expanded in large countries such as France (1994:15.4%; 2007: 21.1%). Upward internationalisation trends are the general rule for all countries for which data are available.

The upward trend is confirmed by patent data. Both datasets, R&D expenditure and patent data, indicate that small and medium EU countries tend to have a higher degree of internationalisation of R&D and innovation (as is the case for trade and FDI). Figure 3.3 illustrates the relationship between size and the degree of internationalisation by comparing the absolute number of patent inventions (horizontal axis) with the share of foreign-owned patent inventions (vertical axis).

The countries with the highest share of foreign-owned patent inventions in the EU according to Figure 3.3 all have a comparable small absolute number of patent inventions: Malta, the Baltic States, Romania, Bulgaria, Slovakia and Luxembourg. Large EU countries such as Germany, France or Italy, by contrast, exhibit moderate levels of internationalisation.

Figure 3.3: Share of foreign-owned patent inventions and total number of patent inventions by country, 2003-2007, EPO



Source: European Patent Office, ZEW/AIT calculations.

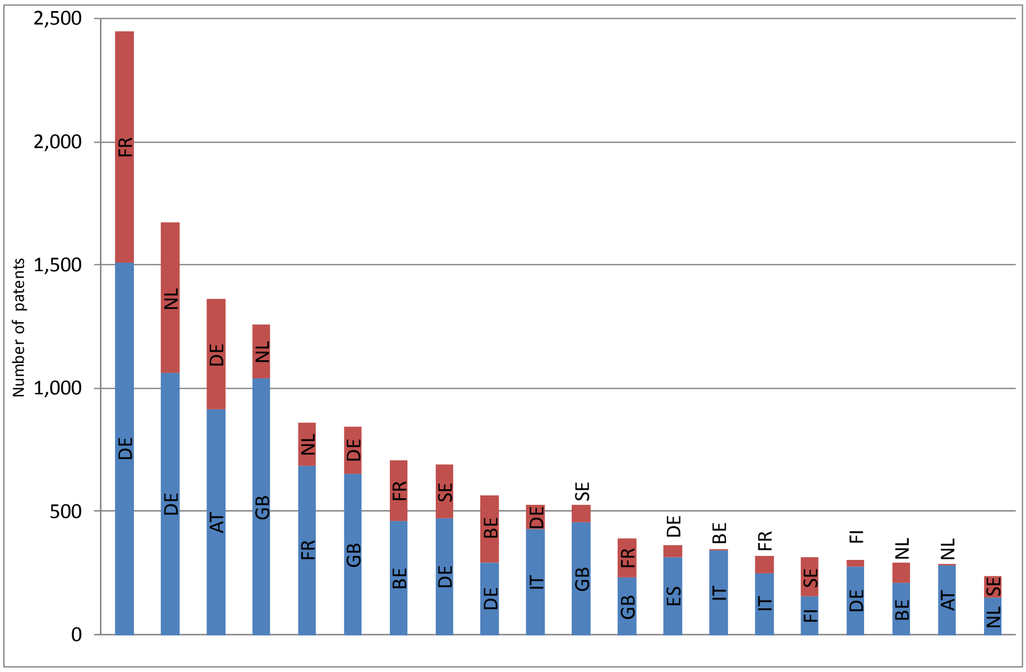
But there are also exceptions to this rule. The United Kingdom has a considerably higher share of foreign-owned patent inventions than other countries of comparable size. This is due to Japanese and US multinationals which have chosen the UK as their main location in the EU. The UK is also the EU country with the largest inward FDI stock of all EU Member States in absolute terms.

Other positive outliers are Austria and Belgium. Their high level of internationalisation can be explained in part by their proximity to a large neighbouring country. Research has identified geographical and cultural proximity (including a common language) as factors that promote R&D internationalisation between two countries (Guellec and van Pottelsberghe de la Potterie 2001; Eden and Miller 2004, Picci 2010). Finland, by contrast, is the EU country with the lowest degree of internationalisation (more than 90% of the impressive number of patents granted in the country in 2003-2007 are the result of Finnish organisations; R&D and innovation efforts). This correlates with a comparable small stock of inward FDI and R&D expenditure by foreign-owned affiliates in Finland.

Similar cross-country internationalisation patterns can be observed for R&D expenditure by foreign-owned affiliates for the countries for which data are available (see Table 1 in the Annex). Smaller EU countries and the United Kingdom have high shares of foreign R&D expenditure, while other large Member States exhibit low levels. Finland is also the least internationalised country in terms of R&D expenditure by foreign-owned affiliates. Countries with a high share of foreign-controlled R&D expenditure include Austria, the Czech Republic, Hungary, Ireland and Slovakia (in these five countries, foreign-owned affiliates account for the majority of total manufacturing R&D expenditure).

As observed (see Figure 3.1 above), intra EU-27 cross-border R&D and innovation activities account for about half of all foreign-owned patents in the EU-27 and contributed in large measure to the overall performance and internationalisation dynamics in the European Union. Figure 3.4 shows the twenty most important country pairs in terms of the absolute number of cross-border patents in the European Union. The values in Figure 3.4 are bi-directional; the value of a country pair A/B includes both patents invented in country B and applied for by country A, and patents invented in country A and applied for by country B.

Figure 3.4: 20 largest country pairs in terms of cross-border ownership EU-27, 2003-2007, EPO



Note: Numbers refer to the country of invention; in Germany, for example, more than 1 500 patents were applied for by France. In turn, around 900 patents applied for in France have a German applicant.

Source: European Patent Office, ZEW/AIT calculations.

With almost 2 500 foreign-owned patents, Germany/France is the most important country pair within the EU. Almost two thirds of these patents are German and have a French applicant; the other third consists of French patents with a German applicant. The pair ranked second is Germany and the Netherlands — again, the majority of these foreign-owned patents are German. Pair number three also involves Germany, this time together with Austria.

The country pairs reveal some important facts about intra-EU internationalisation: i) 15 of the top 20 country pairs feature Germany, France or the United Kingdom, which are also the three largest countries in terms of patents granted; ii) the dominant pattern in Figure 3.4 links a large and a medium-sized or small country. In almost all cases, the large and the medium or small country are neighbours, share a certain degree of cultural similarity (e.g. a common language), and have a long-standing business relationship indicated by a large mutual stock of FDI.

Medium-sized and small Member States play an important role in intra-EU integration in R&D and innovation. But not all such countries are equally represented. The internationalisation of R&D and innovation within Europe mainly involves R&D and innovation-intensive countries. There are 702 possible country pairs in the EU-27, but only half of them (370) are connected by foreign-owned patent. In 332 cases, there is no relationship. Examples for these 'missing links' are Greece/Austria, Finland/Slovenia, Finland/Netherlands and Belgium/Ireland. Other links, by contrast, are considerably stronger in relative terms than the absolute number of foreign-owned patents between two countries would suggest (see Box 3.1).

Box 3.1: Strong and weak links between EU Member States

The strength of cross-border links in absolute numbers of patents may be distorted by the size and patenting activity levels of different countries. A look at relative numbers is therefore useful to identify country links which are not based solely on the size of the country but on above-average strength of cross-border ownership. This can be done by calculating an index relating the strength of the relationship between two countries to their relative size within Europe in terms of the number of cross-border patents. The notion is similar to that of other specialisation indexes, such as the Revealed Technological Advantage (RTA) Index:

$$X_{ai} = \frac{\dfrac{P_{ai}}{\sum_i P_{ai}}}{\dfrac{\sum_a P_{ai}}{\sum_a \sum_i P_{ai}}}$$

Note: P: Number of patents; a: applicant country; i: inventor country

In addition, the analysis corrects for outliers in two ways: i) countries with less than 50 cross-border patents 'are dropped'; ii) values are not reported for country pairs in which both partners have individually less than 500 cross-border patents in total (third row and third column from the end in Table 3.1). These pairs are coloured grey in the table. This filter results in 15 applicant countries (Cyprus, Malta and the EU-15 countries —except Greece and Portugal), 19 inventor countries (the Czech Republic, Hungary, Poland, Slovenia, Slovakia and EU-15 — except Luxembourg) and 205 possible country pairs (Table 3.1).

It can be seen from Table 3.1 that there are considerable differences in the strength of the links between two countries: 25 of the 205 pairs have a very strong link with a value greater than 2, indicating that the number of foreign-owned patents between two countries is twice the number that would result from a uniform distribution across EU countries on the basis of their overall number of cross-border patents. Many of these strong country links can be explained by a common language, geographic proximity or a long history of economic integration; examples include links between the Nordic countries, between Austria and Germany, between Ireland and the UK, or between France and Belgium.

But not all countries which are close in terms of geography or culture have strong ties; the number of foreign-owned patents between Belgium and the Netherlands, for example, is surprisingly low. In contrast, there are also some surprisingly strong links in Table 3.1, which can hardly be explained by geographic or cultural proximity. These pairs are somewhat idiosyncratic, i.e. firm-specific, results of managerial intentions, strategies and action. Italy, for example, is more important for Belgium as an inventor country in relative terms than France. Finland is the largest applicant country of foreign-owned patents in Portugal in relative terms, as is Germany in Slovenia. The majority of the medium and small countries have at least one ‘missing link’ (last row and column to the right; there are, for example, no cross-border patents between Austria and Greece or between Finland and Slovenia).

Table 3.1: Relative strength of country pairs in foreign-owned patents, selected EU-27 countries, 2003-2007, EPO

		Applicant															No of Patents	Strong links	Missing links
		AT	BE	CY	DE	DK	ES	FI	FR	IE	IT	LU	MT	NL	SE	UK			
Inventor	AT		0.07	2.30	2.37	0.08	0.11	1.49	0.19	0.04	0.60	0.09	0.49	1.01	0.09	0.12	1431	2	0
	BE	0.10		1.53	0.79	0.78	0.30	0.41	2.29	3.21	0.33	2.43	0.35	0.85	0.12	0.54	1226	3	0
	CZ	1.08	1.91		1.95			0.35	0.37					0.52	0.10	1.25	100	0	0
	DE	2.17	0.73	0.48		0.74	0.81	0.87	1.50	0.39	1.06	1.18	1.47	0.87	0.75	0.53	4829	1	0
	DK	0.10	0.14		1.48			4.47	0.19					0.20	1.48	1.64	398	1	0
	ES	0.30	0.57	0.00	1.81	1.07		0.20	1.18	0.20	2.29	0.00	0.00	0.22	0.73	1.92	662	1	3
	FI	0.07	0.31		0.35				0.19					0.22	5.63	2.50	275	2	0
	FR	0.30	1.31	0.30	1.20	0.47	1.41	0.09		0.66	1.59	1.30	0.52	1.22	0.66	0.95	2540	0	0
	GR	0.00	0.93		2.01			0.21	0.20					0.05	0.12	3.16	57	2	1
	HU	0.55	0.25		1.56			3.34	0.67					0.07	2.31	0.38	196	2	0
	IE	0.04	0.00		0.82			0.21	0.61					0.28	1.64	7.74	73	1	1
	IT	0.52	3.22	0.59	0.96	0.22	1.99	0.29	0.95	1.78		1.30	2.02	0.30	1.16	1.36	1684	2	0
	NL	0.16	0.81	0.77	1.40	1.39	1.03	0.11	0.67	0.77	0.45	0.10	0.72		0.91	2.32	1364	1	0
	PL	0.88	0.38		1.55			1.75	0.31					0.68	0.79	2.33	72	1	0
	PT	0.30	0.12		2.50			2.86	0.18					0.11	0.24	0.86	113	2	0
	SE	0.37	0.73	2.93	1.00	5.18	0.46	3.75	0.32	0.83	0.10	0.47	1.45	0.58		1.44	756	3	0
	SI	1.08	0.00		2.80			0.00	0.46					0.12	0.00	1.62	71	1	3
	SK	1.22	0.09		1.64			1.10	0.58					0.03	0.00	0.74	58	0	1
	UK	0.49	0.55	0.15	0.82	0.80	0.28	1.05	0.49	1.33	0.67	0.27	0.25	1.81	1.55		2894	0	0
Patents		599	1169	85	4933	395	168	932	2932	350	274	458	63	3554	1828	1051		25	9
strong links		1	1	2	4	1	0	4	1	1	1	1	1	0	2	5	25		
missing links		1	2	1	0	0	0	1	0	0	0	1	1	0	2	0	9		

Note: Applicant countries are in columns, while inventor countries are in the rows of Table 3.1. A value larger than one indicates that the linkage between two countries in terms foreign-owned patent inventions is stronger than the relative size of the two countries would suggest. A value of 1.91 in the case of Belgium (applicant) and the Czech Republic (inventor) therefore reveals that this relationship has almost twice the strength as could be expected from relative shares of the two countries.

Source: European Patent Office, ZEW/AIT calculations.

Medium and small Member States in particular tend to have strong links with only a limited number of EU partners (while links to the other EU countries tend to be weak or even non-existent). Links are also often limited to one direction (e.g. the importance of Italy as an inventor country for Belgian applicants is not mirrored by Belgium as an inventor country for Italian applicants).

The majority of intra-EU cross-border patents are owned by organisations located in EU-15 countries. Cross-border patents between the EU-12 and the EU-15 countries and within the EU-12 are still rare. One important exception is patenting activity between Slovakia and the Czech Republic. Germany is both the most important inventor country for the EU-12 in absolute terms and also by far the most important applicant country for foreign-owned patents in the EU-12. Other countries with growing relationships to the EU-12 are Austria, Sweden, United Kingdom, France and Finland.

R&D expenditure data are sparser but tend to confirm the main patterns found in EU cross-border patents. For example, German multinationals account for 15.6% of all foreign-owned patents in France between 2003 and 2007. The corresponding share of German subsidiaries in total foreign-controlled R&D expenditure in France between 2003 and 2006 is 16.1%. The EU-15 are home to more than ¾ of foreign affiliates' R&D expenditure in Slovakia's manufacturing sector in 2007 (Slovakia is the only EU-12 country with comprehensive and up-to-date inward R&D flows). The corresponding figure for Poland in 2006 is at similar level (71.7%). R&D expenditure by foreign affiliates of EU-15 firms in the EU-12 may suggest a higher degree of R&D and innovation integration that is not yet reflected in the patent data.

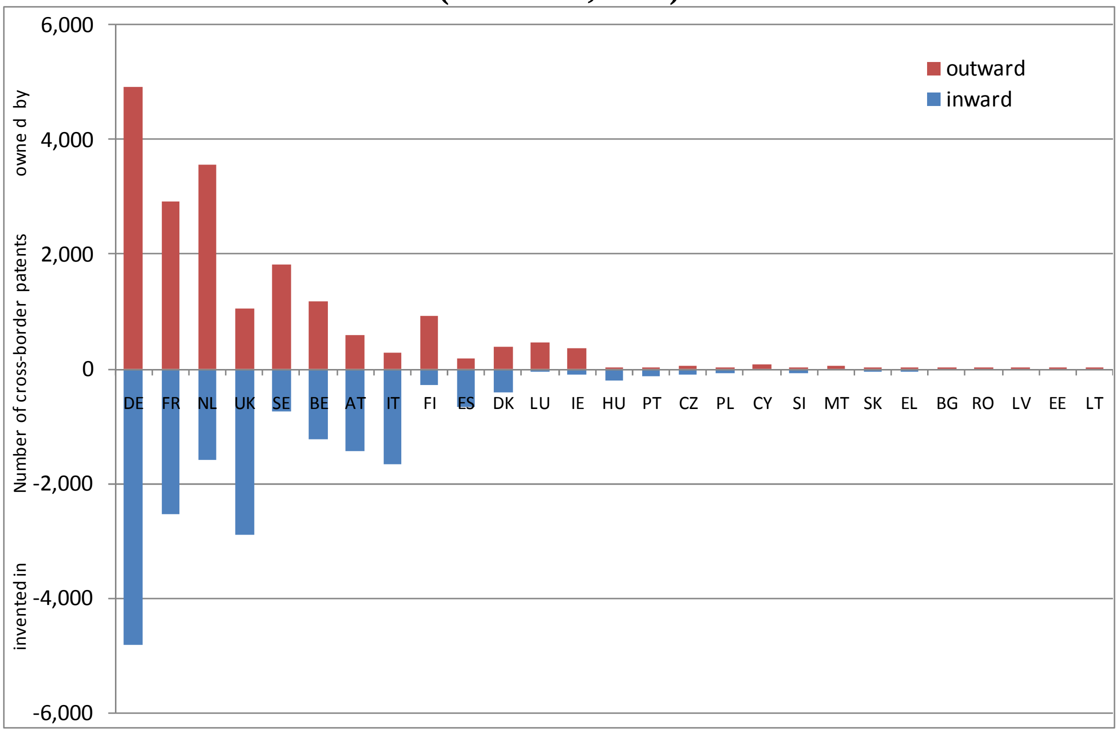
EU countries reveal different patterns in terms of inward and outward internationalisation of R&D and innovation, as measured by cross-border patents. Country A inward internationalisation means patents granted in country A and owned by another country. Outward internationalisation, on the other hand, refers to patents owned by country A but granted in another country. Figure 3.5 depicts outward and inward internationalisation measured by the total number of cross-country patents. Three groups of countries can be identified here:

- Inward is stronger than outward internationalisation in the United Kingdom, Austria, Italy, Spain, Portugal, Greece and all EU-12 countries except Cyprus. These countries are more host than home countries of R&D and innovation internationalisation. With the exception of Austria and the UK, internationalisation tends to be low in absolute terms in these countries, which can be explained by a lack of domestic MNEs investing in other countries.

- Outward internationalisation is stronger in the Netherlands, Sweden, Finland, Luxembourg, Ireland and Cyprus. A common feature of these small and medium countries is that they are home to a number of multinational firms which actively pursue internationalisation.

- In Germany, France, Belgium and Denmark, inward and outward flows are about equally proportioned. Countries in this group take different positions depending on the partner. Germany, for example, is a major location for patents held by French, Dutch, Swedish or Finnish multinationals, but is not very active in the last three countries.

Figure 3.5: Absolute number of intra-EU cross-border patents by country (2003-2007, EPO)



Source: European Patent Office, ZEW/AIT calculations.

3.3.3. Technologies and sectors

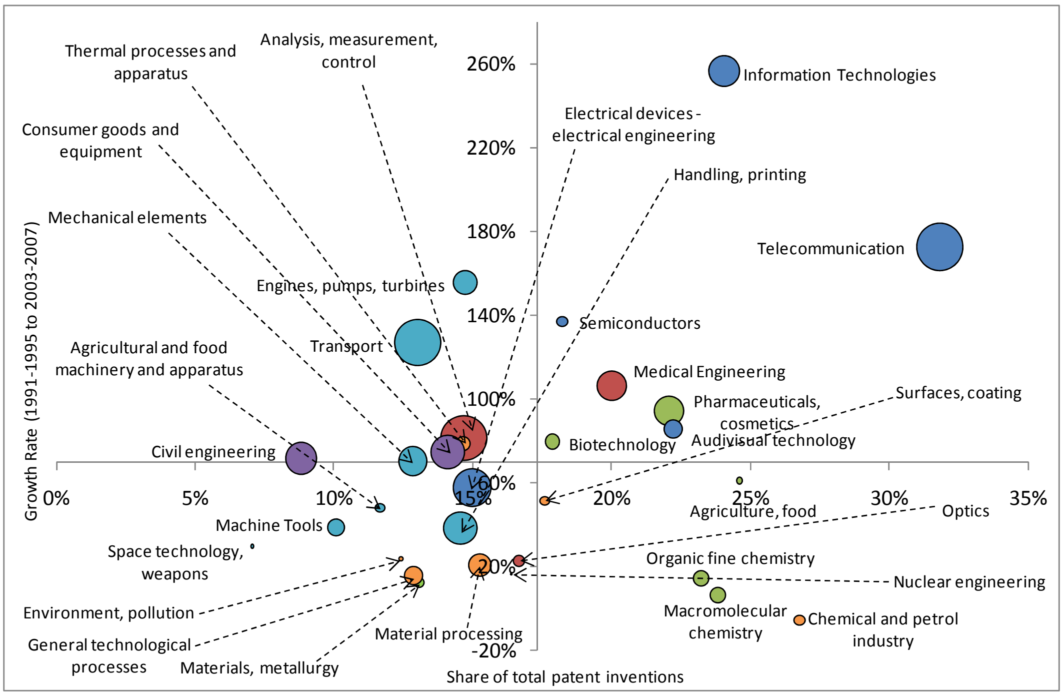
Technology, along with the industrial sector of firms, determine in large measure the level of internationalisation of R&D and innovation. Technologies and sectors differ in their degree of tacitness, their cumulativeness, appropriability, spatial concentration, or the degree they draw on and refer to knowledge external to the firm (Marsili 2001; Malerba 2005a, b).

Technologies do not only differ in the level of internationalisation but also in their absolute size and growth rates. Figure 3.6 sets out the level of internationalisation in 30 different technologies based on patent data (patents invented in the EU were assigned to one of 30 technologies, according to its IPC code, and these 30 technologies were grouped into six broad technology fields — see Dachs et al. (2010) for details). The share of foreign-owned patents in all patents granted in the EU-27 per technology (horizontal axis) is related to growth in the total number of patents in the EU-27 between the periods 1991-1995 and 2003-2007 (vertical axis). In addition, the size of the circle representing a certain technology illustrates the scale of the technology in terms of the absolute number of patents granted in the EU-27 between 2003 and 2007.

Figure 3.6 confirms that R&D and innovation activities still predominantly take place in the home country, but that there is considerable variation across technologies. The share of foreign-owned patents is: i) lowest (7%) for S*pace technology, weapons* (with the corresponding industries concentrated in a few Member States); highest (32%) for *Telecommunication* (a technology characterised by rapid change, a low degree of cumulativeness and the leading role of a number of MNEs with R&D and innovation activities distributed over several countries); iii) the majority of the technologies spread in an intermediate range with limits fixed by the two technologies mentioned previously.

With their high and increasing degree of internationalisation and large number of cross-border patents, *Telecommunication* and *Information Technologies* have been two important drivers of the internationalisation of R&D and innovation in the EU. This can also be observed in R&D data. Other technologies with an above-average degree of internationalisation include various chemical technologies and different technologies from the electronics field. But internationalisation is not only about 'High Technology'. *Agriculture and food*, where a quarter of all patents are foreign-owned, is also among the most internationalised technologies. This is a technology with a considerable degree of product variation and adaptation to differing consumer tastes in different EU countries, which may require a high degree of decentralisation (Filippaios et al. 2009).

Figure 3.6: Share of foreign-owned patents (2003-2007), growth (1991-1995 to 2003-2007) and number of patents (2003-2007) in the EU-27 by technology (EPO)



Source: European Patent Office, ZEW/AIT calculations.

Generally speaking, there is no clear relationship between the growth rate, the absolute size and the level of internationalisation of a particular technology. High and increasing internationalisation is found in *Telecommunication* and *Information Technologies,* two key technologies at the heart of the Europe 2020 'Digital Agenda for Europe' flagship initiative (European Commission (2010b)). Technologies in the field *Chemicals, pharmaceuticals* (coloured green in Figure 3.6), by contrast, all have high levels of internationalisation, but differ considerably in growth rates. The same is true of the technological field *Mechanical engineering, machinery* (light blue). Here, a low level of internationalisation coincides with both low and growth rates.

Box 3.2: Internationalisation in technologies for renewable energy generation

Rising prices for fossil fuels and the global warming threat have placed technologies for renewable energy generation (REG) in the spotlight at Member State and EU levels. The EU is the leader in the development of REG technologies, and this box maps the internationalisation of R&D and innovation in REG cross-cutting technologies, focusing on its specific needs rather than on any traditional technological or sectoral classification.

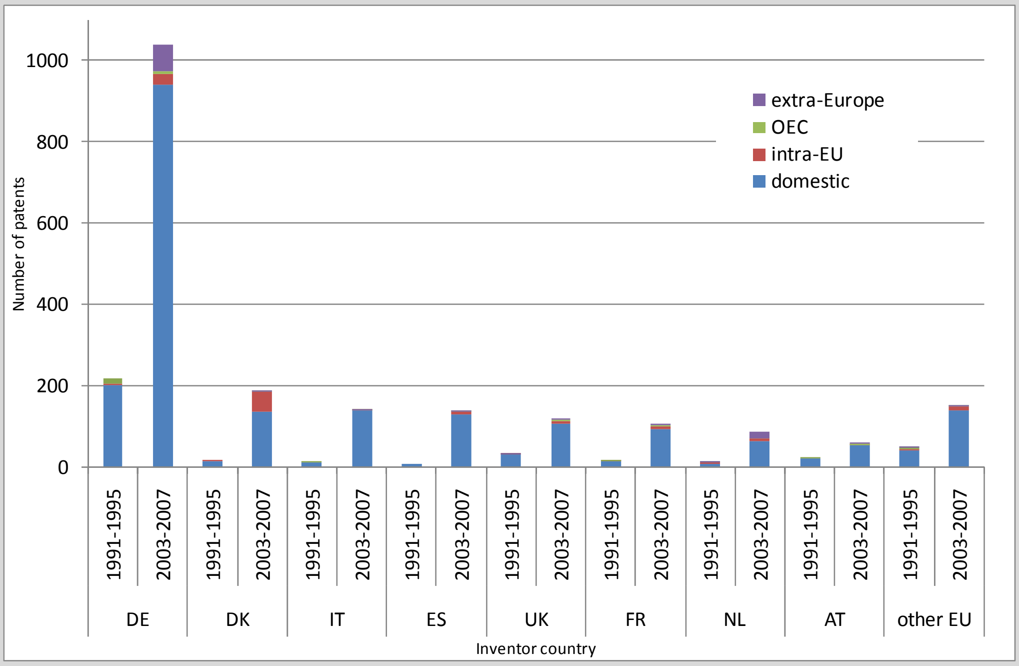
To identify REG in the patent classification, this box follows the definition proposed by the OECD (2009b) and includes the following six technologies: wind power, solar energy, geothermal energy, marine (ocean) energy, biomass energy and waste-to-energy. This gives 2911 EPO patents for the period 2003-2007. REG technologies reveal high growth rates — the number of REG patents in the EU increased by 422% from 1991-1995 to 2003-2007. At the same time, REG is still a niche technology with only 0.9% of all patents granted in the EU.

According to the OECD (2009c, p. 53), the EU-27 accounts for the majority of worldwide PCT (Patent Cooperation Treaty) patent applications in REG, with a share of around 37%, followed by the US (20%) and Japan (19%). Within the EU-27, research and innovation in REG is concentrated in a small number of countries; only Germany, Denmark and Spain exhibit above-average specialisation in the period 2003-2007. Five more countries — Austria, France, Italy, the Netherlands and the United Kingdom — have some role to play in REG. Together, these eight countries account for 92.5% of all REG patents in the EU. Data on R&D expenditure on REG is very incomplete, but seems to support the finding from patent data that the EU-27 and the aforementioned EU Member States are very well positioned in technologies for renewable energy generation (OECD 2009a).

The level of foreign patent ownership in REG is significantly lower than for other technologies: 89% of all patents are domestically owned, 6% owned by organisations from other EU countries, 1% by other European countries and 5% by organisations from outside Europe. More than 90% of the extra-European foreign-owned patents are owned by organisations from the United States. Domestically owned and foreign-owned patent inventions in REG increased at a similarly high pace.

The above-average specialisation of Germany and Denmark in REG may be because these are the only countries in the EU with a noticeable share of foreign-owned patents in REG (see Figure 3.7 below). This indicates that when deciding to internationalise R&D and innovation, firms go primarily to areas that have achieved a critical mass of development and technological leadership, though they may not necessarily have the lowest wages and costs. The example of REG shows that such factors as technological specialisation, favourable market conditions and the availability of specialised knowledge are the main attractors for foreign-owned R&D and innovation.

Figure 3.7: Number of REG patents by inventor country and applicant location (1991-1995 and 2003-2007, EPO)



Note: Bars show the total number of patents in REG in one country, split between domestic applicants, applicants from other EU countries (intra-EU), applicants from European countries not part of the EU (OEC), and applicants from outside Europe (extra-Europe).

Source: European Patent Office, ZEW/AIT calculations.

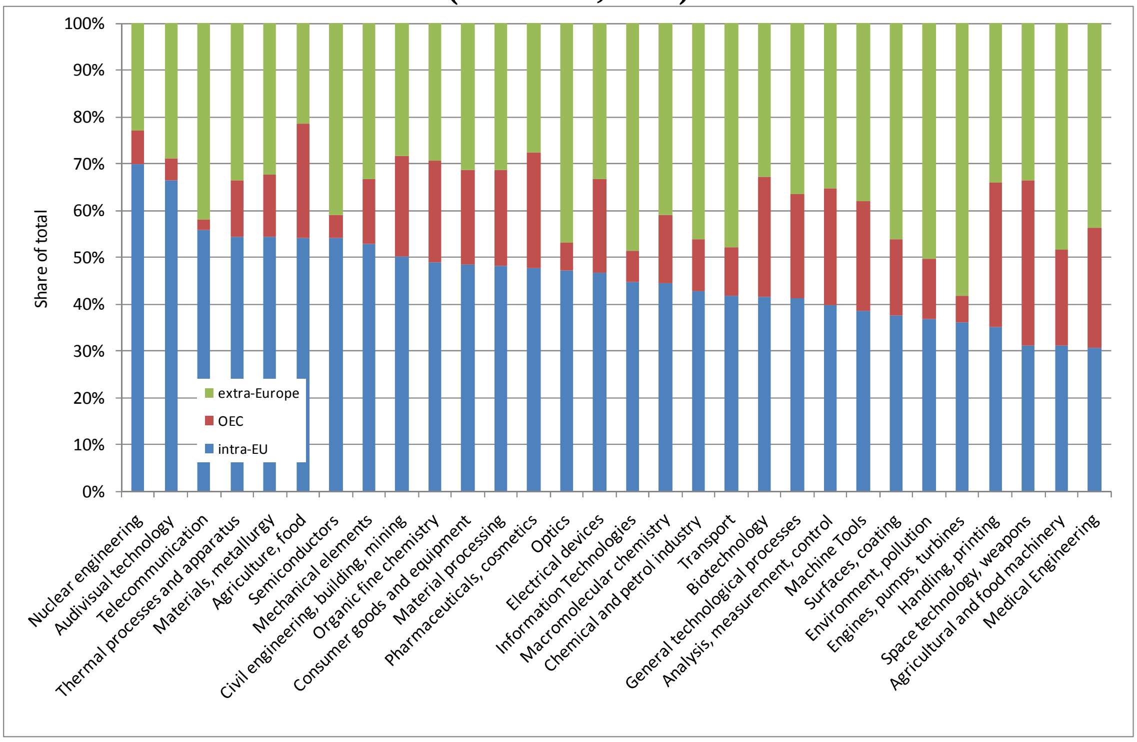
Above-average specialisation and technological leadership, however, also create outward R&D and innovation. Denmark predominantly hosts R&D and innovation from German and Spanish firms, while Germany hosts a considerable number of US-owned, but also Danish-owned patents in REG. REG accounts for about a quarter of all German-owned patents in Denmark, which is a considerable amount given the share of REG in total patent inventions. Spain, the third country with above-average specialisation in REG in the EU, has only few foreign-owned patents in REG. Spanish firms, however, are very active in Denmark in this field.

Figure 3.8 shows that at technology level too internationalisation of R&D and innovation involves — to a considerable degree — European countries. The importance of extra-European ownership (which is mostly US ownership) is lowest in *Agriculture and food* and *Nuclear engineering,* and highest in *Engines, pumps and turbines*, *Environment, pollution* and *Information technologies*. It is also interesting to see that the two technologies with the highest level and growth rates of internationalisation — *Telecommunication* and *Information Technologies* — have very different positions in terms of the applicant's location. Internationalisation in *Telecommunication* is predominantly intra-EU, while *Information Technologies* have a high share (49 %) of patent applicants from outside Europe.

Telecommunication and *Information Technologies* are at the heart of the EU 2020 flagship 'A Digital Agenda for Europe'. Both technologies give a vivid illustration of the power and importance of internationalised R&D and innovation. *Telecommunication* illustrates the importance of strengthening the internal market and intra-EU flows of R&D and innovation. *Information Technologies* illustrates the importance of extra-EU (from the US in particular) flows of R&D and innovation as the EU seeks to catch up in these technologies.

Patent applicants from other European (non-EU, Switzerland in particular) countries tend to be less important: almost non-existent in *Telecommunication* or *Audiovisual technology* (technologies for which intra-EU cross-border patents are preponderant), but important in *Space technology, weapons, Handling, printing, Medical Engineering and Biotechnology* (technologies in which intra-EU cross-border patents are not dominant).

Figure 3.8: Location of applicants for foreign-owned patents by technology (2003-2007, EPO)



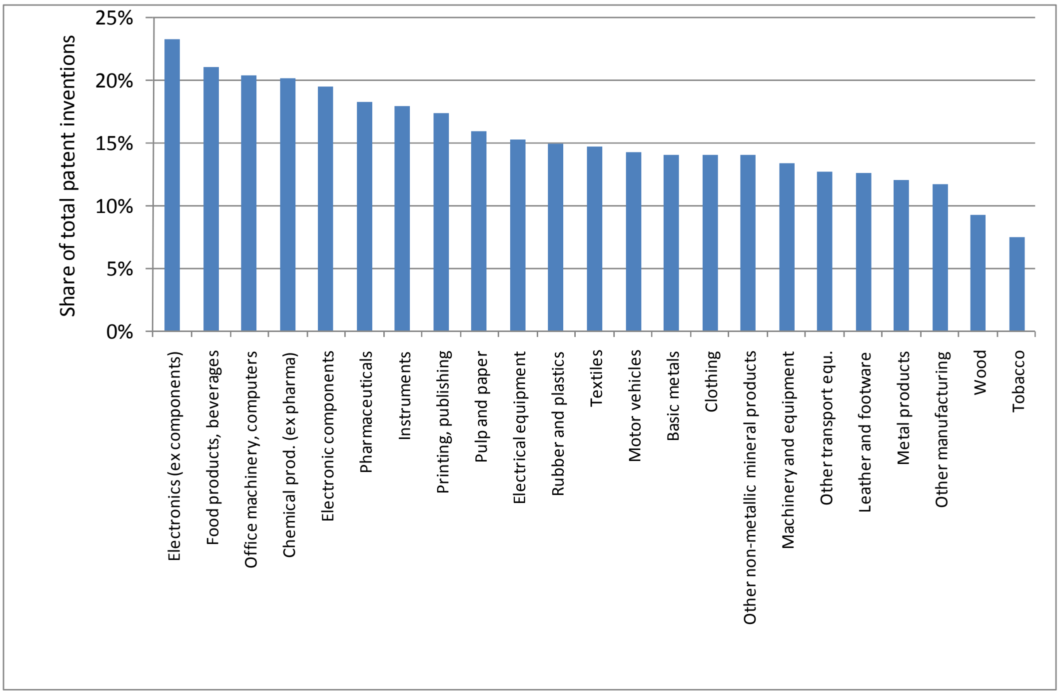
Note: intra-EU: applicants from other EU countries; OEC: applicants from European countries not part of the EU; extra-Europe: applicants from outside Europe.

Source: European Patent Office, ZEW/AIT calculations.

Moving from the technology to the sectoral perspective[2] (see Figure 3.9 below), the most internationalised sectors in terms of R&D and innovation are the manufacturers of electronics (NACE Rev.1.1 section 32 — this also includes producers of telecommunication equipment), electronic components (NACE 32.1), medical, precision, optical and time measuring instruments (NACE 33), computers and office machinery (NACE 30), food products and beverages (NACE 15), and pharmaceuticals (NACE 24.4). Together, these six sectors account for about two thirds of all foreign-owned patents in the EU-27. In contrast, internationalisation of R&D and innovation is lowest in manufacturing of tobacco products (NACE 16), wood and wood products (NACE 20), and metal products (NACE 28) — all so-called 'low-technology' sectors. This sectoral specialisation corresponds with the observation that FDI is concentrated in technology-intensive industries (Barba Navaretti and Venables 2004).

2 Patents are assigned to sectors using the transformation matrix proposed by Schmoch et al (2003).

Figure 3.9: Share of foreign-owned patents by industrial sector (2003-2007, EPO)



Source: European Patent Office, ZEW/AIT calculations.

A similar overall picture emerges when looking at R&D expenditure by foreign-owned affiliates (see Table 1 in the Annex). Foreign-owned affiliates tend to account for a higher share of sectoral R&D expenditures in the chemical and electrical industries, while mechanical industries — including the automotive sector — tend to have lower shares in most countries. A recent study, European Commission (2010c), shows that for the ICT sector in Europe, above 40% of all R&D centres belong to companies with headquarters outside Europe. The variation in internationalisation levels in a single sector across different countries, however, is considerable. Sectors may have a high share of foreign-owned affiliates in total R&D expenditure in one country, and a low share in another.

From a sectoral perspective, it has to be remembered that the internationalisation of R&D and innovation is not restricted to manufacturing industries. Multinational firms exist in a number of service sectors as well. Examples include the software, finance, business services and the transport sector. The internationalisation of R&D and innovation in services, however, is more difficult to measure than in manufacturing, because firms in a number of service sectors engage in R&D less frequently, and many service innovations cannot be protected by patents.

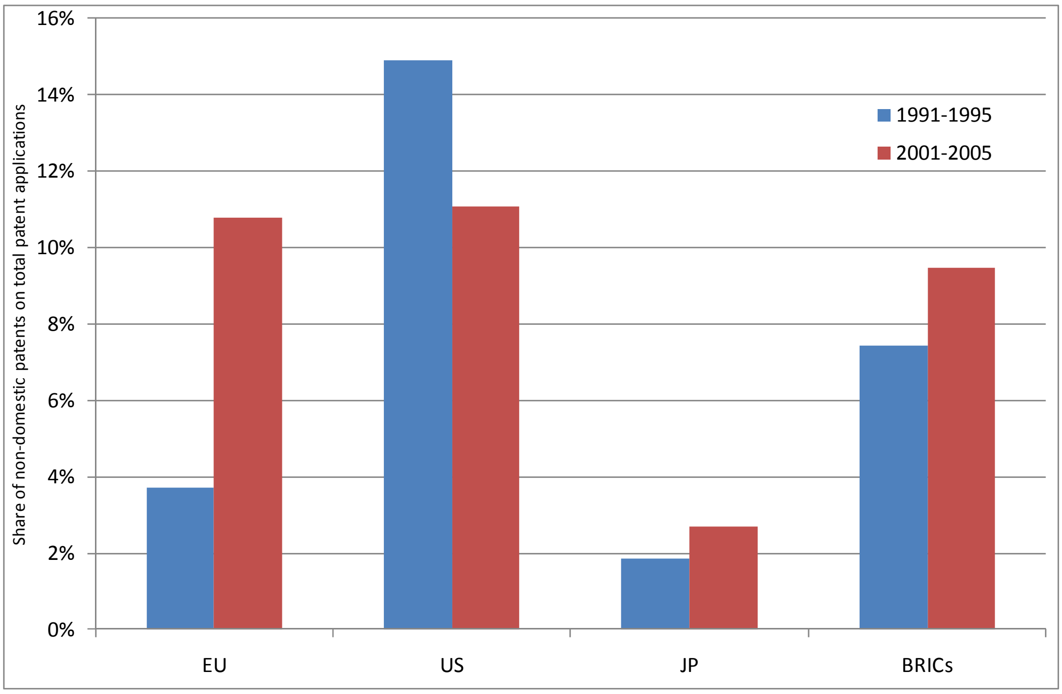
The OECD FATS database includes data on R&D expenditure by foreign-owned affiliates in some service sectors (see Table 1 in the Annex). The figures indicate that in knowledge-intensive services such as finance, insurance or business services, foreign-owned affiliates account for between 16% (Germany) and 60% (Ireland) of total R&D expenditure. In trade, repair, hotels and restaurants, the share is considerably higher. Altogether, the degree of internationalisation in service industries seems to be lower than in manufacturing. This finding, however, is tentative due to weak data coverage of the service sector.

3.4. R&D and innovation activities of EU firms abroad

Outward internationalisation — the degree to which organisations from the EU-27 countries do R&D and innovation outside the EU — is often referred to as 'offshoring', a term suggesting that overseas R&D and innovation substitute and replace similar activities in the home countries. The economic literature offers a more differentiated view on outward internationalisation, pointing out that overseas R&D and innovation are often complements, not substitutes for similar activities in the home country. These activities support the use of company assets by adapting existing technologies to foreign markets and generating knowledge not available in the home country (Narula and Zanfei 2005).

Figure 3.10 shows the share of patents granted abroad compared with total national patent applications, based on Triadic patent data[3]. In all the four areas depicted in Figure 3.10, overseas patents account for a modest fraction of overall patent applications (around 11 % in the EU and US, around 3 % in Japan, in the period 2001-2005).

Figure 3.10: Share of overseas patents in total patent applications (1991-1995 and 2001-2005)



Note*:* The European Union is regarded as one geographical entity here ('overseas' means patents granted outside the European Union). The same applies for the BRIC countries.

Source: OECD Triadic patent database, ZEW/AIT calculations.

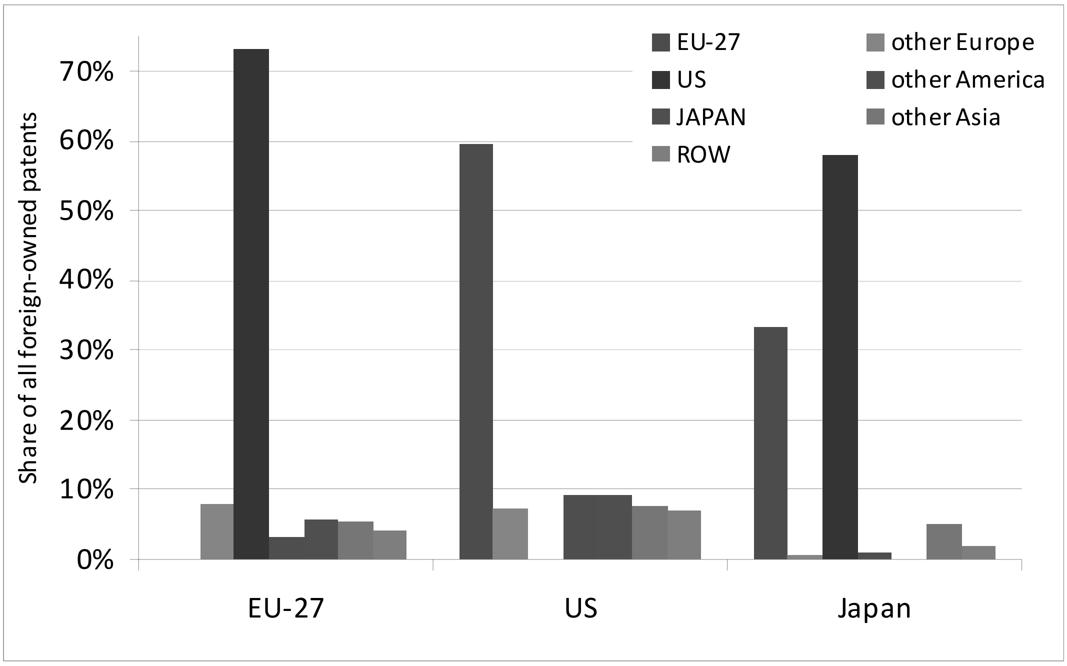
The share of overseas patents in all patent applications in the BRIC countries is already higher than the corresponding value for Japan. However, the number of BRIC patents granted overseas is still very low. The BRIC countries are still mainly a host country for foreign-owned research and only to a much lesser degree a home country for companies doing R&D and innovation abroad.

[3] Triadic patents help to circumvent the so-called 'home office bias' and enable a global comparison to be made. They are patents which have been applied for at all three major patent offices: the EPO, the US Patent and Trademark Office (USPTO), and the Japanese Patent Office (JPO). See annex: measuring the internationalisation of R&D and innovation.

The US and the EU appear to have taken different paths from 1990 to 2005. The share of overseas activities of US organisations decreased, while R&D and innovation of EU organisations outside the EU increased considerably. This mirrors the trends in inward internationalisation (observed in Figure 3.10 above). In the early 1990s most of the cross-border patents involving an EU Member State and a non-EU country were granted in the EU and owned by an organisation from outside the EU. Today, the outward dimension, especially with the US as partner country, is of almost equal importance. In the case of some medium-sized Member States, most notably the Netherlands, the outward dimension is clearly dominant. Technologies with higher levels of EU outward R&D activities include *semiconductors, macromolecular chemistry, pharmaceuticals, cosmetics* and *agriculture, food*; while technologies such as *machine tools* or *transport* exhibit a level of outward R&D internationalisation below the EU average.

Figure 3.11 splits up the foreign-owned patent applications of the EU, the US and Japan according to the place of residence of the inventor(s) in the following seven areas: EU-27, other Europe, US, other America, Japan, other Asia, and the rest of the world (ROW).

Figure 3.11: Location of overseas patents applied for by the EU-27, the US and Japan (2000-2007)

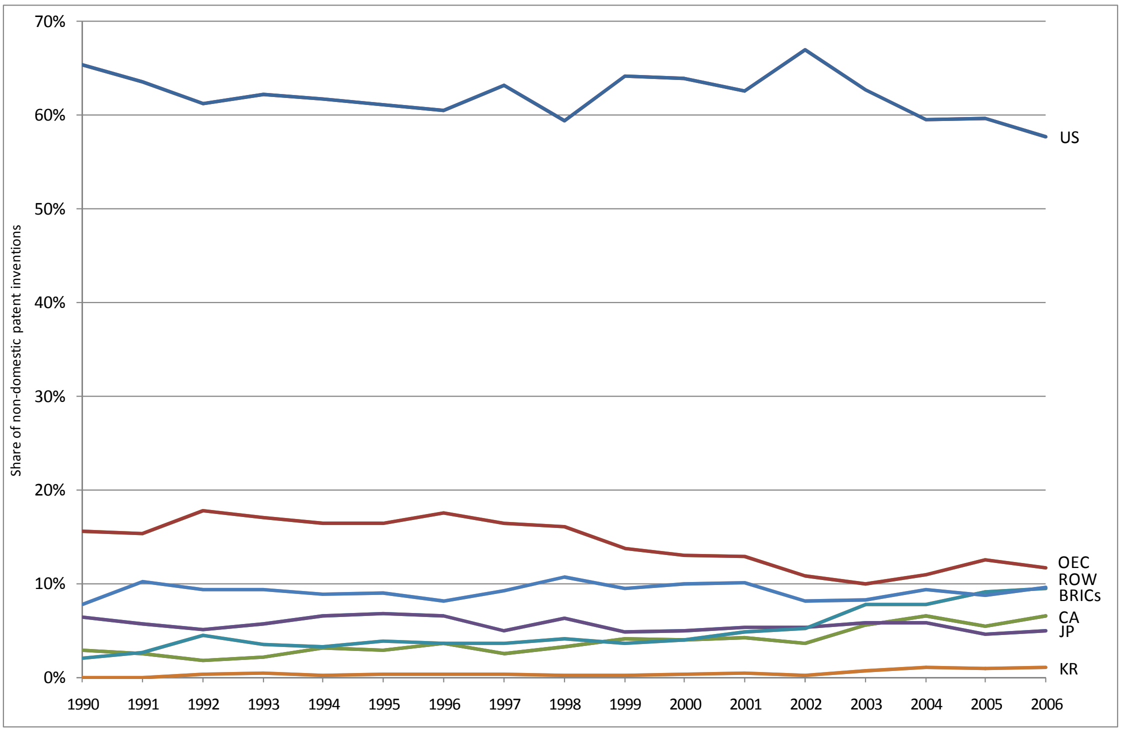


Source: OECD triadic patent database, ZEW/AIT *calculations.*

The data confirm that internationalisation is still predominantly a matter for the EU, the US and Japan. The US is the most important host country for EU overseas patents by far, as is the EU for the US. For Japanese overseas inventions, the US is more important than the EU. Other Asian countries such as China, India or Korea still play a limited role as host countries of the Triadic countries' overseas patents. In relative terms, the US is more active in Asian countries than the EU. These differences, however, are small compared to the scale of the EU-US relationship.

EPO (European Patent Office) data confirm the predominant role of the US for EU outward R&D and innovation activities. Figure 3.12 shows that the US accounts for 60% of all overseas patents applied for by EU entities at the EPO. This share is virtually unchanging over time. The BRIC share in total EU-27 outward R&D and innovation[4] is still small compared to the US, but rising fast. The BRIC countries already account for a larger share of EU overseas patents than Japan or Canada.

Figure 3.12: Location of overseas patents[5] applied for by the EU-27, 1990 to 2006, EPO



Note*:* KR: Korea; CA: Canada; BRIC: Brazil, Russia, India, China; OEC: other European countries not member of the EU; ROW: Rest of the world

Source: European Patent Office, ZEW/AIT calculations.

The 2008 EU Survey on R&D investment business trends (European Commission JRC IPTS 2009b) points to similar results. It includes data on R&D investment by 114 European companies, 35 of them having a high, 68 a medium and 27 a low R&D intensity. R&D expenditure data may be more accurate than patent data with respect to shifts of R&D expenditure from manufacturing to the service sector and other R&D activities that do not lead to patents. Just over 20% of the R&D carried out by these companies was located outside the EU. Almost half of the extra-EU R&D investment is directed to the US and Canada. R&D investment in China (2.7% of the total) and India (3.5%) remains relatively insignificant. There are significant differences between firms with high, medium and low R&D intensities. High R&D intensity firms are the most internationalised ones. This higher share is due to the higher importance of the US and Canada and to a lesser degree India and China as locations for R&D for the high R&D intensity companies.

Outward internationalisation in R&D and innovation at aggregate or sectoral level may mask a considerable degree of variation at company level. In most countries, in particular large countries, only a minority of firms export or invest abroad (Bernard et al. 2007; Greenaway

[4] The BRIC share of EU outward R&D and innovation depicted here should not be confused with the share these countries hold on the world market for certain technologies.

[5] Here, the EU is regarded as a single entity; overseas patents include all patents granted outside the EU-27.

and Kneller 2007). The fraction of firms with overseas R&D and innovation activities is even smaller. The European Manufacturing Survey (EMS — see Box 3.3) suggests that the share of firms which go abroad with R&D ('R&D offshoring' in the terminology of the survey) is below 4% in most of the countries studied. The EMS data confirm that R&D internationalisation strategies are predominantly a matter for large firms. Outward R&D is very rarely found among SMEs. The average size of a firm with R&D offshoring in the sample is 1 602 employees in 2005, compared to 195 in non-offshoring firms. There is also a strong correlation between R&D intensity and R&D internationalisation: higher levels of R&D offshoring firms are found among R&D intensive firms. So the results presented in this section relate in fact to the activities of only a very small number of firms.

Box 3.3: The European Manufacturing Survey: motives for R&D internationalisation

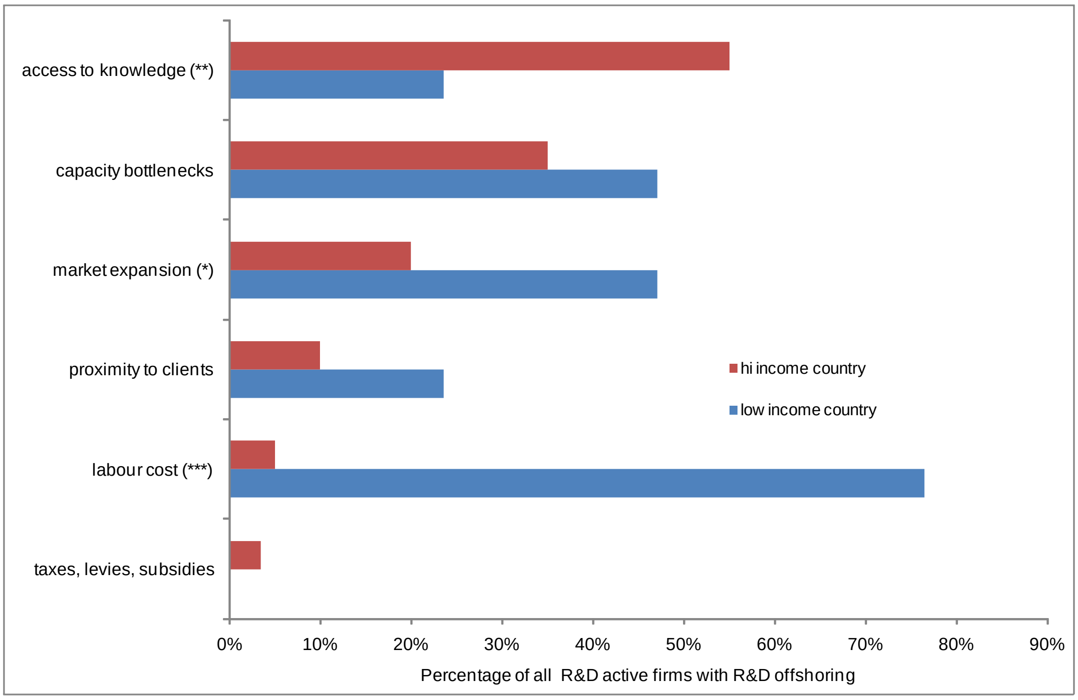
The European Manufacturing Survey (EMS) is a survey on product, process, service and organisational innovation in European manufacturing. It is conducted every three years in 12 European countries by a consortium led by Fraunhofer ISI. The focus lies on the introduction of new production technologies, organisational innovation — this includes workplace organisation, but also outsourcing and offshoring — and service innovation in manufacturing.

The sample features 3 120 firms with more than 10 employees from six European countries with a sufficiently large number of firms: Germany (accounting for about half the sample), followed by Switzerland, Austria, Spain, the Netherlands and Slovenia. The largest sector in the sample is the manufacturing of transport equipment, including cars, with a share of around 9%, followed by electronic and optical equipment (6%), and the chemical, petroleum and pharmaceutical industry (5%).

To investigate the motives for R&D internationalisation in more detail, the analysis distinguishes whether a firm is moving its R&D to a high- or low-income country. High-income countries include North America, Japan and the EU-15, while low-income countries comprise the EU-12, South America and the BRIC countries. The two groups of destination countries are clearly associated with different motives and offer different locational advantages (Figure 3.13). R&D offshoring to high-income countries is significantly more often associated with the wish to gain access to knowledge. Labour cost advantages play less of a role in offshoring to high-income countries.

Low-income countries, on the other hand, are associated with advantages from lower labour costs, but also with market expansion and proximity to clients. This indicates that firms identify growing markets mainly in low-income countries, and try to support market development in these markets with R&D facilities in these countries. Here then, the internationalisation of R&D is mainly a reaction to growing market shares of emerging countries. There is no significant difference between the two country groups with respect to overcoming capacity bottlenecks in R&D, which is the most frequent motive.

Figure 3.13: Motives for R&D internationalisation and destination country, 2004-2006



***, **, * denote statistical significance of differences at the 1 %, 5 % and 10 % error level.
Source: European Manufacturing Survey, ZEW/AIT calculations.

EMS and other survey results indicate that lack of knowledge is one of the most important motives for R&D internationalisation. It is therefore not surprising that the United States — still the most advanced country in many technologies — is the most important location of EU R&D and innovation outside the European Union (see Figure 3.12 above). Besides being a large market, the US offers favourable conditions for R&D and potential spillovers from competitors, suppliers or universities.

All in all, the rising share of innovation and R&D investment in some emerging countries indicates that today's (US/EU) bi-polar world may become multi-polar in the future, taking in China, India and other countries not yet well integrated in the international division of labour in science and technology. The BRIC countries, in particular China, have made impressive progress in science and technology (OECD 2007).

The Innovation Union Flagship initiative recently adopted by the Commission as part of the Europe 2020 strategy aims at increasing the attractiveness of the EU as a location of R&D and innovation investments and at promoting international cooperation on research and innovation (European Commission (2010a, d)). Enhancing Europe's strength in science and technology is the best way to maintain Europe's attractiveness for foreign R&D and innovation. From a European perspective, the EU-15 countries — despite large labour cost differences — still offer considerable locational advantages to firms compared to the BRIC countries, but also to the EU-12. These include access to excellent knowledge, and a skilled S&T workforce that helps overcome capacity bottlenecks.

3.5. Performance differences between foreign-owned and domestically owned firms in the EU

Foreign-owned firms account for a considerable share of the R&D and innovation activities in EU Member States. Their share is above-average in high-technology sectors and in medium-sized and small countries. From a policy point of view, this raises the question of differences between domestically owned and foreign-owned firms. If there are substantial differences in innovation behaviour between foreign-owned and domestically owned firms, countries with a large or small share of foreign ownership may have advantages or disadvantages in innovation, and, in the medium term, in growth and employment at the aggregate level**.**

It is therefore important to understand the characteristics of foreign-owned innovation activity in more detail in order to assess the impact of internationalised innovation and R&D on the EU Member States. This section will investigate whether there are differences between foreign-owned and domestically owned firms in innovation input intensity, innovation output intensity and in cooperation with organisations in the host country.

The analysis is based on data from the Community Innovation Survey (CIS) 2006 (micro-data available in the EUROSTAT Safe Centre, see Box 3.4 and Annex to this chapter). Innovation behaviour is measured by four variables:

- *Innovation input intensity,* defined as the innovation expenditure of the firm in 2006 as a share of turnover in the same year. Innovation expenditure includes internal and external R&D, machinery, equipment, and software, other external knowledge and training related to innovation.

- *Innovation output intensity,* measured by the share of turnover generated with products new to the market in the total turnover of the firm. The reference period is 2004 to 2006. Products new to the market are a subset of all product innovations that are new to the firm.

- *Domestic cooperation* includes cooperation with any type of partner outside the enterprise group in the host country. The reference period is 2004 to 2006.

- *Domestic cooperation with science* includes only external cooperation with universities and research centres in the host country. The reference period is 2004 to 2006.

Box 3.4: The Community Innovation Survey (CIS) 2006

The descriptive and multivariate analysis of this section is based on a sample drawn from the Community Innovation Survey (CIS) 2006. CIS is a survey on innovation behaviour of firms in the Member States of the EU, Norway and Iceland. EUROSTAT[6] provides access to CIS data at company level. The sample used for this analysis includes 315 375 firms (weighted) from 17 European countries. Spain has the largest share of the sample with about 45 %, followed by the Czech Republic and Romania (around 8 % each). Data from Germany, France, the UK or Italy were not available for the analysis.

83 % of the firms in the sample are domestically owned non-group firms (DnGFs), another 11 % are domestically owned group firms (DGFs). 7 % of the firms are foreign-owned (FOFs).

6 We thank Sergiu-Valentin Parvan from EUROSTAT for his support.

In the sectoral taxonomy of Peneder (2010), which classifies sectors according to their innovation intensity, 19% of the firms are from a non-innovation sector. 31% of the firms are from the low-innovation sector, 10% from low-med innovation and another 22% from med-innovation sectors. Med-high and high innovation sectors account for 18% of the sample. The share of firms in the med-high and high innovation sectors is considerably larger among foreign-owned firms than among domestically owned firms. In addition, foreign-owned firms are, on average, considerably larger than both domestically owned group and non-group firms. The latter are also smaller than domestically owned group firms.

The vast majority of the foreign-owned firms in the sample — 72% — are from another EU-15 country. The second largest group are firms from the US. Canadian and Australian firms were added to the US firms. Together, this group accounts for 14% of all foreign-owned firms. The remaining firms have a parent company from another European, but non-EU country (6%), from the EU-12 (4%), from an Asian country (2%) or from another country (2%).

The analysis distinguishes between three types of firms:

- Domestically owned non-group firms (DnGF); this type of firm is not affiliated to an enterprise group and is typically a small or medium sized firm.
- Domestically owned group firms (DGF); this type of firm belongs to a domestic enterprise group, and could be a domestic multinational.
- Foreign-owned firms (FOF); this type of firm is domiciled in the country, but owned by a firm or individual from another country.

3.5.1. Descriptive analysis of differences in innovation behaviour between domestically owned and foreign-owned firms

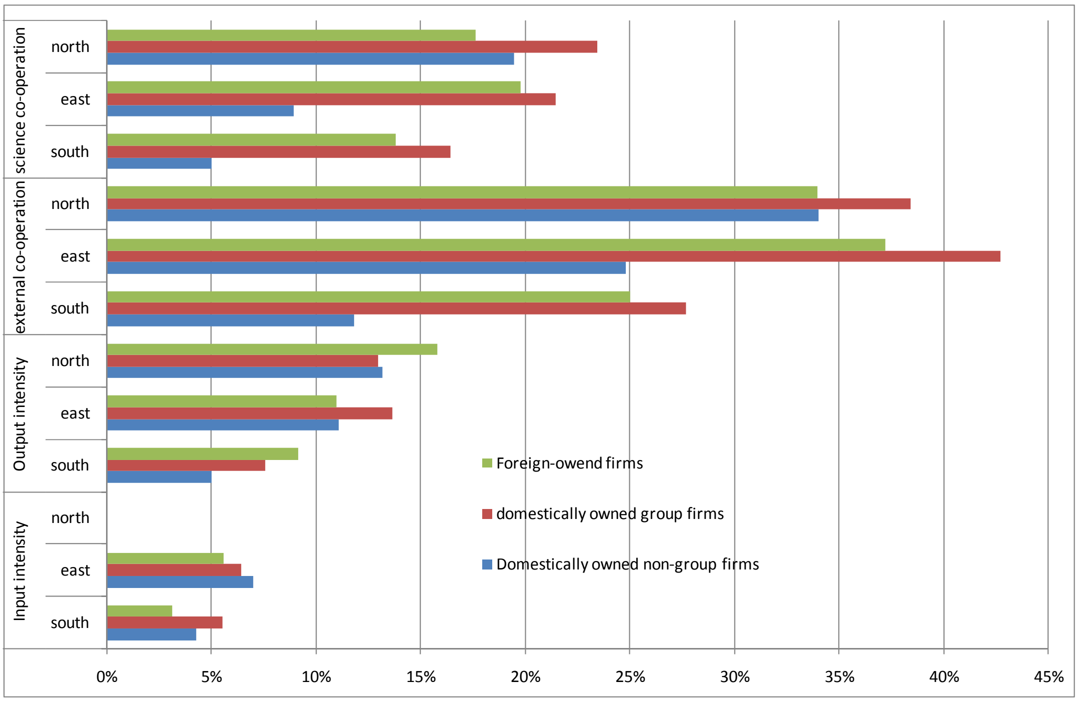
Descriptive results reveal some important differences between the three groups of firms. Figure 3.14 reports the means of each of the four above-mentioned variables for FOFs, DGFs, and DnGFs. In addition, it distinguishes between countries in Northern, Southern and Eastern Europe.

FOFs exhibit lower innovation input intensity than both DGFs and DnGFs. Innovation output intensity, on the other hand, is higher in two of the three country groups. There is even more variation in innovation output intensity when looking at the country level. Innovation cooperation is more frequent among DGFs than among FOFs, and more frequent among FOFs than among DnGFs. The same hierarchy can be observed for science cooperation. There is no single country where DnGFs have a higher propensity to cooperate than FOFs. Differences between DGFs and FOFs, however, are considerably smaller than between FOFs and DnGFs.

In addition, descriptive statistics suggest that group membership, besides foreign or domestic ownership, is decisive for differences between the three groups in cooperation behaviour. In many respects, differences between DnGFs and DGFs are greater than between FOFs and DGFs. It can be assumed that FOFs and DGFs, but not DnGFs, share some factors that favour innovation and cooperation. One of these is size. Bearing in mind that DnGFs are considerably smaller than both DGFs and FOFs in the sample — they have fewer than 50 employees on average, compared to a mean of between 100 and 150 for DGFs and FOFs —

the gaps in cooperation can evidently be explained in many ways by the specific challenges small and medium-sized firms (SMEs) face in the innovation process rather than by domestic and foreign ownership. Smaller firms, for example, may find it more difficult to raise the resources to maintain cooperation over a longer period of time and are usually less R&D oriented, which may indicate that they lack the capabilities to put the results of the cooperation to good use (see for example Schmidt 2005).

Figure 3.14: Variables describing innovation behaviour by ownership status and location of the firm, means



Notes*:* north includes Finland, Denmark, Luxembourg, Norway; east includes Bulgaria, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Romania, and Slovakia; south includes Cyprus, Greece, Spain, Malta, Portugal. Data on innovation input are not available for Finland and Denmark, so no value for input intensity if reported for north. Results are weighted with weights provided by EUROSTAT.

Source: EUROSTAT CIS database, ZEW/AIT calculations.

Similar differences between DnGFs, DGFs and FOFs can also be observed for innovation input and output intensity. FOFs are superior in many cases to DnGFs, but perform worse than DGFs, which are themselves domestically owned multinationals in a number of cases.

3.5.2. Innovation behaviour of foreign-owned firms in a multivariate analysis

Descriptive statistics reveal differences between foreign-owned and domestically owned firms, and between group and non-group firms, but are unable to tell whether these differences are related to foreign ownership or to differences between the groups in terms of other variables such as firm size, sector, etc.

In order to disentangle the effects of foreign ownership from other characteristics, four econometric models with the variables of the descriptive analysis as dependent variables are estimated. Independent variables include firm size, international market orientation, R&D orientation, incoming spillovers, public funding, the sector of the firm and country dummies.

To account for influences from the sectoral level, the analysis employs a new taxonomy of economic sectors according to their innovation intensity proposed by Peneder (2010). It distinguishes between six sectoral aggregations, which refer to different levels of innovativeness.

The analysis employs a Heckman-selection model with the decision to innovate as selection equation. Innovation input intensity, innovation output intensity, the propensity for external cooperation and the propensity for cooperation with science in the host country are the dependent variables of the function equation.

The results of the regression analysis (see Table 2 in the Annex) indicate that performance differences between foreign-owned and domestically owned firms can be explained by company characteristics to a considerable degree. Coefficients for size, sectoral affiliation, R&D activities, received funding, or sectoral affiliation are significant in a number of cases (see Table 2 in the Annex). The relationship between size and innovation activity, for example, is U-shaped in a number of cases, indicating differing advantages and disadvantages of small and large firms in the innovation process. Small firms are more flexible and can react faster to new technological or market opportunities, while large firms have more internal resources, can spread the risk and uncertainty over more projects and have more potential application areas for a new invention.

After correcting for company characteristics, the results of multivariate analysis confirm that FOFs have a lower innovation input intensity compared to DnGFs, but reap similar or even higher benefits from products new to the firm (the coefficient for innovation output, however, is only significant at the 10% level). This behaviour of FOFs fits well into the 'asset-exploiting' strategy described in the literature (Cantwell and Mudambi 2005; Narula and Zanfei 2005): FOFs benefit from technology received by the parent company to a considerable degree; the FOF can also rely on the technological expertise and support from other parts of the group. Hence, innovation input of the FOF can be lower, but innovation output is similar to or even higher than that of a domestically owned firm.

There is a significant positive correlation between foreign ownership and cooperation after checking for company characteristics. FOFs have a higher propensity than DnGFs to cooperate with all types of domestic organisations. The same is true for DGFs. A similar result is found for cooperation with science. This positive and highly significant relationship between foreign ownership and innovation cooperation can be explained by the knowledge requirements of FOFs. A lack of knowledge in the home country is one of the main driving forces for the internationalisation of R&D and innovation. This gives FOFs a strong incentive to enter into cooperation with domestic organisations to gain access to this knowledge. From a policy point of view, a high propensity of foreign-owned firms for domestic cooperation is positive, because cooperation is a main channel for spillovers of knowledge between foreign-owned firms and organisations in the host country.

But there may be other factors that facilitate cooperation and are not accounted for in the regression, because a higher propensity to cooperate is also found in DGFs. The high degree of cooperation between FOFs and the science sector in the host country in particular indicates that asset-exploiting and asset-augmenting strategies are often inseparable (Criscuolo et al. 2005). In addition, joint projects between research organisations and firms have other goals than the creation of new knowledge; the joint supervision of PhD and Master's theses, for example, is a way to recruit new employees (Schartinger et al. 2002).

3.5.3. Innovation behaviour and the home country of foreign-owned firms

Foreign-owned firms are embedded in the corporate culture and standards of their enterprise group and their home countries. Activities abroad are shaped by these factors to a considerable degree (Forsgren 2008, chapter 7). The corporate culture of an enterprise group affects the behaviour of the subsidiary, even if its staff and management are mostly locals. Firms with a specific background may find it harder to enter local networks and tap into localised knowledge than firms from a neighbouring country because of the 'liability of foreignness' (Eden and Miller 2004). It is therefore feasible that not only foreign ownership, but also the home country of the FOF matters when it comes to innovation performance.

To analyse differences between foreign-owned firms of different home countries in more detail, a sub-sample of the CIS 2006 which includes only foreign-owned firms was used (see Box 3.4 for details).

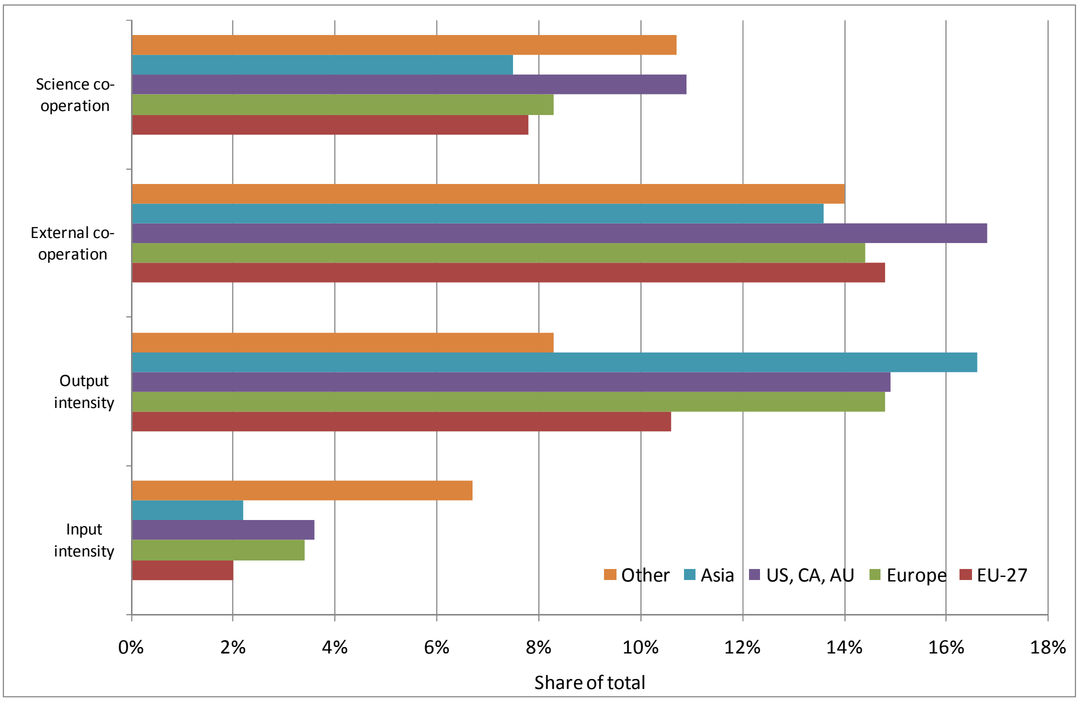
Descriptive statistics provide evidence of differences between FOFs from different home countries (see Figure 3.15). Innovation input intensity of FOFs from 'other' countries is significantly higher than of any other group in Figure 3.15. This can be explained by the presence of a number of very R&D intensive Israeli firms in the 'other countries' sub-sample.

Innovation output intensity, by contrast, is higher for firms with an Asian, a US, Canadian or Australian parent company or a parent company from another non-European country than for an FOF from another EU-27 country. Science cooperation is more frequently found among US and 'other' firms than among EU-27 and Asian firms.

The differences from descriptive analysis are only partly confirmed by the results of regression analysis (Table 3 in the Annex). Regression results show no significant association between innovation input intensity and the home country at the usual significance levels. Thus, the differences observed in the above figure are more likely due to different firm sizes, different sectoral affiliations or other factors than to the country of origin.

Innovation output intensity, on the other hand, is significantly lower for FOFs from the EU-27 than for non-EU-27 firms. By further distinguishing between various home countries, it can been seen that this effect is mainly due to Asian and US/Canadian/Australian firms, which are likely to introduce radical innovations in their home markets first and then transfer them to their European subsidiaries. The experience they have gained in their home markets with these new products may explain the performance differences compared with EU-27 firms.

Figure 3.15 Innovation input and output intensity and cooperation by country of origin of the foreign-owned firm, means



Note: figure only includes foreign-owned firms. Results are weighted with weights provided by EUROSTAT.

Source: EUROSTAT CIS database, ZEW/AIT calculations.

There are no significant results for external cooperation in general. Cooperation with science, in contrast, is negatively associated with Asian ownership at the 5 % error level. This indicates that subsidiaries of Asian groups cooperate significantly less often with universities and research centres than FOFs owned by EU-27 parent companies, after checking for company characteristics. This may be because firms with a very different cultural background find it hard to link to local networks and the host country.

US/Canadian/Australian firms, though, enjoy an advantage over EU-27 firms in science cooperation, as indicated by a significant and positive coefficient. One can only speculate about the reasons for this premium; it may be because US MNEs are still the technological leaders in many areas, in particular in ICT and biotechnologies. US-owned affiliates may therefore be attractive cooperation partners. In addition, the corporate culture of US, Canadian or Australian firms may be more open for science-industry cooperation, and this preference may be transferred to their affiliates in Europe. Differences between EU-27 firms and other home country groups are not significant.

3.6. A dynamic perspective on innovation performance differences between foreign-owned and domestically owned firms

Sections 3.2 to 3.4 have highlighted the long-term shift towards a higher degree of internationalisation in R&D and innovation at the *EU-27 level* as well as at the *country level*. The previous section brought out some important differences and similarities in innovation behaviour between domestically owned firms and foreign-owned firms in a *cross-section of firms in various European countries*. This section complements the preceding ones by making a *dynamic analysis of* performance differences between foreign-owned and domestically owned firms *at the company level*.

Given that innovation is key for firms' competitiveness, globalisation raises two questions which are of particular interest from a policy point of view. First, do foreign-owned affiliates *persistently* differ from domestically owned firms? Or do foreign-owned firms change their innovation behaviour after entering the foreign market and adjust to innovation strategies and to the level of innovation of firms in the host country?

Globalisation increases international competition in the home market. This can stimulate innovation by innovation competition or cooperative innovation activities. Thus, it is interesting to see whether foreign-owned firms become more embedded in domestic networks over time in terms of interacting with domestic customers, suppliers or science institutions.

This section investigates how the innovation behaviour of foreign-owned and domestically owned firms has developed over the last twenty years using a long panel data set. Unfortunately, the dynamic analysis is restricted to foreign-owned and domestically owned firms in Germany, since this is the only country for which a long innovation panel exists. But as pointed out in section 3.3, Germany is an important country in the EU regarding the internationalisation of R&D and innovation. The analysis makes use of the Mannheim Innovation Panel (MIP — see Box 3.5 below).

Box 3.5: The Mannheim Innovation Panel (MIP)

The Mannheim Innovation Panel (MIP) is an annual survey carried out by the Centre for European Economic Research (ZEW), infas Institute for Applied Social Sciences and Institute for Systems and Innovation Research (ISI), on behalf of the German Federal Ministry of Education and Research (BMBF). The MIP represents the German contribution to the CIS. In contrast to the CIS, however, the surveys are conducted annually and can be linked over time.

The sample taken from the MIP and used in this section contains 110 324 observations over the years 1992-2008. About two thirds of these observations refer to domestically owned non-group firms (DnGFs). 28 % of the firms in the sample belong to domestically owned group firms (DGFs). 8 084 observations are from foreign-owned firms, accounting for roughly 7 %. These 8 084 observations can be attributed to 2 305 individual foreign-owned firms.

Around half of the observations come from manufacturing, another 43 % from service industries. Compared to the overall distribution, foreign-owned firms are overrepresented in high-tech manufacturing industries like chemicals, electrical engineering, machinery, vehicles, medial / precision and optical instruments and metals, and in the banking and insurance sector. DnFGs have above-average shares in services, in particular in retail and transport services. The sample also reveals some interesting details about the home country of the foreign-owned firm. Firms from outside Europe and the US are more frequently found in industries like electrical engineering, chemicals and machinery (nearly 40 % of all US subsidiaries belong to these three sectors). The foreign ownership by European firms is spread more across industries. They particularly own firms belonging to the metal, machinery and chemical industries. Together, these three industries account for 34 %.

The subsequent sub-sections first present trends in time series for different indicators. The indicators include the measures for *innovation input intensity* and *innovation output intensity* used in the previous section. In addition, innovation input is measured by R&D intensity, which is the share of R&D expenditure in the firm's turnover in 2006. Additional innovation output indicators include the share of firms with process innovation, the share of firms with product innovation and the share of firms which introduced products new to the firm, but not new to the market. *Measures for innovation cooperation* include cooperation with all domestic partners, with foreign partners, with clients and suppliers, and with scientific organisations.

Since differences in innovation behaviour over time between domestically owned and foreign-owned firms can have various causes, panel data regression methods are employed. The econometric analysis makes it possible to gauge the effect of different forms of ownership on the respective innovation indicator and to separate its effect from the impact of other company characteristics, industry and time effects. The econometric analysis checks for firm size, firm age, region, export intensity, creditworthiness (only for innovation input) and innovation intensity (only for innovation output and cooperation). A main advantage of panel data is that they also make it possible to check for unobserved heterogeneity among firms. Random effects probit or tobit models are estimated, depending on the nature of the innovation indicator.

In a third step, the section explores the results of a ‘quasi experiment’ to see whether there is any convergence in innovation behaviour after market entry. For foreign-owned firms which have been created by an acquisition, this experiment asks ‘what would the innovation behaviour of the firm have looked like after a certain period if it had not been taken over by the foreign-owned firm'? This part of the analysis identifies firms which were taken over by a foreign-owned MNE, traces their innovation behaviour after the acquisition and compares it to domestically owned firms that have not been taken over, using either random effects probit or tobit models.

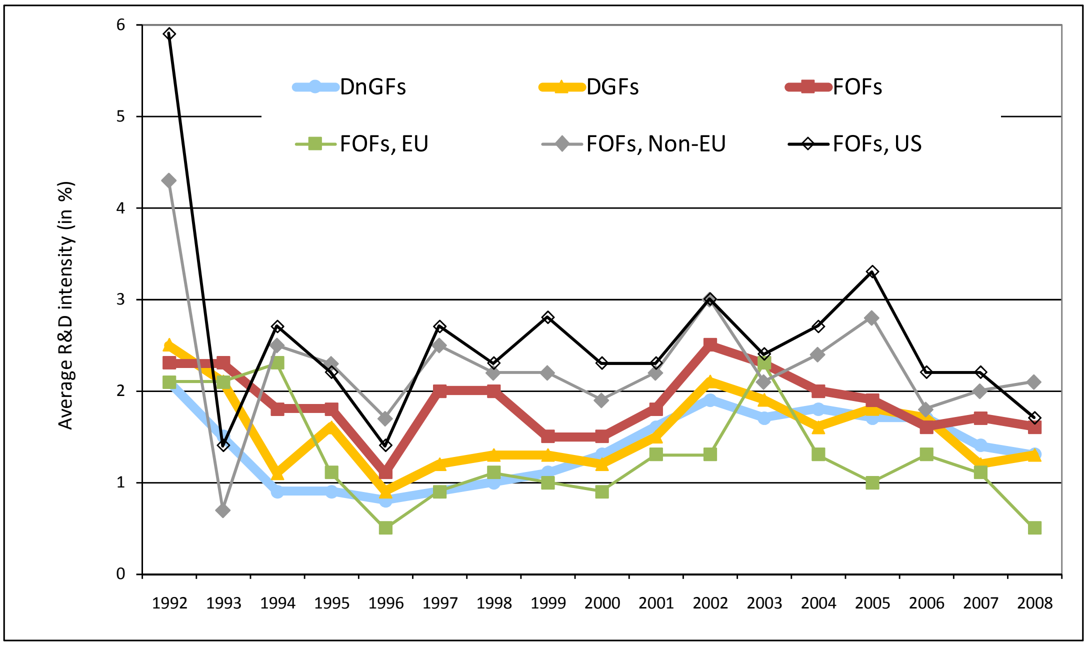
3.6.1. Innovation input

Consistent with the findings of the previous section, FOFs show lower innovation input intensity than DGFs and DnGFs over time. This is not true, though of every single year.

The result is different for R&D intensity. FOFs show the highest R&D intensity among all firms (Figure 3.16). This is mainly driven by FOFs belonging to groups from outside Europe. The time trends for most of the above innovation indicators reveal similar patterns, except for the share of sales of new products and, in part, for innovation expenditure.

These differences in innovation input over time may reflect differing innovation strategies or different ownership-specific advantages on the part of FOFs. On the other hand, since FOFs are typically larger firms that belong to high-tech industries such as chemicals, machinery or electrical engineering, it might not be surprising that FOFs in general and non-European firms in particular outperformed DGFs and DnGFs over the period 1992-2008.

Figure 3.16: R&D intensities by ownership, 1992-2008



Source: ZEW — Mannheim Innovation Panel, own calculation.

Panel estimations draw a differentiated picture of FOFs' innovation input over the last twenty years (see Table 4 in the Annex): FOFs in Germany exhibit on average significantly *higher innovation input intensity* than DnGFs, but less than DGFs. This result differs from the cross-sectional analysis in the previous chapter, which showed a significantly negative effect of foreign ownership on innovation input intensity after checking for company characteristics.

The fact that FOFs have demonstrated relatively higher innovation input intensities over the last twenty years is mainly due to FOFs belonging to groups from outside Europe. They tend to outperform FOFs from EU countries, which themselves spend significantly less on innovation than DGFs and DnGFs. However, as time goes by, the initial stimulating effect of foreign ownership on innovation intensity fades. That is, there is *convergence in innovation intensity* at the firm level over time after market entry.

The higher R&D intensity of FOFs is because relatively more FOFs are large firms and belong to technology-intensive industries. Foreign ownership itself *does not boost R&D* intensity. The finding that FOFs behave in a way similar to DGFs and DnGFs with respect to R&D expenditure is consistent across different home countries of FOFs. The quasi experiment further shows that the R&D intensity of newly-born FOFs does not differ from that of domestically owned firms just in the year of the acquisition, but also in the subsequent five years. Only in large upswing phases do FOFs tend to react differently by investing a significantly higher proportion of sales in R&D (see Dachs et al. (2010)).

3.6.2. Innovation output

The greater innovation efforts of DGFs are only partly reflected in the figures on innovation output. In the last two decades, *DGFs* have proved to be *more likely to introduce new products* (either new to the firm or to the market) than FOFs or DnGFs. There are thus grounds for supposing that DGFs pursue a more pronounced strategy geared towards the introduction of product innovations.

Another finding is that the country of origin matters for product innovation strategies. The negative effect that foreign ownership exerts on product innovation, though, is driven mainly by the behaviour of FOFs from other EU countries, which are less likely to introduce new products compared to DGFs, even given the same innovation intensity. This finding indicates a lower innovation productivity of FOFs from EU-27 countries compared to DGFs. Non-EU and US subsidiaries, however, do not significantly differ in their product innovation strategy compared to DGFs.

Over time, both *FOFs and DGFs* are *more successful in generating market novelties* than DnGFs. This is partly consistent with the cross-sectional analysis of the previous section, which showed a significant effect on market novelties only for FOFs. Hence, FOFs and DGFs are more likely to be technology leaders. Once again, though, market novelty strategies of FOFs differ with respect to their parents' country of origin. Compared to the results for product innovation, there is — surprisingly — no indication that non-European firms are more strongly oriented towards market novelties. European subsidiaries, though less innovative in terms of introducing product innovations in general, behave in a similar way to DGFs with respect to the introduction of market novelties. This is even more remarkable given their generally lower innovation intensities. It shows that when investing in other EU countries, European firms are more strongly oriented to the introduction of market novelties.

Foreign ownership in general *makes for successful market novelties*. Compared to DGFs, FOFs have a *lower share of sales with new products in general*, but not with the more technologically advanced market novelties. This pattern holds true independently of the country of origin. This may well be explained by the higher innovation expenses in particular for market introduction or by better sales channels and networks of the part of firms belonging to a (larger) group. However, this stimulating effect on market novelties seems to work only for more established FOFs, as suggested by the outcome of the quasi experiment. That is, there is no higher innovation success with market novelties in firms that have been acquired by a foreign company in the first five years after the acquisition.

Consistent with this finding, newly-established FOFs would seem to have a stronger focus on improving their success with product innovations that are only new to the firm, but which are not new to the market. More precisely, firms which have been taken over by a foreign company achieve a significantly lower share of sales with new-to-the-firm innovations in the year of takeover. However, they are able to improve their innovation success in the years after the takeover, with the result there are no longer any differences three or five years after the takeover (see Dachs et al. (2010)). Thus, convergence again kicks in after market entry.

3.6.3. Innovation cooperation

The dynamic analysis confirms the cross-sectional result from the previous section: both FOFs and DGFs are associated with a significantly higher propensity to cooperate than DnGFs. FOFs, independently of their parent company's country of origin, are more frequently engaged in innovation cooperation.

The dynamic analysis cannot, however, support the view that FOFs in Germany are more likely to cooperate with domestic partners in general and with domestic science organisations in particular compared to German firms in the last twenty years. FOFs prefer foreign firms and suppliers as cooperation partners. Similarly, domestically owned firms prefer domestic partners. The econometric analysis leads to suppose that the difference is country-induced, rather than a time effect. The finding that FOFs are not significantly more interested in domestic innovation partnerships than national firms is surprising since FOFs could benefit from the host country knowledge. Note that in countries where no such pattern can be observed, it is not possible to draw any conclusion as to whether FOFs are not interested in domestic partners because they have similar or fewer market motives and technological capabilities than international operating firms, or whether they find it harder to acquire suitable innovation partners.

3.7. Productivity and job creation of foreign-owned and domestically owned firms

Innovation is not an end in itself, but seeks to improve the firm’s competitiveness and performance. Thus, innovation has to be assessed in the light of economic success or, more generally, by its impact on company performance measures (Janz 2003). More jobs and higher productivity are two major performance measures which are also high on the political agenda. Hence, this section broadens the analysis to take in the effects of innovation on productivity and employment and examines differences between FOFs, DnGFs, and DGFs in these respects using CIS data. This gives an insight into how internationalisation changes the productivity and job creation of firms moderated by innovation.

3.7.1. Productivity effects

With respect to productivity, countries can benefit from the presence of FOFs in two ways: directly through higher productivity in foreign-owned firms, and indirectly through productivity increases in domestically owned firms as a result of knowledge spillovers or fiercer competition.

A first important finding with regard to productivity is that FOFs in Europe operate at higher productivity levels than both DnGFs and DGFs (see Table 5 in the Annex). In addition, the country of origin does not matter for productivity. Both FOFs from other EU countries and

FOFs from outside the EU exhibit a similar productivity lead over DnGFs and DGFs. The productivity advantage of FOFs is in line with the literature, which holds that only the most productive firms go abroad with foreign direct investment (Helpman et al. 2004).

Evidence for higher productivity growth rates of FOFs is mixed. FOFs show slightly higher growth rates than DGFs, but not than DnGFs, after controlling for size and other company characteristics. Due to data constraints it is not possible to measure indirect (spillover) effects on the productivity of DGFs and DnGFs. However, the fact that the growth rates are similar for FOFs and domestically owned firms gives at least indirect evidence that domestically owned firms do not fall too far behind foreign-owned firms.

One major channel for strengthening productivity is innovation (see Box A.1 in the Annex). Rising innovation activity (measured either as innovation input or as innovation output) has a stimulating effect on productivity levels and productivity growth. This works through product innovation. The innovation-productivity nexus turns out to be similar in DnGFs, DGFs and FOFs from outside the EU. FOFs from another EU country, on the other hand, achieve significantly smaller (but still positive) absolute productivity gains from investing in innovation. However, there are no differences in terms of relative productivity gains (productivity growth).

3.7.2. Employment effects

Employment effects are closely related to productivity effects. If process innovation leads to an increase in productivity, firms are able to produce the same with less input and thus, all other things being equal, at lower unit cost. At the same time, the reduction in unit cost allows the innovative firm to lower their output prices, resulting in higher demand for the product and higher output. The magnitude of this compensating price effect depends on the amount of price reduction, the price elasticity of demand, the degree of competition and the behaviour and relative strength of different agents within the firm (Garcia et al. 2002).

Product innovation, by contrast, affects employment mainly via demand effects. When a new product has successfully been introduced to the market, it creates new demand for the innovating firm. Note that this demand effect can be the result either of market expansion or of business-stealing at the expense of the firm's competitors. In addition to this direct demand effect, there are usually some indirect employment effects. If the new product replaces (partially or totally) the old one, labour demand for the old product will decrease, and the overall effect is ambiguous. However, in the case of complementary demand relationships, the innovation causes the demand for existing products to rise as well. Product innovation may also have productivity effects. The new or improved product may require a change in production methods and input mix, which could either reduce or increase labour requirements (see Harrison et al., 2008).

The employment effects of innovation will be examined by reference to a model recently developed by Harrison et al. (2008). It makes it possible to disentangle some of the relationships between employment, prices and production discussed above and establishes a link between employment growth rate and innovation output in terms of sales growth stemming from innovative products. The latter can be directly calculated with CIS data.

The econometric results reveal that employment growth is lower in FOFs, and in DGFs, compared to DnGFs after controlling for country and industry effects. In the service sector, employment growth rates of FOFs are even lower than DGFs. But not all FOFs behave in the same way. In manufacturing, FOFs with a parent company from another European country grow slower than North American affiliates. FOFs from European countries, however, tend to perform better than FOFs from the rest of the world.

But can these differences between foreign-owned and domestically owned firms be attributed to differences in process and product innovation performance? To answer this question, the average employment growth of each group is separated into four components:

- The change in employment due to a general industry and country-specific productivity trend in the production of old products (productivity gains unrelated to process innovation).

- The net employment contribution made by process innovations related to the production of old products. It is the result of displacement effects brought about by process innovations and the compensatory demand effects responding to cost and price reductions.

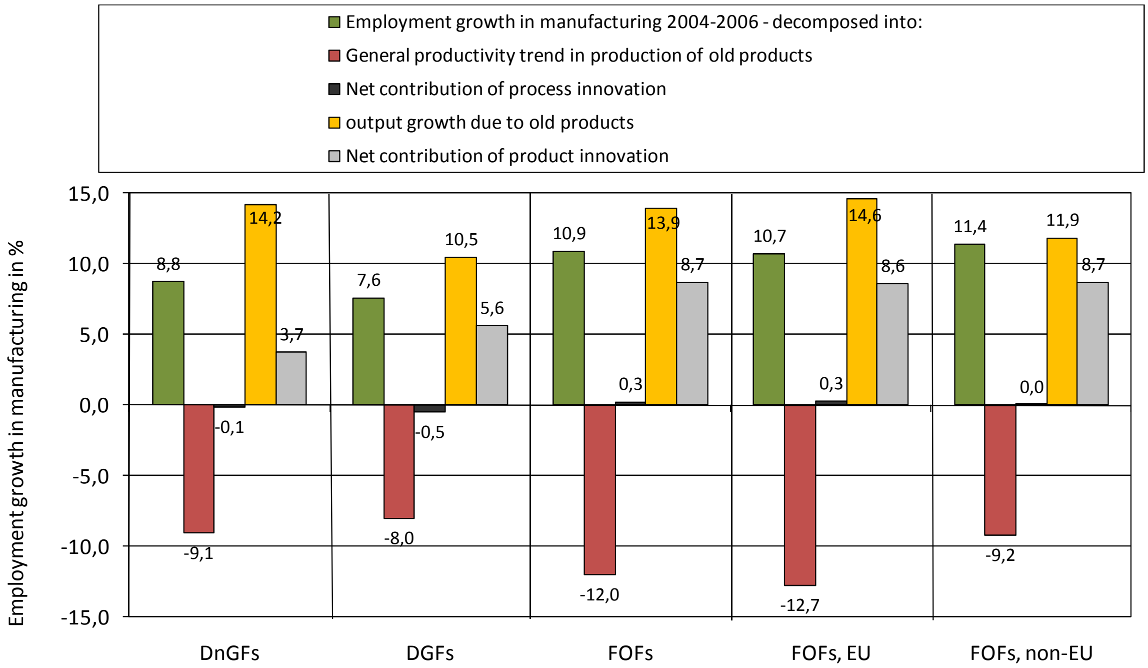
- Employment change associated with output growth of old products for firms that do not introduce new products or, in other words, the shifting demand for the existing product.

- Finally, the fourth term summarises the net contribution of product innovations on employment for product innovators.

Figure 3.17 shows this detail of employment growth in manufacturing by ownership status for the period 2004-06 based on the regression results[7]. Similar calculations, not reported here, have been done for the period 2002-04.

[7] Note that this divides up actual average employment growth. This growth rate turned out to be higher in foreign-owned firms, this can be explained by industry and country effects. Ownership itself, all other things being equal, has a significantly negative effect on employment growth. For each group of firms, industry and country effects are captured by the general productivity trend.

Figure 3.17: Breakdown of employment growth by ownership, manufacturing, 2004-2006



Note*:* DnGFs: domestically owned non-group firms; DGFs: domestically owned group firms; FOFs: foreign-owned firms; FOFs, EU: foreign-owned firms from an EU country; FOFs, non-EU: foreign-owned firms from a country outside the EU.

Source: CIS2006, Eurostat, ZEW/AIT calculations.

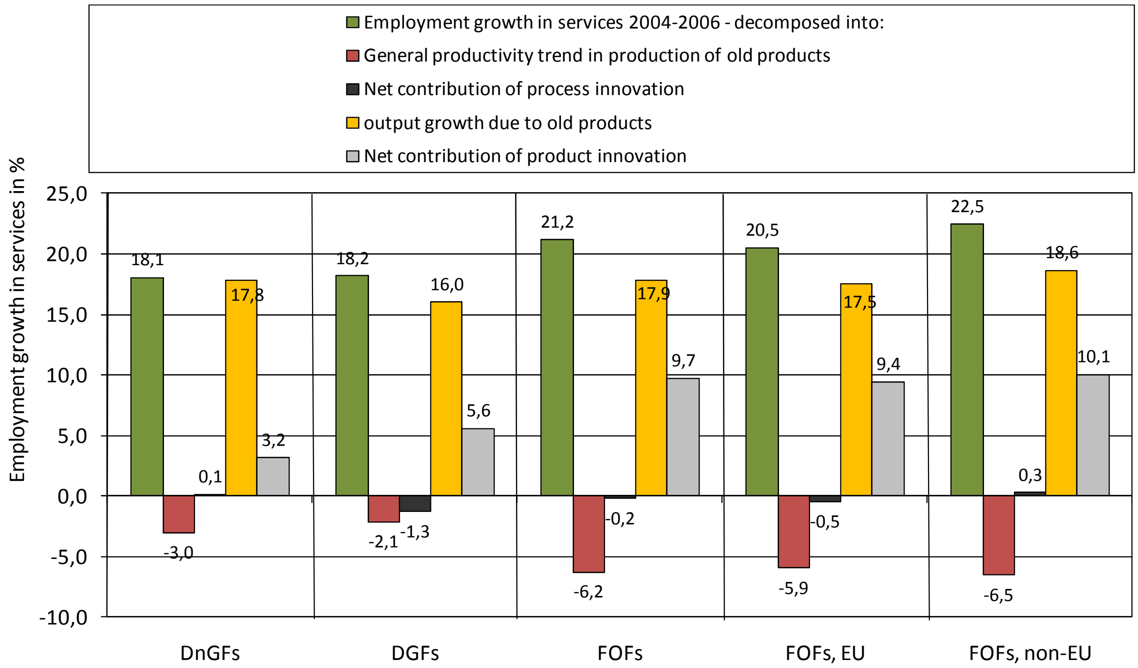
Process innovations generally play only a minor role for employment change in all sub-samples. Foreign-owned firms experience a much higher general productivity trend than domestically owned firms, leading to greater job losses. Affiliates from another EU Member State achieve the strongest general productivity gains due to organisational changes, sales of less productive firm components, the acquisition of more productive firms, improved capital endowment, and learning or spillover effects.

These negative employment changes, however, are outweighed in each sub-sample by the output growth for old products and by the contribution of new products to employment growth. In general, output growth for old products spurs employment more than product innovation for all types of firms. Interestingly, job creation arising from increased demand for existing products is highest for affiliates from another EU Member State, closely followed by domestically owned unaffiliated firms.

The main difference between foreign-owned and domestically owned firms lies in the contribution of product innovation to employment growth. This is smaller in absolute terms than the contribution of old products in absolute terms. New products, however, play a much stronger role in employment creation in foreign-owned affiliates than in domestically owned unaffiliated firms or firms belonging to a domestic group in both periods. Here, affiliates of EU and non-EU MNEs tend to be similar.

Similar relationships can be observed in services (Figure 3.18). Again, employment growth is driven mainly by shifts in demand for old products, and the effects of product innovation on employment growth, both of which more than compensate job losses resulting from general productivity gains and displacement effects of process innovations. New products make an even greater absolute and relative contribution to employment growth for both non-European and European affiliates.

Figure 3.18: Breakdown of employment growth by ownership, services, 2004-2006



Notes: DnGFs: domestically owned non-group firms; DGFs: domestically owned group firms; FOFs: foreign-owned firms; FOFs, EU: foreign-owned firms from an EU country; FOFs, non-EU: foreign-owned firms from a country outside the EU.

Source: CIS2006, Eurostat, ZEW/AIT calculations.

Both observations accord with the literature (Dunning 1981; Caves 1996 (1974); Markusen 2002). Foreign-owned affiliates have access to superior technology and organisational and management capabilities internal to the multinational firm which domestically owned firms might not have. These capabilities allow foreign-owned firms to enjoy higher productivity gains than the average domestically owned firm.

A second advantage of foreign-owned firms is that they can utilise existing products and technologies of the parent company, and learn from their experience with product innovation in other countries. This may help them to reap higher output growth from new products, which translates into a higher contribution to employment growth.

3.8. Summary and policy implications

The above analysis has yielded various insights into the internationalisation of R&D and innovation in the European Union.

The level of internationalisation of R&D and innovation has been on the increase in the EU since 1990. Today, some 17% of all patents granted in the EU-27 are owned by foreign organisations from inside or outside Europe. Increases in foreign and domestic activities indicate that the two complement one another and satisfy different needs, rather than being substitutes. The Innovation Union Flagship initiative recently adopted by the Commission as part of the Europe 2020 strategy therefore aims at increasing the attractiveness of the EU as a location of R&D and innovation investments and at promoting international cooperation on research and innovation (European Commission (2010a,d)).

Small and medium EU Member States show a higher degree of internationalisation than large countries. There are at least five countries in the EU where foreign-owned firms currently hold more than 50% of R&D expenditure in manufacturing. Cultural and geographical proximity between countries goes a long way to explaining the internationalisation of R&D and innovation. Despite high levels of internationalisation in the EU-12, the bulk of foreign-owned R&D and innovation activity takes place between EU-15 Member States.

A high share of foreign-owned R&D and innovation activity can be found in technology-intensive sectors, such as electronics, pharmaceuticals, office equipment and the computer industry. Innovation in services is less affected by internationalisation in R&D expenditure than manufacturing.

Outward internationalisation of EU firms has increased as well over the last decade. Today, some 10% of all EU patent (triadic) applications are based on inventions made outside the EU. The preferred location for overseas R&D and innovation of EU firms is the United States. Similarly, the EU is the preferred location for US firms.

Outward R&D and innovation activities of EU firms in China, India, Brazil or other emerging economies start from low levels but are rising fast. Bearing in mind that overseas R&D activities follow outward foreign direct investment to a considerable degree, the share of the BRIC countries in EU overseas R&D and innovation activities can be expected to rise considerably in the future.

Multivariate analysis reveals that foreign-owned firms (at least from a static perspective) have a lower innovation input intensity than domestically owned firms, but achieve a similar innovation output, which is the key determinant in assessing the contribution these firms make to growth. This confirms that their innovation efforts are based to a considerable degree on technologies, brands, and other assets they receive from the parent company or other parts of the enterprise group. A number of differences between foreign-owned and domestically owned firms are due to related firm characteristics — foreign-owned firms are larger, have higher absorptive capacities, or operate more often in technology-intensive sectors.

One important finding is that cooperation with domestic partners, in particular domestic universities and research centres, is frequent among foreign-owned firms. The analysis reveals that foreign-owned firms have at least the same propensity to cooperate with external organisations in the host country as domestically owned firms. This seems to indicate that foreign-owned firms are well embedded in the national innovation systems of their host countries. Moreover, if cooperation is viewed as a two-way relationship, it follows that knowledge from foreign-owned firms has the potential to spill over to domestic organisations. Hence, host economies can benefit from the knowledge the foreign-owned subsidiary receives from its enterprise group. Foreign-owned firms therefore can act as agents of international technology diffusion and as bridges between organisations in the host country and foreign sources of knowledge.

Foreign-owned firms show significantly higher productivity levels (measured by sales per employee) than domestically owned firms. The country of origin has no influence on the strength of the effect. Foreign-owned firms also show higher levels of productivity growth, although here the differences to domestically owned firms are considerably smaller and less significant. Productivity growth is mainly related to output growth for old products and the effects of product innovation, but not process innovation. There are no major differences between foreign-owned firms, domestic group enterprises and domestic unaffiliated firms in the way innovation affects productivity levels. Subsidiaries of European MNEs, however, seem to benefit less from innovation expenditure than do subsidiaries of non-European MNEs.

Foreign-owned firms also differ from domestically owned firms in the way they transform new technologies into employment growth. Foreign-owned firms shed more jobs in the wake of general productivity increases; these are, however, overcompensated by the employment-creating effects of higher sales of old products and product innovation in foreign-owned firms, which are higher than in domestically owned enterprises.

Together, these three effects result in net employment growth, including higher demand for skilled personnel. Overcoming capacity bottlenecks in the home country is indeed one of the main reasons why firms take their R&D and innovation activities abroad. Combining this finding with the fact that foreign-owned firms tend to operate more in technology-intensive industries, foreign-owned R&D and innovation activities in a country may also trigger structural change in the sense of boosting the share of high- and medium-tech industries.

What challenges and opportunities emerge for the EU?

Empirical evidence shows that foreign-owned firms contribute in many ways to a country's innovative capacity and performance. They innovate differently, but not necessarily less intensively than domestically owned firms. Foreign-owned firms have a lower innovation input intensity (after controlling for their main characteristics), but a similar innovation output, which is the key determinant in assessing the growth contribution of these firms.

There is no evidence that the presence of foreign-owned firms is detrimental to national innovation systems, e.g. by siphoning off knowledge resources or crowding out innovation by domestically owned firms.

A survey of current internationalisation policies (see Dachs et al. (2010)) showed that the principle of non-discrimination is adopted in all EU Member States. There is very little formal discrimination against foreign-owned firms with respect to access to funds or other restrictions of their business activities, as long as they are domiciled in the country. There may, however, be certain *de facto* preferences in some Member States for domestically owned firms in national innovation programmes.

The analysis in this chapter reveals no evidence in support of negative discrimination against (by limiting the activities of) foreign-owned firms[8]. The empirical findings indicate no support for a positive discrimination either (e.g. by offering special incentives to foreign-owned firms). The high level of R&D and innovation activities of foreign-owned firms indicates that the EU is an attractive location for these types of activities. Empirical evidence suggests that the decisive factors in attracting R&D and innovation activities of foreign-owned firms are economic stability, high market growth expectations, or the excellence of the science sector, IPR protection and the availability of S&T personnel (Cantwell and Mudambi 2000; Thursby and Thursby 2006). These factors are often more important than financial incentives, like tax breaks for foreign-owned firms[9].

[8] In addition, limiting the activities of foreign-owned firms would violate EU competition law.

[9] The 2008 EU survey on R&D (European Commission JRC IPTS 2009b) points further to some differences between firms. High R&D intensity firms appear to give relatively more importance to tax incentives.

Countries which are successful in attracting and benefiting most from foreign R&D and innovation tend to have stable macroeconomic conditions and policies and dynamic scientific and technology bases. They are also keen to foster capabilities for innovation in both foreign-owned and domestically owned firms. This conclusion is underpinned by the finding that many differences between foreign-owned and domestically owned firms are related to company characteristics such as size, sectoral affiliation, export orientation etc., rather than to foreign ownership as such.

Moreover, R&D and innovation activities of foreign-owned firms are often the last step in their expansion at a certain location and are preceded by investment in production or sales activities. The most appropriate way to encourage R&D-intensive foreign-owned firms is to give them backing throughout their expansion by administrative simplification, matchmaking with domestic partners and other 'after-care' services following market entry (Guimón (2009)).

Policies which strengthen the links and integration of foreign-owned firms into domestic innovation networks, particularly with other firms in the host country, can deliver substantial benefits. Both supplier and user links to foreign-owned firms, as well as pre-competitive cooperation schemes with foreign-owned competitors, can help domestically owned firms to learn from these internationally experienced companies. Learning and technology transfer from foreign-owned firms can contribute in three ways to competitiveness:

- Foreign-owned firms tend to apply more advanced innovation management techniques, including ideas for successfully commercialising new products.

- Foreign-owned firms — with their higher productivity levels — may have technologies that can help domestically owned firms to advance their own production methods and product portfolios.

- Finally, domestically owned firms can use their contacts to foreign-owned firms to learn for their own internationalisation activities, including R&D and innovation internationalisation. Linking domestically owned and foreign-owned firms may also include ways and means of raising the capacities of domestically owned firms to absorb and make use of external knowledge.

There is some evidence that supporting domestically owned firms' outward R&D and innovation activities can be advantageous for a national innovation system. R&D and innovation activities abroad help to gear innovative products to the requirements and preferences of foreign markets, which in turn increases the sales potential of domestic innovations. In addition, foreign R&D and innovation improves access to foreign knowledge sources, which can be used to advance domestic R&D and innovation, e.g. by accessing new research findings or lead markets abroad. So far, there have only been very few national programmes that actively support foreign R&D and innovation by domestically owned firms. This may be because of concerns of knowledge leaking out or of using taxpayers' money to support R&D at foreign locations. Empirical evidence suggests, however, that the internationalisation of firms will strengthen the entire business, i.e. also business activities in the home country (see for example Europe Economics (2010), Pfaffermayr (2004)).

It is not possible from today's perspective to fully ascertain the effects of the economic and financial crisis on the internationalisation of R&D and innovation. Innovation and R&D, however, show a high degree of robustness and consistency over time (see Filippetti and Archibugi 2010), which suggests that the crisis will have only minor consequences. Evidence from panel data described above indicate that R&D and other innovation expenditure by both foreign-owned and domestically owned firms is affected in the same way by the business cycle. In a cyclical downward trend, foreign-owned firms tend to keep up their higher R&D investment for a longer time. A high degree of foreign-owned R&D activity in a country may therefore even have a stabilising effect on gross national R&D expenditure in times of crisis.

There are several ways in which the European Commission can help firms to benefit from the internationalisation of R&D and innovation.

At the EU level there could be programmes linking EU partners with non-EU industrial partners in joint R&D and innovation projects. These would indirectly stimulate both inward R&D investment by non-EU firms and active R&D internationalisation of EU firms. It might be beneficial for unaffiliated, small and medium sized firms in particular (see SBA, principle VIII), encouraging investment in research by SMEs and getting them to take part in transnational research activities — which can be achieved in part by getting them actively involved in the 7th RTD Framework Programme. The analysis has shown that this group cooperates considerably less with domestic partners. There are specific obstacles to cooperation in SMEs, such as a lack of resources and long-term funding of R&D, which are found less frequently in large firms.

In addition, support for SMEs to take their R&D and innovation activities abroad and forge links to specific foreign sources of knowledge may also yield considerable benefits for these firms. Empirical evidence suggests that internationalising innovation may boost the economic performance of the SME in the home country. Foreign-based R&D and the exploitation of innovations in foreign markets helps SMEs to significantly increase employment at domestic locations (Rammer and Schmiele 2008). Large domestic multinational firms do not need support from public policy to intensify their international linkages.

There may be advantages from making the European Research Area and the Framework Programme more open to non-EU firms, universities and other organisations. Cooperation between EU and non-EU organisations within the Framework Programme could strengthen links between Europe and other parts of the world. Linking MNEs more closely to domestic research organisations in joint projects may step up the transfer of knowledge between foreign and domestic partners.

Another channel for knowledge spillovers from foreign-owned firms to the domestic innovation system is staff mobility (see e.g. Kaiser et al. (2008)). Creating a culture that encourages spin-offs by employees of domestic and foreign-owned multinationals can foster growth and create more jobs.

There are some issues related to the internationalisation of R&D and innovation where a pan-European discussion and further comparisons of actual policies in the Member States would be beneficial: one of these is the treatment of non-domiciled foreign-owned firms (with no subsidiary in a Member State) in national funding schemes for R&D and innovation.

The locational advantages of the European Union could be enhanced by removing more barriers to trans-European R&D and innovation activities. One example is the European Patent. A single EU patent with centralised application and litigation procedures and a sound application and renewal fee structure could have a stimulating effect on R&D and innovation by foreign-owned firms in particular.

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ANNEX

Measuring the Internationalisation of R&D and Innovation

There are at least three approaches to measuring the internationalisation of R&D and innovation activities. **Patent data** feature the location of the applicant and the location of the inventor of a particular patent. By comparing the two, it is possible to derive a measure for the foreign ownership of domestic patent inventions, which can be used as an indicator for the internationalisation of R&D and innovation (Guellec and van Pottelsberghe de la Potterie 2004; Belderbos et al. 2009). Patent data are available in great detail for many countries, years and technologies. There are, however, some shortcomings that must be considered (see also the preceding chapter): time lags between application and invention; not all inventions are patentable; differences in the propensity to patent between sectors (with very little patents in the services sector); no indication of its application or economic value; potential distortions from 'strategic' patenting.

This study employs two types of patent data: first, data provided by the European Patent Office (EPO); second, triadic patents which have been applied for at all three major patent offices: the EPO, the US Patent and Trademark office (USPTO), and the Japanese Patent Office (JPO). The number of triadic patents is relatively small, especially in the more recent years. However, triadic patents help to circumvent the 'home office' bias in patents which results from the tendency of an inventor to apply at the patent office of her/his home country first. As a consequence of this bias, US inventors are overrepresented at the USPTO, while European inventors dominate the EPO.

Innovation surveys, in particular the **Community Innovation Survey (CIS)** and the **European Manufacturing Survey (EMS)**, are a second data source employed in this chapter. Innovation surveys provide detailed information on goals, hindering factors, financial inputs and outcomes of corporate innovation processes. This study employs CIS data in the multivariate analysis featuring in chapters four, five and six, and EMS data in chapter three.

An advantage of innovation survey data is that they cover the whole innovation process, not just R&D, and usually include the service sector. They often include information on various company characteristics, which makes it possible to relate innovation activity to company size, sector, employment structure etc.. Disadvantages of innovation survey data include problems with their scope and definitions (Salazar and Holbrook 2004) and with data access. This chapter employs firm-level data from the CIS and the EMS.

A third data source is **R&D expenditure of foreign affiliates** published by national statistical offices. The biggest advantage of data on R&D spending by foreign subsidiaries is that it allows a direct comparison with R&D expenditure at the sectoral or aggregate level. The broad coverage of national R&D surveys makes them highly representative and includes R&D in the service sector. However, a number of countries have not yet extended their R&D surveys to cover the ownership status of the firm, and coverage is still poor at the sectoral level, with respect to outward internationalisation. Data on R&D expenditure by foreign affiliates is presented in section three.

Table A.1: Share of R&D expenditure by foreign-owned affiliates in manufacturing and services (most recent year)

	AT	CZ	DE	FI	FR	HU	IE	IT	NL	PL	PT	SE	SK	UK
Year	2004	2007	2007	2006	2007	2004	2005	2007	2001	2007	2007	2007	2007	2007
Total Business Enterprise	44.9	54.7	26.2	17	19.6	73.9	70.3	27.4	19.6	30.7	23.1	35.5	37.5	37.5
Manufacturing	54.5	67.7	27.4	13.5	21.1	58.7	76	24.3	22.2	31.6	39.4	40.3	66.8	..
Food, beverages and tobacco	25.2	64.9	54.9	26.6	36.8	69.8	36.2	14	12.5	..	..	46.4	95.7	42.9
Textiles, wearing apparel, leather, footwear	..	24.9	..	..	18.3	0	34.8	12.4	22.2	..	5	64.8	..	32
Wood and paper products, publishing, printing	41.3	0	..	6.4	29.2	30.8	16.7	..	21.4	..	46.6	27.1	..	23.8
Chemical products	67.3	68.8	35.6	34.6	23.3	40.7	94.5	49.9	26.4	24.2	20	91	74.9	34.6
Drugs and medicines	73.2	87.7	52.8	34.3	21	..	96.3	..	25.7	..	21	..	92.1	34.1
Rubber and plastic products	6.6	58.5	36.5	10.6	11.3	47.4	28.6	17.9	37	..	10	23.4	75.6	42.9
Non-metallic mineral products	11.7	23.1	41.2	41.5	19.4	11.1	24.7	8	40.7	12.2	30.9	78.3	87	51.9
Basic metals	6.3	50.6	21.7	20.8	68.9	78.3	0	..	18.2	22.8	18.8	16.1	..	..
Fabricated metal products	21.7	42.9	22	54	30.9	20	46.3	..	12.7	..	20.3	9.9	62.5	61.9
Total machinery and equipment	..	51.4	29.3	..	28.2	86.4	76	..	9.2	..	57.2	..	..	50.7
Non-electrical machinery and equipment	..	46.7	26	..	35	65.5	63.8	..	7.2	..	39.4	43.3	..	56.8
Machinery and equipment n.e.c.	38.2	47.4	18.7	26.4	35	67.9	62.2	33.2	8	24.8	41.9	45.2	38.3	56.1
Office, accounting and computing machinery	..	0	77.4	..	33.9	0	64.8	..	3.3	..	0	8.1	..	64.6
Electrical machinery and electronic equipment	83.8	57.2	33.5	..	25.7	91.4	83.7	..	31.1	..	69.4	..	69.4	45
Electrical and optical equipment	..	61.3	30.9	..	24.7	83.6	78.3	18.5	27	..	..	..	..	..
Radio, TV and communication equipment	95.3	66.9	34.7	..	24.3	92.4	88.6	..	..	8.1	75.9	..	93.5	55.5
Medical, precision, opt. instruments	18.1	68.4	17	..	21.6	14.3	77.9	..	40.9	..	..	43.7	..	58.6
Motor vehicles	50.3	95.2	14.9	25.4	19.2	96.9	86	..	89.9	..	65.4	50.3	..	89
Other transport equipment	33.6	9.8	81.4	..	2.3	0	0	..	5.6	..	..	7	..	..
Furniture, recycling and manufacturing n.e.c.	..	28.6	28.1	24.8	27.5	0	1.1	24.8	27.3	..	..	6.2	..	..
Electricity, gas and water supply, construction	0	1	..	10.2	..	2.6	0	..	10.8	..	0.3	39.4	..	36.8
Trade, repair, hotels and restaurants	42.9	56.4	..	87.3	..	..	0	67.9	36.9	83.4	..	42.2	..	42.9
Finance, insurance, real estate, business act.	20	35.7	16.4	19.4	..	..	60.1	43.7	16.8	48.9	24.4	20.3	..	..

Source: OECD FATS, ZEW/AIT calculations.

Table A.2: Impact of foreign ownership and domestic group membership on innovation and cooperation behaviour of EU firms

COEFFICIENT	lintens	turnmar	co_dom_ex	co_dom_sci
domgp	-0.0733**	0.0075	0.2627***	0.3417***
	(0.0320)	*(0.0050)*	*(0.0426)*	*(0.0518)*
forown	-0.1505***	0.0107*	0.1372***	0.2736***
	(0.0374)	*(0.0056)*	*(0.0484)*	*(0.0508)*
lemp	-0.8864***	-0.0177**	0.0318	0.0056
	(0.0523)	*(0.0078)*	*(0.0726)*	*(0.0762)*
lemp2	0.0445***	0.0017**	0.0117*	0.0117*
	(0.0049)	*(0.0007)*	*(0.0067)*	*(0.0065)*
rrdin	0.4960***	0.0459***	0.5086***	0.6099***
	(0.0264)	*(0.0041)*	*(0.0372)*	*(0.0495)*
spill	0.3566***	0.0495***	0.6778***	1.0018***
	(0.0485)	*(0.0074)*	*(0.0667)*	*(0.0849)*
mar_int	-0.2823***	0.0367***	-0.0107	-0.0280
	(0.0541)	*(0.0088)*	*(0.0612)*	*(0.0683)*
finsup	0.8309***	0.0228***	0.5042***	0.6738***
	(0.0274)	*(0.0044)*	*(0.0389)*	*(0.0454)*
low	0.2552***	0.0332***	0.4666***	0.3310***
	(0.0751)	*(0.0121)*	*(0.1038)*	*(0.1179)*
med_low	0.6288***	0.0259**	0.4486***	0.2691**
	(0.0754)	*(0.0121)*	*(0.1014)*	*(0.1119)*
med	0.8903***	0.0351***	0.4959***	0.3177***
	(0.0730)	*(0.0117)*	*(0.0993)*	*(0.1102)*
med_high	0.8746***	0.0298**	0.4988***	0.4242***
	(0.0739)	*(0.0118)*	*(0.0996)*	*(0.1111)*
high	1.4314***	0.0862***	0.6488***	0.6317***
	(0.0746)	*(0.0119)*	*(0.1016)*	*(0.1116)*
Constant	-1.3666***	-0.0388	-2.3949***	-2.8199***
	(0.2805)	*(0.0480)*	*(0.3765)*	*(0.4880)*
Wald chi2	5108.10***	858.56***	1545.60***	952.22***
Observations	78403	85456	84677	84677
Uncensored observations	20797	18484	27071	27071

Notes: lnintens is the ln of innovation expenditures as percentage of turnover in 2006; turnmar is the share of turnover generated by market novelties in 2006. co_dom_ex is 1 if the enterprise had co-operation agreements during 2004-2006 with suppliers, clients or customers, competitors or other firms, consultants, commercial labs, private R&D institutes, universities, government or public research institutes at the national level. Co_dom_sci is 1 if the enterprise had co-operation agreements during 2004-2006 with universities, government or public research institutes at national level. Domgp identifies domestically owned group enterprises, forown is 1 if the firm is foreign-owned. Description of the other independent variables (see Dachs et al. (2010)): Size (*lemp*): ln (total number of employees) in the reference year 2006; $Size^2$ (*lemp2*); Intramural R&D (*rrdin*): 1 if the enterprise is engaged in intramural (in-house) R&D; 0 otherwise; External Spillovers (*spill*): Sum of scores of importance of the following information sources for the innovation process [number between 1 (low) and 3 (high)]: sources from Professional and industry associations, sources from scientific journals, trade/scientific publications and sources from professional conferences, trade fairs, meetings; (rescaled between 0 and 1); International market-orientation (*mar_int*): 1 if a firm exported goods or services during the years 2004-2006; 0 otherwise; Public funding (*finsup*): 1 if the firm got public funding for innovation from local or regional authorities, or from central government, or from the EU; 0 otherwise; Sectoral affiliation (*none, low, low_med, med, med_high, high*): taxonomy of economic sectors (six categories) according to their innovation intensity (Peneder 2010); sectors are classified according to cumulativeness of the knowledge base, appropriability conditions, technological opportunity and creative vs. adaptive strategies.

lintens and *turnmar* are estimated by Heckman regression; *co_dom_ex* and *co_dom_sci* are estimated by Heckman Probit;

***, **, * denote statistical significance at the 1%, 5% and 10% test level; Standard errors in parentheses; observations cover innovative and non-innovative firms; Uncensored observations relate to firms with innovation activities; the χ^2 test is a Wald test that all coefficients in the regression model (except the constant) are 0

Country dummies are not reported in the table.

Source: ZEW/AIT calculations, CIS2006, EUROSTAT

Table A.3: Innovation and cooperation behaviour of FOFs from different home country groups

COEFFICIENT	lintens	turnmar	co_dom_ex	co_dom_sci
asia	0.269	0.0857 **	-0.192	-0.3840 **
	(0.220)	*(0.0423)*	*(0.142)*	*(0.167)*
noneu	0.0418	0.0562	-0.0290	0.0266
	(0.233)	*(0.0431)*	*(0.140)*	*(0.147)*
usca	-0.0690	0.0289 *	0.0796	0.3010 **
	(0.138)	*(0.0166)*	*(0.115)*	*(0.124)*
other	0.534	-0.0465 *	-0.160	0.119
	(0.329)	*(0.0244)*	*(0.185)*	*(0.198)*
lemp	-0.9390 ***	-0.0503 *	-0.0276	-0.200
	(0.222)	*(0.0298)*	*(0.184)*	*(0.183)*
lemp2	0.0370 *	0.00390	0.0158	0.0252 *
	(-0.0191)	*(0.00255)*	*(0.0145)*	*(0.0136)*
rrdin	0.4870 ***	0.0307 **	0.5100 ***	0.6000 ***
	(0.115)	*(0.0138)*	*(0.0724)*	*(0.0879)*
spill	0.0682	0.0183	0.6700 ***	1.3380 ***
	(0.236)	*(0.0296)*	*(0.179)*	*(0.187)*
mar_int	-0.0179	0.0074	-0.2250 **	-0.125
	(0.168)	*(0.0164)*	*(0.107)*	*(0.110)*
finsup	0.5750 ***	0.0308 *	0.5130 ***	0.6530 ***
	(0.118)	*(0.0173)*	*(0.0828)*	*(0.0918)*
low	-0.111	0.111 ***	0.449 **	0.0371
	(0.369)	*(0.0214)*	*(0.222)*	*(0.260)*
med_low	0.536	0.0622 ***	0.3810 *	-0.0244
	(0.369)	*(0.0154)*	*(0.218)*	*(0.250)*
med	0.6580 *	0.0656 ***	0.3770 *	0.0052
	(0.362)	*(0.0168)*	*(0.215)*	*(0.249)*
med_high	0.8030 **	0.0882 ***	0.5630 ***	0.4790 **
	(0.351)	*(0.0157)*	*(0.209)*	*(0.242)*
high	1.0000 ***	0.1170 ***	0.6270 ***	0.4440 *
	(0.364)	*(0.0167)*	*(0.215)*	*(0.245)*
Constant	-0.318	0.2130 **	-1.9750 **	-1.688
	(0.947)	*(0.0952)*	*(0.786)*	*(1.027)*
Wald chi2	226.74 ***	158.27 ***	298.31 ***	241.45 ***
Observations	7782	8650	8525	8525
Uncensored Observations	3149	2911	3892	3892

Notes: lnintens is the ln of innovation expenditures as percentage of turnover in 2006; turnmar is the share of turnover generated by market novelties in 2006. co_dom_ex is 1 if the enterprise had cooperation agreements during 2004-2006 with suppliers, clients or customers, competitors or other firms, consultants, commercial labs, private R&D institutes, universities, government or public research institutes at the national level. Co_dom_sci is 1 if the enterprise had cooperation agreements during 2004-2006 with universities, government or public research institutes at national level. Domgp identifies domestically owned group enterprises, forown is 1 if the firm is foreign-owned.
Descriptions of the other independent variables can be found in Dachs et al. (2010).

lintens and *turnmar* are estimated by Heckman regression; *co_dom_ex* and *co_dom_sci* are estimated by Heckman Probit; ***, **, * denote statistical significance at the 1%, 5% and 10% test level; Standard errors in parentheses; observations cover innovative and non-innovative firms; Uncensored observations relate to firms with innovation activities; the χ^2 test is a Wald test that all coefficients in the regression model (except the constant) are 0.
Country dummies are not reported in the table.

Source: ZEW/AIT calculations, CIS2006, EUROSTAT.

Table A.4: Impact of foreign ownership and domestic group membership on innovation and cooperation behaviour of EU firms, panel regressions

	Dependent Variable			
	Innovation input intensity	Innovation output intensity	Cooperation with domestic partners	Cooperation with domestic science
Ownership				
DGF	0.972***	1.452**	0.029**	0.011
	(0.198)	(0.666)	(0.015)	(0.007)
FOF	-	-	-	-
FOFEU	-0.902	0.526	0.034	0.004
	(0.598)	(1.536)	(0.039)	(0.018)
FOFNONEU	0.171	0.620	0.042	0.034
	(0.706)	(1.763)	(0.042)	(0.023)
FOFUS	-	-	-	-
FOFROW	-	-	-	-
Innov. Intensity in t-1		1.799***		
		(0.224)		
Firm size	1.018***	-4.608***	0.079***	0.040***
	(0.074)	(0.772)	(0.005)	(0.003)
East Germany (0/1)	1.146***	-1.587***	0.112***	0.045***
	(0.264)	(0.365)	(0.016)	(0.009)
Firm age	-1.800***	0.376***	-0.018**	-0.010***
	(0.118)	(0.019)	(0.007)	(0.003)
Export intensity	3.670***	9.188***	0.131***	0.080***
	(0.310)	(1.144)	(0.025)	(0.013)
Creditworthiness	0.431	16.180***		
	(0.417)	(0.549)		
constant	-1.877	-35.964***		
	(2.532)	(2.428)		
Year dummies [a)]	0.000***	0.000***	0.000***	0.000***
Industry dummies [a)]	0.000***	0.000***	0.000***	0.000***
sigma_a	13.372***	19.351***		
	(0.116)	(0.414)		
sigma_e	11.385***	19.431***		
	(0.054)	(0.237)		
rho	0.58	0.498		
Observations	63942	10321	10109	11961
LL			-5160.070	-4775.694
W: DGF=FOFEU	0.002***	0.543	0.925	0.681
W: DGF=FOFNONEU	0.254	0.634	0.883	0.285

Notes: Estimation method: random effects tobit model. [a)] Year and industry dummies are included but not reported. Reported is only the p-value of a test on joint significance. W: DGF=FOFEU reports the p-value of a test on joint significance of DGF and FOF, EU (H0: not jointly significant). W: DGF=FOFNONEU reports the p-value of a test on the difference between DGF and FOF, non-EU (H0: no significant difference). Sigma_a and sigma_e denotes the standard deviation of the individual fixed/random effects and the idiosyncratic error term, respectively.

Source: ZEW — Mannheim Innovation Panel, own calculation.

Table A.5: Effects of foreign ownership and innovation on productivity in EU firms

	Traditional approach					
	Productivity Level			**Productivity Growth**		
Innovation						
INNOVATION INTENSITY	0.096***	0.096***	0.106***	0.007***	0.007***	0.010***
	(0.006)	(0.006)	(0.005)	(0.002)	(0.002)	(0.003)
PROCESS INNOV.	-0.058**	-0.058**	-0.058**	0.000	0.000	-0.000
	(0.020)	(0.020)	(0.020)	(0.006)	(0.006)	(0.006)
Ownership (reference: DnGF)						
DGF	0.218***	0.219***	0.124**	-0.009	-0.010	-0.035*
	(0.015)	(0.015)	(0.052)	(0.009)	(0.009)	(0.019)
FOF	0.383***	-	-	0.009	-	-
	(0.028)			(0.011)		
FOFEU	-	0.376***	0.177*	-	0.013	-0.043
		(0.039)	(0.089)		(0.013)	(0.041)
FOFNONEU	-	0.389***	0.319**	-	0.005	-0.063*
		(0.034)	(0.119)		(0.010)	(0.033)
*Innovation * Ownership*						
INNOVATION INTENSITY * DGF	-	-	-0.016	-	-	-0.004
			(0.009)			(0.003)
INNOVATION INTENSITY * FOFEU	-	-	-0.034**	-	-	-0.009
			(0.012)			(0.006)
INNOVATION INTENSITY * FOFNONEU	-	-	-0.012	-	-	-0.012**
			(0.017)			(0.005)
	CDM Model					
	Productivity Level			Productivity Growth		
Innovation						
PRODUCT INNOVATION OUTPUT	0.491***	0.405***	0.453***	0.034***	0.028***	0.030***
	(.021)	*(0.026)*	*(0.030)*	*(0.007)*	*(0.006)*	(0.010)
PROCESS INNOV.	-0.097***	-0.101***	-0.105***	-0.004	-0.002	-0.002
	(0.014)	*(0.015)*	*(0.014)*	*(0.004)*	*(0.005)*	(0.005)
Ownership						
DGF	0.121***	0.147***	-0.151	-0.001	0.001	0.005
	(0.020)	*(0.019)*	*(0.111)*	*(0.006)*	*(0.007)*	(0.038)
FOF	0.197***	0.231***	-0.082	0.004	0.010	-0.033
	(0.021)	*(0.022)*	*(0.127)*	*(0.007)*	*(0.009)*	(0.050)
*Innovation * Ownership*						
*PRODUCT INNOV. OUTPUT*DGF*	-	-	-0.082***	-	-	0.001
			(0.030)			(0.010)
*PRODUCT INNOV. OUTPUT*FOF*	-	-	-0.089**	-	-	-0.013
			(0.037)			(0.014)

Notes: The dependent variable is labour productivity measured by sales per employee and labour productivity growth, respectively.

Labour productivity is explained either by innovation input (innovation intensity measured by the innovation expenditures as percentage of turnover; traditional approach) or product innovation output (share of sales with new products; CDM model). Further explanatory variables include process innovation (dummy- yes/no) and a set of dummy variables indicating ownership: DGF (domestically owned group firm), FOF (foreign-owned firm), FOFEU (foreign-owned firm from an EU country), FOFNONEU (foreign-owned firm from a non-EU country). Reference group is DnGF (domestically owned non-group firm). The third estimation further includes interaction terms between innovation input (output) and ownership.

Additional control variables (not reported here) include firm size (log. Number of employees), physical capital (log. investment per employee), human capital (share of high skilled employees), export intensity, country dummies and industry dummies. The CDM model only reports the final stage. The hypothesis on equal effects of DGF and FOF on productivity growth in the traditional approach is rejected at the 10% level (p-value: 0.093).

Source: CIS 3, Eurostat, ZEW/AIT calculations.

Box A.1: Linking Productivity to Innovation

There is an enormous amount of work examining the factors underlying productivity and productivity growth. Two different approaches can be distinguished. The traditional approach uses a Cobb-Douglas (CD) production function as its theoretical framework to explain productivity, augmented by knowledge capital as an additional input besides labour and physical capital. Taking logs and assuming constant-returns to scale lead to the following estimation equation:

$$q_{it} - l_{it} = a_i + \lambda t + \alpha\left(c_{it} - l_{it}\right) + \gamma k_{it} + \left(\mu - 1\right) l_{it} + u_{it},$$

where *l* denotes labour, *q-l* labour productivity, *c-l* physical capital per employee, *k* knowledge capital and *t* exogenous technological change. γ measures how much a firm benefits in terms of a percentage increase in production if it boosts its innovation investment by one percent. Instead of the productivity level, one can similarly derive the productivity growth. To compare domestically owned firms, the specification will be enhanced by including ownership dummy variables.

The second approach is based on the CDM model by Crepon, Duguet and Mairesse (Crepon et al. 1998). It was developed because the traditional approach does not take into account the fact that not all firms are engaged in innovation, which can lead to biased results. Furthermore, the link between innovation input and innovative outcome remains a black box. The CDM approach is a three-step model consisting of four equations. In the first step, firms decide on the strength of the expected profits whether to engage in innovation activities (selection equation) and on the amount of money to invest in innovation. If the firm opts to innovate, the second step describes the relationship between innovation input and innovation output (knowledge production function, see Pakes and Griliches 1984). The third step is similar to the traditional approach. An augmented CDM production function is estimated in which productivity results from knowledge capital, now proxied by innovation output, and other explanatory factors. Innovation input is proxied by innovation intensity; the share of sales of new products measures innovation output.

4. EUROPEAN COMPETITIVENESS IN KEY ENABLING TECHNOLOGIES

4.1. Introduction

What products will be demanded in the future, what will producers be able to offer, and which production processes will be available in years to come? These crucial questions are of course impossible to answer and it would be foolhardy to make an attempt: history is full of examples of futile prophecies, guesses and market analyses that over time have proved to be wide of the mark.

It is however possible to say something meaningful about the technologies that will be crucial to the development of a multitude of new products and processes in many different industries and fields of application. Such *key enabling technologies* are attracting increasing interest, not least in difficult economic times, as they are seen as the route to new and better products and processes, capable of generating economic growth and employment and strengthening the competitiveness of the economy. They are moreover expected to provide significant economic benefits, offering a widening variety of uses in an increasing number of application areas and industries.

The discussion of key enabling technologies is not new. The concept is in fact closely related to the concept of general purpose technologies coined by Bresnahan and Trajtenberg (1995) and further developed notably by Helpman (1998) and Lipsey et al. (2005). The link was in fact established already in the introduction to Bresnahan and Trajtenberg (1995):

> 'Most general purpose technologies play the role of 'enabling technologies', opening up new opportunities rather than offering complete, final solutions. For example, the productivity gains associated with the introduction of electric motors in manufacturing were not limited to a reduction in energy costs. The new energy source fostered the more efficient design of factories, taking advantage of the newfound flexibility of electric power.' (Bresnahan and Trajtenberg, op. cit., page 84)

In 2002 the Commission presented an industrial policy communication (EC 2002) in which it called on the European Union to reinforce its position in certain enabling technologies such as information and communication technologies (ICT), electronics, biotechnology and nano-technology. This is reflected in the current framework programme for research, technological development and demonstration activities (2007-2013), as well as its specific programmes, where key enabling technologies feature prominently. Furthermore, one of the chapters of the 2007 Competitiveness Report (EC 2007*a*) included a survey of existing literature on a number of future key technologies: ICT, microsystems, advanced and smart materials, and nano- and biotechnologies. In 2009 the Commission presented a standalone communication on key enabling technologies (EC 2009*a*) accompanied by a working document on the state of play regarding these technologies in Europe (EC 2009 *b*), both of which are central to this chapter. Two recent strategy communications, on Europe 2020 (EC 2010*a*) and on a digital agenda for Europe (EC 2010 *b*), have further underlined the importance of key enabling technologies.

There is no universally accepted definition or agreed list of key enabling technologies. For the purpose of this chapter, the definition in EC (2009*a*) will be used:

Box 4.1: Definition of key enabling technologies (KETs)

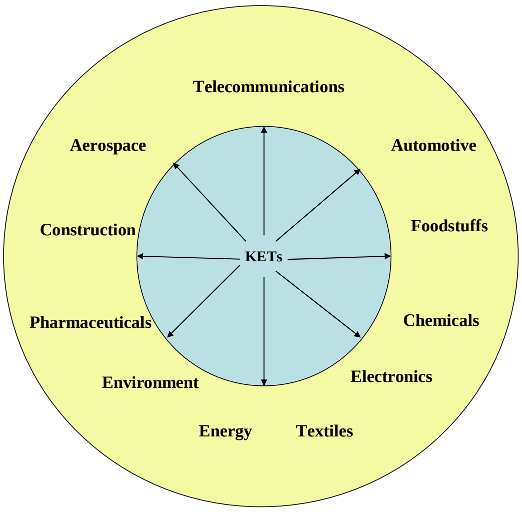
KETs are knowledge-intensive and associated with high R&D intensity, rapid innovation cycles, high capital expenditure and highly-skilled employment. They enable process, goods and service innovation throughout the economy and are of systemic relevance. They are multidisciplinary, cutting across many technology areas with a trend towards convergence and integration. KETs can assist technology leaders in other fields to capitalise on their research efforts. (EC 2009*a*)

Moreover, the key enabling technologies examined in this chapter — nanotechnology, industrial biotechnology, advanced materials, micro and nanoelectronics including semi-conductors, photonics, and advanced manufacturing technologies — are essentially the same as in EC (2009*a*), the only difference being that given the importance of process innovation in industrial competitiveness and the important role of advanced manufacturing as enabler of process innovation, advanced manufacturing technologies have been added and will be considered alongside nanotechnology, industrial biotechnology, advanced materials, micro and nanoelectronics, and photonics. Including advanced manufacturing technologies in the analysis is in line not only with EC (2009*a*) but also with EC (2007*a*).

4.2.Applications of key enabling technologies

An important aspect of key enabling technologies which is clearly expressed in the quoted paragraph from Bresnahan and Trajtenberg (1995) but is perhaps less clear from the definition in Box 4.1 is that whilst developing and mastering a key enabling technology is likely to require considerable input of resources (capital, time, labour, R&D), the direct return on that investment tends to be disproportionally small. It is instead the *applications* it enables that are expected to create jobs, growth and wealth in the economy and boost competitiveness. A number of current and future applications are discussed further in Section 4.5, while existing estimations of market potential are reported in Section 4.6. Europe's competitiveness is assessed in Section 4.7, followed by implications and priorities in Section 4.8.

Figure 4.1: Key enabling technologies and some areas of application



Source: Adapted from Confindustria (2009).

Figure 4.1 is a schematic representation of the links between key enabling technologies, at the core of the process and interacting with one another, and some of their applications, which is where value, growth and employment are created. In many cases small and medium-sized enterprises (SMEs) play a vital role, often as part of a cluster, in the development and commercialisation of applications, whereas their role in the development of key enabling technologies is more limited because they lack the necessary resources.

The case of environment applications may serve as an illustration of the links in Figure 4.1. Due to scarce resources and the need to meet climate change targets, the market for eco-friendly technologies is expected to continue to grow faster than the economy as a whole, as it has done in recent years. Key enabling technologies such as nanotechnology for filtering polluted water or used in desalination plants, advanced manufacturing technologies and advanced materials to come up with environmentally-friendly building materials, and industrial biotechnology are some of the technologies likely to play a role on this expanding market.

Given the considerable resources needed to develop key enabling technologies, might it be preferable not to make the investment, wait for them to be developed elsewhere and then either purchase or acquire them through cooperation with external partners? There are at least two arguments against such a ‘free-rider’ approach. Firstly, developing commercial applications based on key enabling technologies often requires a certain degree of technological competence in order to absorb and apply new knowledge, as well as close interaction between fundamental research and industrial innovation. The need for interaction often manifests itself in the forming of clusters, a topic which is discussed in Section 4.7.7. Secondly, first-mover advantages are particularly important in the case of path-breaking technologies. First-mover advantages include learning and reputation effects as well as standard-setting and developing innovation-friendly regulation. The issue of first movers is discussed further in Section 4.3 below.

4.3. Key enabling technologies and the economy

The development of a key enabling technology can be regarded as a technological push to the innovation efforts of firms and can be expected to raise the overall level of innovation activities in an economy (Helpman 1998; Baptista 1999; van Ark and Piatkowski 2004). Moreover, research has shown that innovative firms are often more productive and grow faster than other firms, indicating a higher level of competitiveness (Crépon et al. 1998; Griffith et al. 2006; Harrison et al. 2008; Janz et al. 2004). Similarly, greater innovativeness in terms of the degree of novelty and the amount of R&D effort tends to be associated with higher economic performance in terms of productivity and growth (Peters 2008).

Applying new technologies early and broadly often requires close interaction between the producers and users of these technologies (Fagerberg 1995; Porter 1990). Competitiveness effects of new technologies strongly depend on the speed of their diffusion and on the rate at which the opportunities they present are exploited. Being the first to generate new scientific findings is not a sufficient condition for securing economic returns from new technologies. The main challenge for any innovation project, including innovations based on key enabling technologies, is to balance technological opportunities originating from research with user needs, cost-efficient production and the capabilities of business partners (suppliers, distributors, users), without losing sight of the innovative strategies of competitors. As a consequence, innovators use a variety of inputs to orient their innovative activities.

From a macroeconomic point of view, key enabling technologies can increase productivity and wealth through more efficient use of production factors and through structural change. Within a production function environment, their positive productivity effects may be reflected in a higher rate of technical progress. Alternatively, one may model the effect of key enabling technologies as a separate input factor; a stock of new knowledge resulting from R&D. Efforts to develop key enabling technologies result in larger knowledge stocks and increased output. Within a sector-specific production function environment, key enabling technologies are likely to shift sector shares since the output of sectors that produce such technologies and can obtain productivity advantages from them is likely to grow faster. In a dynamic perspective, positive productivity effects from structural change driven by key enabling technologies are likely since technology sectors will experience above-average productivity growth.

Box 4.2: The economics of key enabling technologies

The economic rationale for developing key enabling technologies can be illustrated in the framework of a knowledge-augmented Cobb-Douglas production function:

$Y = T\,C^{\alpha} L^{\beta} M^{\kappa} K^{\gamma}$ where *C*, *L*, *M* and *K* are the input factors physical capital, labour, material, and knowledge; *α*, *β*, *κ* and *γ* are their associated partial output elasticities; *T* is total factor productivity, and *Y* is output in the economy. Developing and mastering key enabling technologies can be expected to have a positive effect on *K*, *T* and *Y*. The effects on *C*, *L*, *M* and the four elasticities will depend on the degree of substitution, efficiency and other factors**.**

Another way of looking at the introduction of applications of key enabling technologies is in the context of the production frontier of the economy. Developing a key enabling technology will expand the production set so that previously unobtainable output combinations become feasible while previously possible combinations can be obtained at a lower cost, using fewer inputs. It should however be noted that the outward shift of the production frontier associated with the expansion of the production set is unlikely to be a parallel shift: in all likelihood the new equilibrium output will differ in its composition from the old equilibrium.

Key enabling technologies play a crucial part in accelerating technical progress. In general, applying them will enable producers to use labour, capital, energy and other inputs more efficiently. It is important to stress that unlike other drivers of technical progress — diffusion of existing technologies, improving skills through education and training, learning from good practice — key enabling technologies are more likely to result in leaps in efficiency levels, particularly when their use affects many sections of the economy simultaneously. The case of information and communication technologies illustrates the point. The productivity growth generated by them was due mainly to their wide diffusion across many different industries, including sectors with traditionally low technology intensities (in terms of the amount of new technology used in production) such as retail or transportation. In addition, the particularly strong productivity impact of ICT resulted from their network characteristics. Productivity stemmed not only from a firm's own use of ICT but also from the use by business partners (suppliers and customers) since ICT fostered more efficient external business processes. Technologies exerting less significant network effects are likely to result in lower economy-wide productivity gains.

However, ICT have also shown that there may be substantial time lags between the invention and first application and the economic impact of a new technology. For many new technologies the most important applications may not be evident in the early stages of technology development. Potential applications typically emerge from the interaction of suppliers, producers and users of a new technology, through learning by using (Rosenberg 1982) and from fierce competition among technology producers who are seeking competitive advantages by customising the new technology to the needs of users. More complex technologies tend to generate particularly high returns to adoption (Arthur 1989).

A preliminary conclusion is therefore that the scale of the effects on productivity from a key enabling technology will depend on: (*i*) the speed and breadth of its diffusion across sectors and users; (*ii*) the extent to which its use gives rise to network effects; (*iii*) how mature it is, in terms of the various technological applications and innovative solutions developed in its wake.

A second dimension of the macroeconomic importance of key enabling technologies is that they can open up entirely new markets, or at least step up product quality in existing markets. Such industrial change is likely to involve higher levels of input-output relations since entirely new products on new markets and higher-quality products are likely to command higher output prices per unit. Opening up new markets can also help unlock additional demand and new resources for production, thereby increasing net output.

An important issue in this respect is the timing of new markets. Economies able to open up new markets before others could gain a temporary monopoly, as a source of additional income. More importantly, in a dynamic sense such first-mover advantages can translate into positive cumulative effects (Porter 1990). These cumulative effects may result from network effects among producers, suppliers and users who can learn from each other and leverage economies of scale and scope. In addition, first movers may be able to define global standards, establish global distribution channels and build up a reputation as technology leaders. Follow-up innovations can build on the accumulated knowledge in a specific field of technology. These cumulative effects will also act as entry barriers and can secure a long-term lead in a specific technology.

History abounds with examples of such cumulative technological advantages, e.g. in aircraft, space and defence technologies (USA), microelectronic household applications (Japan), and mechanical engineering (Germany). Cumulative technological advantages can be reinforced by adapting education, innovation, production and policy systems to the specific needs of the leading technology sector. While such adaptations support the further advancement of these technologies, they may also be a source of lock-in effects and path dependence which can make it more difficult to adjust to new upcoming technologies.

4.4. Public policy in support of key enabling technologies and applications

As pointed out above, turning key enabling technologies into commercial applications typically requires close interaction between fundamental research, which is often publicly funded and carried out by universities or research organisations, and industrial innovation and R&D. There is a need for exchange of knowledge between these two sectors and for incentives for researchers in the public sector to engage actively in technology transfer. There is also a need for firms to possess the right technological skills to absorb and apply the new technologies, including the ability to conduct in-house R&D and the organisational skills to manage innovation processes and integrate new technologies into existing business practices. A third need is for an adequate regulatory framework to be developed and adapted in parallel with the technological progress achieved, in order to foster commercialisation of applications. Interaction between the developers of new technologies and the designers of the regulatory framework will facilitate an innovation-oriented regulatory framework. Being the first to introduce such a framework can also generate a competitive advantage.

For these reasons, and because of the first-mover advantage described above, it is vital to put in place a comprehensive and coherent public policy covering all areas from the funding of academic research and industrial R&D projects to cooperation and networking initiatives, public awareness measures, standardisation, promotion of venture capital supply, to education and training (OECD 2009*a*). Networks and clusters constitute a particularly important aspect of public policy. Clusters are important because they facilitate exchange between different scientific disciplines and fields of technology, as well as interaction among actors from public research and various industries. They also encourage knowledge spillovers and mutual learning, and provide a breeding ground for ventures commercialising new technologies (Enright 2003; Keeble and Wilkinson 1999; Sternberg 1996). The importance of clusters is further discussed in Section 4.7.7.

4.5. Six key enabling technologies: history, current state, applications

This section describes briefly the six technologies that are the focus of this chapter, their current state of development and how they may be applied. It neither represents a complete list of applications nor seeks to distinguish between current and future applications. It does however aim to give an impression of the importance of each technology as a generator of future prosperity and utility.

4.5.1. Nanotechnology

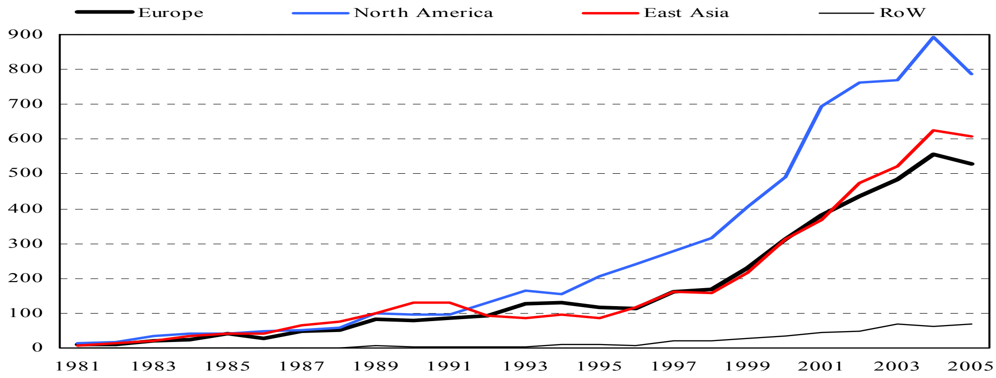
Nanotechnology is a generic term for the design, manufacturing and application of structures, devices and systems for analysis and control on a molecular or atomic scale, defined as 100 nanometres (nm) or smaller. It can involve scaling down materials to a nanolevel (‘top-down nanotech’) by means of physical techniques such as lithography, cutting, etching, electro-spinning or milling. For instance, this approach has enabled the construction of integrated circuits based on structures of 32 nm in semiconductor production. An alternative approach (‘bottom-up nanotech’) is to create new materials directly at a nanoscale, typically using physical, chemical and biological methods such as deposition, nanoparticle synthesis or liquid-phase processes. Controlled self-assembly of molecules and their macrostructures based on the manipulation of individual atoms is a predicted extension of the latter approach and is expected to lead to the discovery of completely new dimensions of nanotechnology.

Nanoscale (≤100 nm) structures frequently possess electrical and magnetic properties, surface and mechanical properties, stability, chemical processes, biological processes and optical features that differ radically from those of their micro/macroscale counterparts. Similarly, many materials exhibit new characteristics as nanomaterials, adding to the variety of application areas and implying that nanotechnology can have a significant impact in every industry where materials are processed and used. These changes in properties and characteristics are at the heart of the innovative power of nanotechnology.

4.5.1.1. Background and current state

Nanotechnology is a relatively young technology into which systematic research began in the 1960s. The original idea was to construct complex materials and devices out of single atoms (molecular nanotechnology) but since the 1990s all work related to nanostructures is regarded as being part of nanotechnology. Since the mid-1990s, nanotechnology research has been developing an increasing number of industrial applications, illustrated by the fast-growing number of nanotechnology patents (Figure 4.2) and by growing sales of products using nanomaterials or produced with the help of nanotechnological processes.

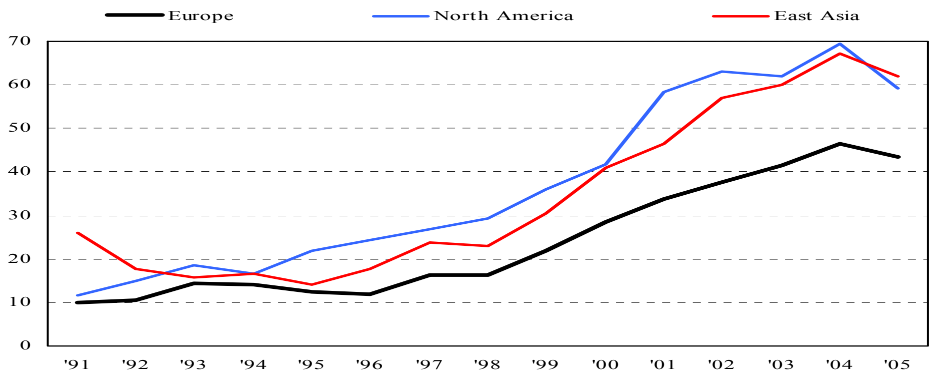
Figure 4.2: Number of nanotechnology patent applications (EPO/PCT) by region of applicant, 1981-2005



Source: EPO Patstat; background study.

Figure 4.2 shows how the rapid growth in nanotechnology patents in recent years is attributable to rising numbers of North American, East Asian and European applicants[10] whereas the number of patent applications from the rest of the world remains low. The most active applicants from the three leading regions between 2000 and 2007 were Hewlett-Packard (USA; 107 applications), Samsung (South Korea; 169 applications) and Commission à l'énergie atomique (France; 111 applications). Furthermore, Figure 4.2 shows how North America (mainly USA) has forged ahead since becoming the lead applicant region in 1992. It also shows how in recent years applications from East Asia (mainly Japan and South Korea) have overtaken European applications. This is made even clearer in Figure 4.3, in which the number of patent applications from the three leading regions is related to their GDP levels. It is clear that once the differences in GDP have been accounted for, North American and East Asian application intensities are very similar. European researchers, on the other hand, are falling behind and should, given Europe's GDP, account for 50 percent more patent applications in order to match the intensities of their North American and East Asian counterparts.

Figure 4.3: Nanotechnology patent application intensity (number of EPO/PCT patents per trillion of GDP at constant PPP US dollars), 1991-2005



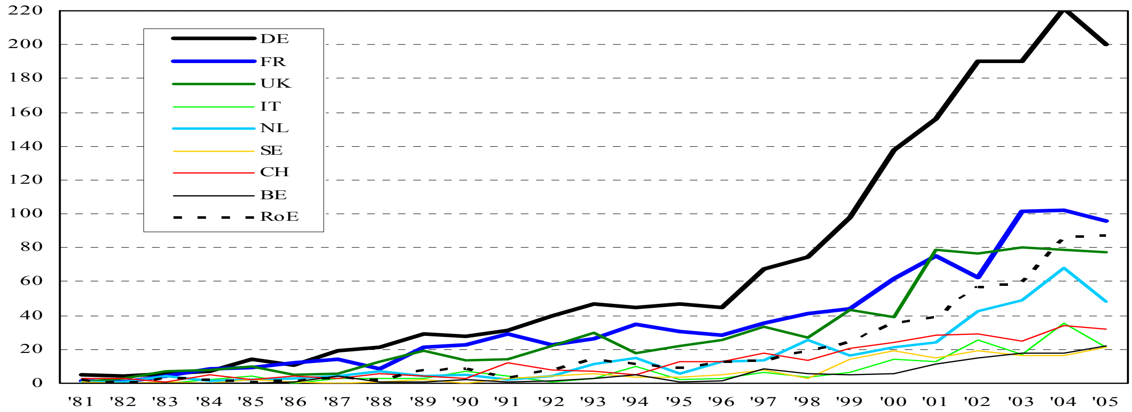
Source: EPO Patstat; OECD (2009*b*); background study.

Within Europe, German applicants account for most nanotechnology patent applications (34%) at EPO/PCT, followed by France (17%), UK (14%) and the Netherlands (8%)

[10] In this chapter Europe is defined as all EU Member States plus Switzerland, Norway, Iceland, Liechtenstein, Monaco, Andorra, San Marino, Croatia, Serbia, Bosnia-Herzegovina, Montenegro, FYROM and Albania; North America as USA, Canada and Mexico; and East Asia as Japan, South Korea, China, Singapore and Taiwan.

(Figure 4.4). German applications increased particularly fast from 1997 onwards and are over-represented (in relation to Europe as a whole) in nanomaterials and nanoanalytics. It is interesting to note that in recent years applications from European countries that are not among the eight countries with the largest number of nanotechnology patent applications have increased markedly, indicating stronger efforts in nanotechnology in those countries.

Figure 4.4: Nanotechnology patent applications (EPO/PCT) by country, 1981-2005



Source: EPO Patstat; background study.

In relation to its GDP, however, Germany is not the main producer of nanotechnology patent applications in Europe. Switzerland (over-represented in nanoanalytics and nanoelectronics) has by far the highest application intensity, followed by the Netherlands (over-represented in nanoelectronics and nanomagnetics), with Germany in third place.

4.5.1.2. Nanotechnology applications

By combining disciplines such as physics, chemistry and biology, nanotechnology applications cover a wide spectrum ranging from materials, electronics and chemicals to process engineering, transportation and medicine. Notwithstanding their enormous potentials, most of the nanotechnological products and processes commercialised so far rely on a few nanomaterials such as carbon nanostructures, silver and gold nanoparticles and nanowires, and nanoscale metal oxides (PCAST 2008). By no means exhaustive, Table 4.1 nevertheless gives a flavour of the wide range of existing and future applications of nanotechnology.

Table 4.1: Examples of current and future nanotechnology applications, by industry

Industry	Established nanoproducts	Recent market launch	Prototype stage	Concept stage
Chemicals	nanopowder nanostructured active agents nanodispersions	carbon nanotubes nano-polymer composites hybrid composites	nano porous foams switchable adhesives electro-spun nanofibres	self-healing materials self-organising composites molecular machines
Electronics	silicon electronics nanoscale transistors polymer electronics nanodots/nanowires spintronics	CNT field emission displays MRAM memories phase-change memory	MEMS memory CNT data memory CNT inter-connected circuits nanojoining	molecular electronics nanowires for electricity production spintronic logics orbitronics
Optics	ultra-precision optics anti-reflection layers LED and diode lasers nanobeam x-ray photochromics	nanoresolution in microscopes OLED 2D photonic crystals waveguiding	EUV lithography optics quantum-dot lasers 3D photonic crystals electrochromics	all-optical computing optical meta-materials data transmission via surface plasmons
Medicine, Pharma-ceuticals	nanoparticles as contrast media nanoscale drug carriers nanomembranes for dialysis nanoscale sunscreens tissue engineering	nanostructured hydroxylapatite as bone substitute quantum-dot markers nano cancer therapy nanodentistry skin-delivered vaccines	biocompatible implants selective drug carriers nanoprobes and nanomarkers for molecular imaging tissue engineering antimicrobial planes	artificial organs through tissue engineering nano-engineered gels for supporting nerve cell growth neuro-coupled electronics for active implants
Environ-mental techno-logies	nanostructured catalysts nanomembranes for sewerage anti-reflection layers for solar cells	nano-optimised micro-fuel cells iron-nanoparticles for groundwater sanitation nano-titanium oxide for photo catalysis	large-area polymer solar cells nanosensorics for environmental monitoring nano-catalysts for hydrogen generation	artificial photosynthesis quantum-dot solar cells nanoscale rust for cleaning water
Auto-motive	nanostructured coatings nanocoated diesel injectors nanostructured admixtures for tyres	nanoparticles as diesel additives nano-optimised lithium-ion batteries LED headlights anti-fog surfaces	thin-film solar cells for car roofs nano-optimised fuel cells nano-adhesives in production	switchable, self-healing coatings adaptive body shell for lower air resistance
Textiles	nanoparticles for dirt repellence nanosilver for antibacterial textiles nanocontainers for scent impregnation	nano-titanium oxide for UV protection aerogels for thermal protection ceramic nanoparticles for abrasion resistance	phase-change materials for active thermal regulation textile-integrated OLEDs electrically conductive textiles	textile-integrated sensorics/actorics for control of body functions textile-integrated digital assistance systems

Source: Luther and Bachmann (2009); Gennesys (2009); background study.

It is evident from the examples in Table 4.1 that nanotechnology applications are relevant in a number of different sectors. It is therefore not surprising that it is the key enabling technology with the most links to other KETs; nanotechnology is in fact strongly linked to all the other five technologies in this chapter.

4.5.2. *Micro and nanoelectronics including semiconductors*

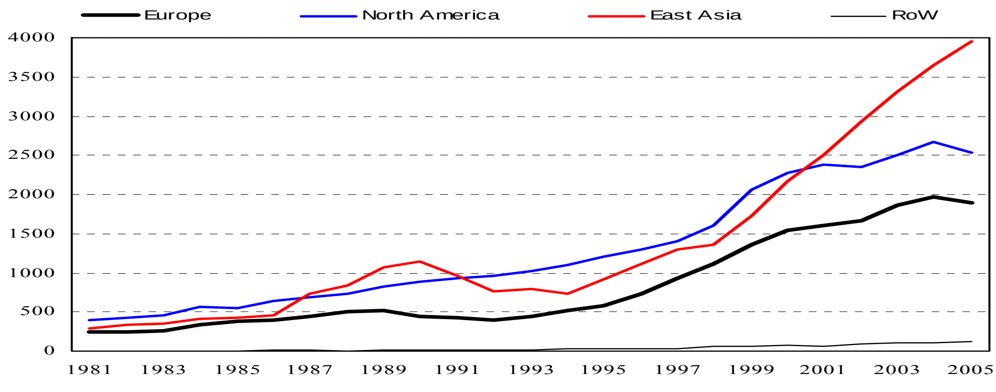
Micro and nanoelectronics refers to semiconductor components as well as highly miniaturised electronic subsystems and their integration in larger products and systems. Miniaturisation is the main technological driver, with several benefits in terms of cost reduction, faster propagation over shorter distances and, in the case of nanoelectronics, new and interesting properties at atomic and molecular levels. As pointed out in the previous subsection, semiconductor production has already mastered 32 nm structures in integrated circuits. Technical progress is expected to result in a further reduction of structural widths (BMBF 2005) and the next step in semiconductor production will be to build 22 nm structures, expected to be achieved in 2011.

Recent advances in miniaturisation have meant that some of the latest microelectronics could in fact be called nanoelectronics as they are measured in nanometres. In a narrow sense though, nanoelectronics can be limited to techniques based on silicon and to a structural width of less than 100 nanometres, and in many cases nanoelectronics refers to structures so small that inter-atomic interactions and quantum mechanical properties need to be studied extensively (BMBF 2002).

4.5.2.1. Background and current state

Although the first computer was invented in the 1940s and the principles behind mobile telephone communication have been known since the 1920s, microelectronics dates back no longer than to 1958 with the discovery of the integrated circuit (BMBF 2005). Following the invention in 1971 of the first microprocessor, successive waves of advances in miniaturisation and nanotechnology have led to ever smaller, cheaper and more effective components and systems. This rapid growth is reflected in the number of patent applications shown in Figure 4.5.

Figure 4.5: Number of micro and nanoelectronics patent applications (EPO/PCT) by region of applicant, 1981-2005

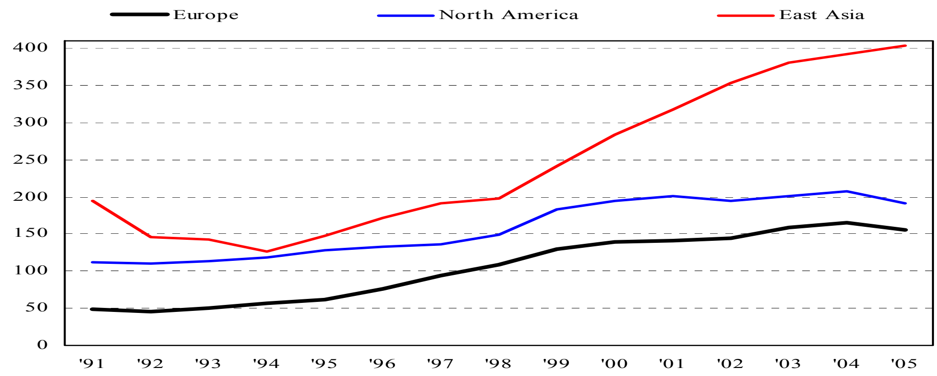


Source: EPO Patstat; background study.

It is clear that East Asian applicants dominate the world market for patents and have done so since 2001, with North America trailing in second place and Europe in third. The number of patent applications from the rest of the world is very limited by comparison. The most active applicants from the three leading regions in the period 2000-2007 were Infineon (Germany; 1525 applications), Tokyo Electronics (Japan; 1498 applications) and Applied Materials (USA; 1051 applications). It should however be noted that in East Asia both Matsushita

(Japan; 1392 applications) and Samsung (South Korea; 1077 applications) made more applications in that period than the leading North American applicant. Figure 4.5 also shows how East Asia (mainly Japan and South Korea) has increased its lead since 2001. The dominant position of East Asian applicants is made even clearer when related to GDP, see Figure 4.6. Microelectronic patent application intensities in East Asia are more than twice as high as in North America or Europe, which follow the same stagnating pattern.

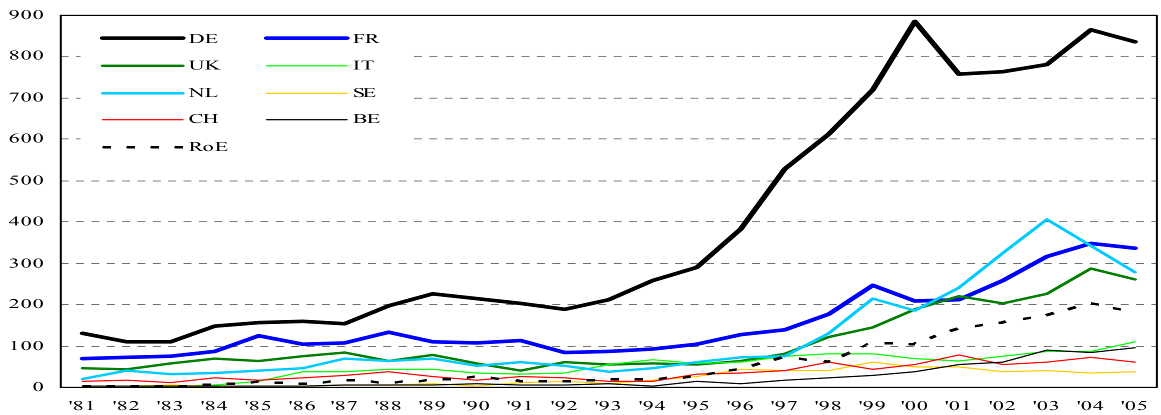
Figure 4.6: Micro and nanoelectronics patent application intensity (number of EPO/PCT patents per trillion of GDP at constant PPP US dollars), 1991-2005



Source: EPO Patstat; OECD (2009 *b*); background study.

The European picture concerning micro and nanoelectronic patent applications is similar to that of nanotechnology (cf. Figure 4.4), except for a more prominent role played by Dutch applicants. Germany again dominates (41 %), followed by France (16 %), with the Netherlands and UK in third place (12 % and 11 % respectively).

Figure 4.7: Micro and nanoelectronics patent applications (EPO/PCT) by country, 1981-2005



Source: EPO Patstat; background study.

When differences in GDP are taken into consideration, Germany no longer leads in terms of application intensity but is relegated to second place by the Netherlands, which exhibits much stronger application intensities in micro and nanoelectronics than its European peers, notably in the area of x-ray where it is over-represented in comparison with Europe as a whole.

4.5.2.2. Applications of micro and nanoelectronics including semiconductors

Traditionally, micro and nanoelectronic components and systems have been applied mainly in the ICT sector, in applications such as memories, displays and processors, as well as products enabling communication between devices or systems. In recent decades advances in miniaturisation have meant that micro and nanoelectronic applications have expanded into new sectors such as the automotive, medical and consumer goods sectors with products ranging from sensors to toys being based on semiconductors (Confindustria 2009). This expansion of micro and nanoelectronics into new sectors of application is set to continue.

Micro and nanoelectronic applications are often linked to one or more other key enabling technologies. The closest links are with nanotechnology, photonics and advanced manufacturing technologies.

4.5.3. Industrial biotechnology

Industrial biotechnology, also known as white biotechnology, means the use of microorganisms such as mould, yeast, bacteria and enzymes in industrial processes to produce biochemicals, biomaterials and biofuels. The many products manufactured using biotechnological processes include various chemicals, plastics, biofuels, detergents, vitamins and enzymes. Industrial biotechnology is also used in the final stages of production of textiles, leather and paper (BMBF 2008). It is distinct from medical ('red') and agricultural ('green') biotechnology.

Industrial biotechnology competes with other production methods, in particular chemical synthesis. It tends to be more environmentally friendly since it uses renewable raw materials such as vegetable oils and starch, and produces less harmful by-products and higher yields, all of which combine to reduce dependence on fossil resources. However, biotechnological processes are not always less energy-intensive; they sometimes need considerably more energy than other processes. Even so, industrial biotechnology presents an opportunity to improve the quality of existing products and develop completely new products which cannot be produced by traditional synthetic methods and processes (OECD 2009*c*; OECD 2009*d*; OECD 2010).

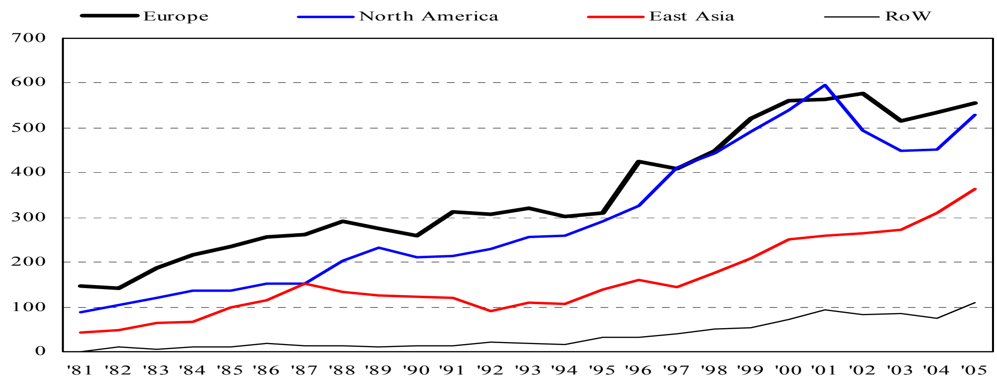
4.5.3.1. Background and current state

Ancient examples of the practical application of biotechnology — brewing beer, making wine and cheese, baking leavened bread, to name but a few — suggest it was developed in parallel with agriculture. However, it was only thanks to the scientific work of Louis Pasteur and his peers in the 19th and 20th centuries that the processes behind the old techniques could be explained and bettered, and new processes discovered. Modern biotechnology dates back to the early 1970s when recombinant DNA technology was first developed (EC 2007*b*). Recent advances in genome research and microbiology have enabled more targeted use of molecular biology, for instance in the discovery of enzymes as biocatalysts or using bacteria to produce medical substances (BMBF 2008). As a result the use of enzymes for the production of foods, detergents, textiles, chemicals, pharmaceuticals, pulp and paper is well established.

The importance of industrial biotechnology differs across industries. In basic chemicals only 1.5 percent is based on biotechnology. In active pharmaceutical ingredients the share of biotechnology sales exceeds 18 percent (OECD 2009*d*). Biotechnology-based polymers are the most important biomaterials and are produced in quantities estimated at between 300 000 and

600 000 tonnes per year but still represent less than 1 percent of total polymer production (EC 2007*b*; OECD 2009*c*). In pulp and paper on the other hand, biotechnological applications account for 10 percent, in detergents 30 percent and in some food production processes (e.g. some fruit juices) up to 100 percent (EC 2007*b*).

Figure 4.8: Number of biotechnology patent applications (EPO/PCT) by region of applicant, 1981-2005

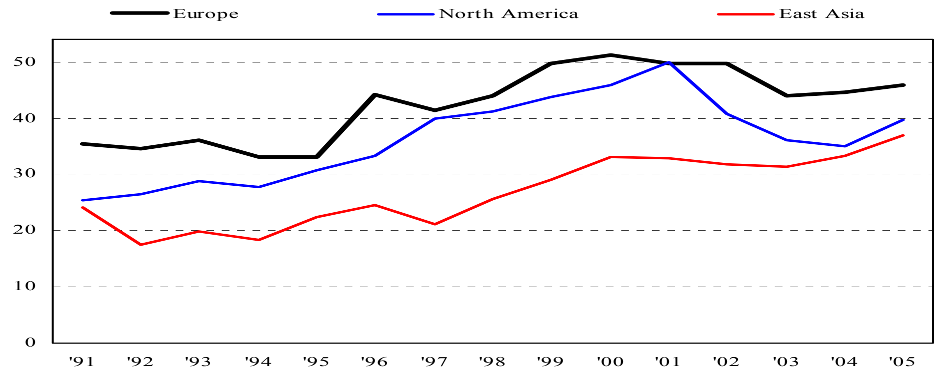


Source: EPO Patstat; background study.

Figure 4.8 shows the increase in biotechnology patent applications from 1981 to 2005 and how European and North American applicants have dominated in the past but suffered from a slowdown in patenting activity in the early years of the new century, allowing East Asian applicants to close the gap to some extent. European and North American applicants account for around 35 percent each of all biotechnology applications, with East Asia at 23 percent and the remaining 7 percent of applications coming from the rest of the world. The three leading biotechnology patent applicants in the period 2000-2007 were all European: BASF (Germany; 235 applications), Novozymes (Denmark; 159 applications) and Evonik Degussa (Germany; 136 applications), followed by DuPont and University of California (both U.S.) with 126 and 119 applications respectively. The leading East Asian applicants were all Japanese, led by Matsushita, but in terms of numbers did not come close to the leading European or North American applicants.

Patent application intensities, adjusted for differences in GDP, are depicted in Figure 4.9. It is evident how the slowdown in biotechnology patenting in Europe and North America since 2000/01 has enabled East Asian applicants to reach almost the same application intensities as in North America.

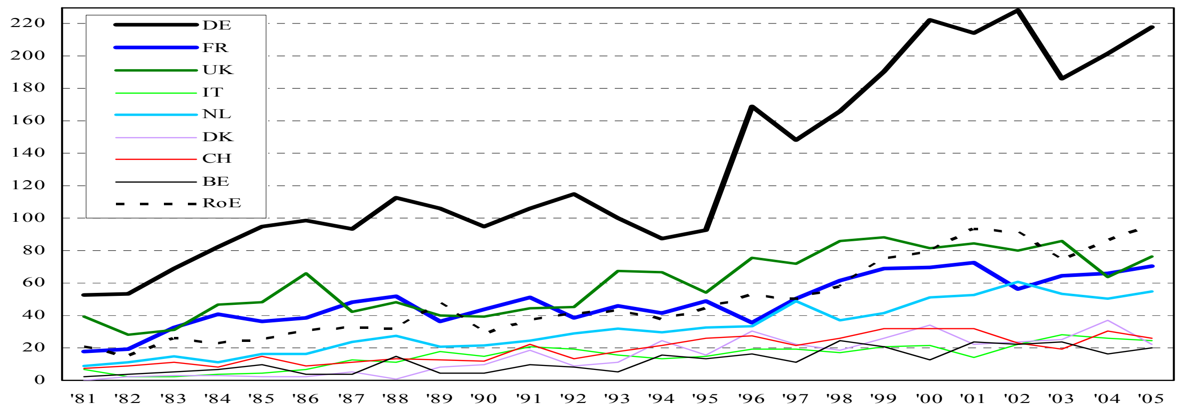
Figure 4.9: Biotechnology patent application intensity (number of EPO/PCT patents per trillion of GDP at constant PPP US dollars), 1991-2005



Source: EPO Patstat; OECD (2009*b*); background study.

In Europe, most biotechnology patent applications come from German applicants (Figure 4.10), particularly in the area of established biochemicals where German applications are over-represented in relation to Europe as a whole. Another contributing factor behind Germany's present dominance is that the rate of German biotechnology applications almost doubled in the second half of the 1990s, from around 110 a year to over 200. The UK and France, both of which are over-represented in applications concerning enzymes, have 12 percent each of all European EPO/PCT applications, followed by the Netherlands with 9 percent on the back of a particularly high number of applications in fermentation. Applications from European countries that are not among the top eight countries represent around 20 percent of all European EPO/PCT applications.

Figure 4.10: Biotechnology patent applications (EPO/PCT) by country, 1981-2005



Source: EPO Patstat; background study.

When adjusting the data in Figure 4.10 for GDP differences though, it emerges that Germany has only the fourth highest patent application intensity in industrial biotechnology, behind Switzerland, Denmark and the Netherlands.

4.5.3.2. Industrial biotechnology applications

Established applications such as using enzymes in the production of foodstuffs, detergents, textiles, chemicals, pharmaceuticals and other products have already been mentioned in the previous subsection, as have fermentation and basic chemicals. More recent applications of industrial biotechnology include the use of waste from farming or forestry for the production of biochemicals and biofuels (Confindustria 2009). Biopolymers, whether produced from waste or otherwise, are still in an early development phase (EC 2007*b*). Examples include biopolymers based on lactic acid, polyhydroxyalkanoates, bio-propanediol, and bio-acrylamide. In biofuels, the bioethanol and biodiesel industries are in a similar state of technological development. Another relatively new application is bioremediation of contaminated water, soil, air and solid waste, using mainly micro-organisms to transform contaminations into less harmful substances. Even less developed is the new discipline of synthetic biology using DNA synthesis and genetic engineering. Its potential applications include energy production, bioremediation, smart materials, biomaterials, and sensors and detection systems (EC 2007*b*).

There are close links between many applications of industrial biotechnology and other key enabling technologies, notably nanotechnology and advanced materials.

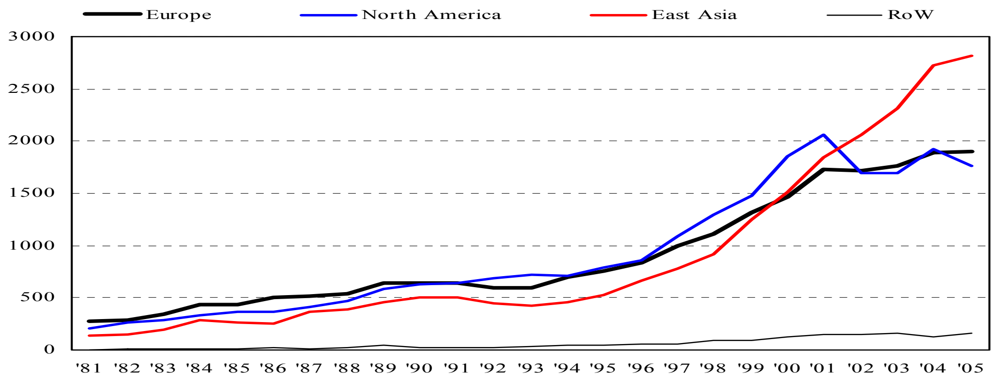
4.5.4. Photonics

Photonics is the science and technology of generating, detecting and managing light. It is defined in Jahns (2001) as the use of photons as carriers of energy and information, thereby in a way gradually assuming the role previously played by electrical and electronic processes. It is a cross-sectoral technology, bringing together the disciplines of physics, nanotechnology, materials science, biotechnology, chemistry and electrical engineering (EC 2008). With the development in the 1960s of electronics, laser technology and fibre optics, the technological environment for optical communication was created and the term photonics was coined (Jahns 2001; EC 2008).

4.5.4.1. Background and current state

Though photonics is a relatively young technology into which systematic research began in the 1960s, its foundation was the discovery by Einstein that light is composed of indivisible, energy-rich elementary units (quanta) which we now call photons. Developments in several other sciences from the 1960s on paved the way for rapid advances in photonics in recent decades, as illustrated by the increasing number of patent applications shown in Figure 4.11. It is interesting to note that until 2001 the three regions from which most photonics patent applications came followed more or less the same pattern and their shares of the total number of applications were very similar, whereas from 2001 to 2005 the numbers levelled out in Europe and North America but continued to rise in East Asia, whose share of total EPO/PCT applications in photonics consequently rose to 42 percent, compared to 29 percent for Europe and 27 percent for North America.

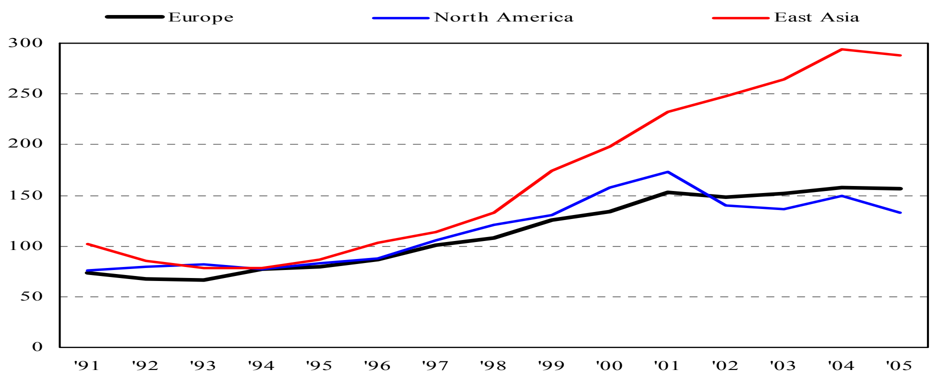
Figure 4.11: Number of photonics patents (EPO/PCT) by region of applicant, 1981-2005



Source: EPO Patstat; background study.

The most active applicants from the three leading regions in the period 2000-2007 were Samsung (South Korea; 1029 applications), Osram and its owners Siemens (Germany; 964 applications), Matsushita (Japan; 750 applications) and 3M (USA; 748 applications).

Figure 4.12: Photonics patent application intensity (number of EPO/PCT patents per trillion of GDP at constant PPP US dollars), 1991-2005

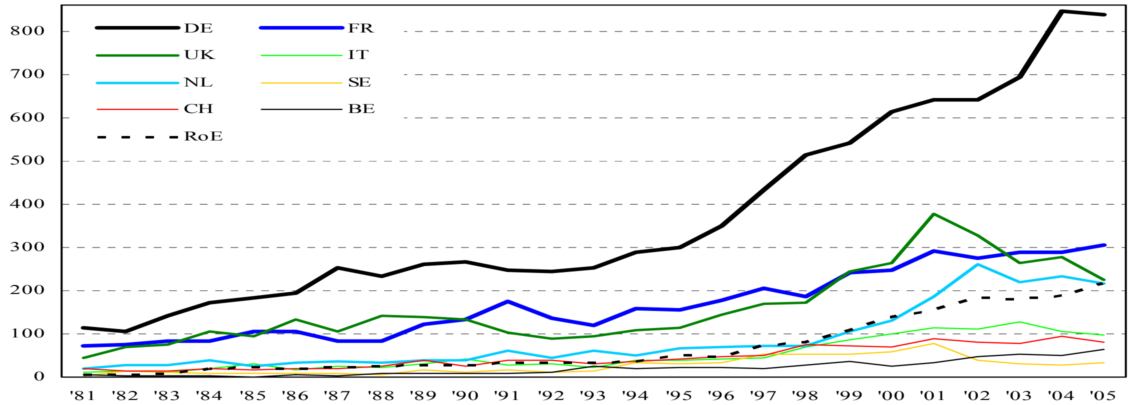


Source: EPO Patstat; OECD (2009 *b*); background study.

The dominance of East Asian applicants over European and North American applicants is even more striking when differences in GDP are taken into account. Patent application intensities are almost twice as high in East Asia (mainly Japan and South Korea) as in Europe and North America.

In Europe as well as globally, Germany has a very strong position in terms of EPO/PCT applications. Figure 4.13 illustrates the dominance of German applicants and how far away it has moved from France, UK and the Netherlands. However, Germany has only the third highest patenting intensity when GDP is factored in: applicants from the Netherlands and Switzerland submitted around 20 percent more patent applications in relation to their GDP than Germany.

Figure 4.13: Photonics patent applications (EPO/PCT) by country, 1981-2005



Source: EPO Patstat; background study.

In relation to the European average, German patent applications are over-represented in solar cells, an area where French and UK applicants are under-represented. The latter are instead over-represented in laser applications and optical devices (UK also in lighting). Applicants from the Netherlands are over-represented in patent applications concerning lighting.

4.5.4.2. Photonics applications

By combining disciplines such as physics, nanotechnology, materials science, biotechnology, chemistry and electrical engineering, applications of photonics cover a variety of sectors including information processing, communication, imaging, lighting, displays, manufacturing, life sciences and healthcare, safety and security (EC 2008). Its exceptional properties — which include being focusable, travelling at the speed of light, combining ultra-short pulses with high power — make it a key enabling technology to consider when developing new applications. Photonics can furthermore be considered a green technology insofar as it enables conventional applications (such as lighting, data communication) to be developed more efficiently, or the production of cleaner energy (solar cells). Although by no means exhaustive, Table 4.2 gives an idea of the range of existing and future applications of photonics.

Table 4.2: Examples of current and future photonics applications, by field of industry

Field of technology	Examples of applications	
Production technology	Laser materials processing systems lithography systems (IC, FPD, mask)	Lasers for production technology objective lenses for wafer steppers
Optical measurement and machine vision	Machine vision systems and components Spectrometers and spectrometer modules Binary sensors	Measurement systems for: – semiconductor industry – optical communications – other applications
Medical technology and life sciences	Lenses for eyeglasses and contact lenses Laser systems for medical surgery, therapy and cosmetics Endoscope systems Microscopes and surgical microscopes	Medical imaging systems (only photonics-based systems) Ophthalmic and other in-vivo diagnostic systems Point of care diagnostic systems Systems for in-vitro diagnostics, pharmaceutical & biotech R&D
Data communication	Optical transmission, networking and coding systems for core and access networks	Components for optical networking systems
IT: consumer electronics, office automation, printing	Optical disk drives Laser printers and copiers, PODs, fax and MFPs Digital cameras and camcorders, Scanners Barcode scanners	Systems for commercial printing Lasers for IT Sensors (CCD, CMOS) Optical computing Terahertz systems in photonics
Lighting	Lamps LEDs	OLEDs
Displays	LCD displays Plasma displays	OLEDs and other displays Projection displays Display glass and liquid crystals
Solar energy	Solar cells (organic and inorganic)	Solar modules (organic and inorganic)
Security, safety and defence photonics	Vision and imaging systems, including periscopic sights Infrared and night vision systems Ranging systems Munition / missile guiding systems	Military space surveillance systems Avionics displays Image sensors Lasers Terahertz systems
Optical systems and components	Optical components and optical glass optical systems ('classical' optical systems)	Optical & optoelectronic systems

Source: Photonics21 (2007); background study; Commission services.

As has been made clear in the preceding subsection, there are close connections between photonics and most other key enabling technologies, in particular nanotechnology, micro and nanoelectronics including semiconductors, biotechnology and advanced manufacturing technologies.

4.5.5. Advanced materials

The meaning of advanced materials has shifted over time and nowadays tends to include materials possessing new and different types of internal structures and exhibiting innovative properties and higher added value, as a result of modifying and improving structures and properties (Moskowitz 2009). The importance of advanced materials lies in their potential applications in various sectors such as aerospace, construction and healthcare, and the reduction in costs, resource consumption and environmental impact as well as improved performance often associated with the substitution of existing materials. More efficient use of resources and smaller environmental impact are especially important aspects for Europe and other parts of the world where natural resources are scarce (Confindustria 2009).

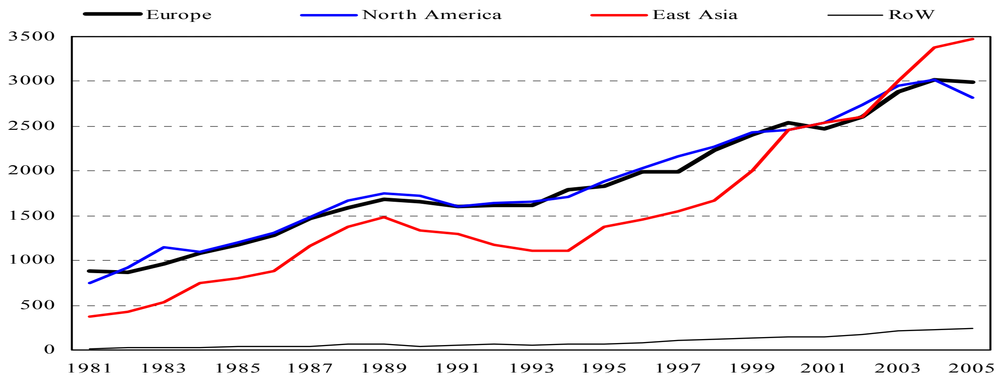
4.5.5.1. Background and current state

Efforts to improve the material base for the manufacture of goods, allowing for higher product quality and new product characteristics, go back a very long time in human history. In modern times, the focus was initially on improving metals by introducing new alloys with superior performance characteristics (such as steel) and exploring the industrial applicability of new metals (such as aluminium). In addition, a number of innovations took place in the field of non-metallic materials such as glass, ceramics and concrete. In the late 19th century the focus shifted to chemicals and a large number of synthetic materials were invented as a result. In the 20th century the focus shifted again and most efforts went into building up so-called 'macrostructures' or 'superpolymers' by linking together molecular units into super-long chains (e.g. polyethylene, styrene, Teflon) possessing desirable physical and chemical properties (Moskowitz 2009). The latest shift took place in the late 1970s and involved customisation of the atomic structure of materials by creating, manipulating and reconfiguring molecular or atomic units within a wide range of material categories. Despite the shifts in priorities over time, material innovations still occur along the all the lines mentioned above.

The recently renewed interest in advanced materials is due to the latest materials having application rates nearly three times higher than previous generations of materials. It has been estimated that the eight most important materials entering the market in the first seven decades of the 20th century — electrometals, synthetic ammonia, nylon, styrene, etc. — had an average of 2.7 applications per material, whereas the 14 latest advanced materials (including nanocrystals, nanocomposites, nanotubes, and organic electronic materials) have on average 8.6 applications per material (Moskowitz 2009).

Figure 4.14 shows the increase in patent applications in advanced materials in recent decades, illustrating the growing number of applications enabled by continued innovation. The graphs are very similar to those in Figure 4.11 for photonics in the sense that the European and North American numbers are very similar and have stagnated in the early years of the 21st century, whereas East Asian applications have continued to increase and resulted in East Asia becoming the primary source of EPO/PCT patent applications in advanced materials, with 37 percent of all applications. Even so, the most active applicants in the period 2000-2007 were all European or North American: BASF (Germany; 1410 applications), DuPont (USA; 1303 applications), Dow (USA; 1170 applications), 3M (USA; 1101 applications), Evonik Degussa (Germany; 885 applications), Arkema (France; 796 applications), Bayer (Germany; 646 applications). The most active East Asian applicant was Fujifilm (Japan) with 602 EPO/PCT patent applications.

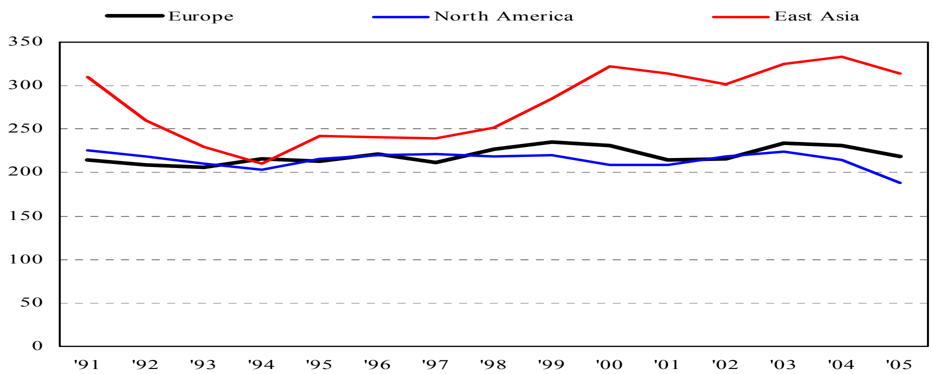
Figure 4.14: Number of advanced materials patent applications (EPO/PCT) by region of applicant, 1981-2005



Source: EPO Patstat; background study.

The differences between the three main regions become even more evident when GDP is taken into account, as shown in Figure 4.15 below. It also shows that the increase in the number of European and North American patent applications from 1991 to 2005 was similar to their respective GDP increases, leaving the patent application intensity more or less constant, whereas East Asian applications increased faster than the rate of GDP growth.

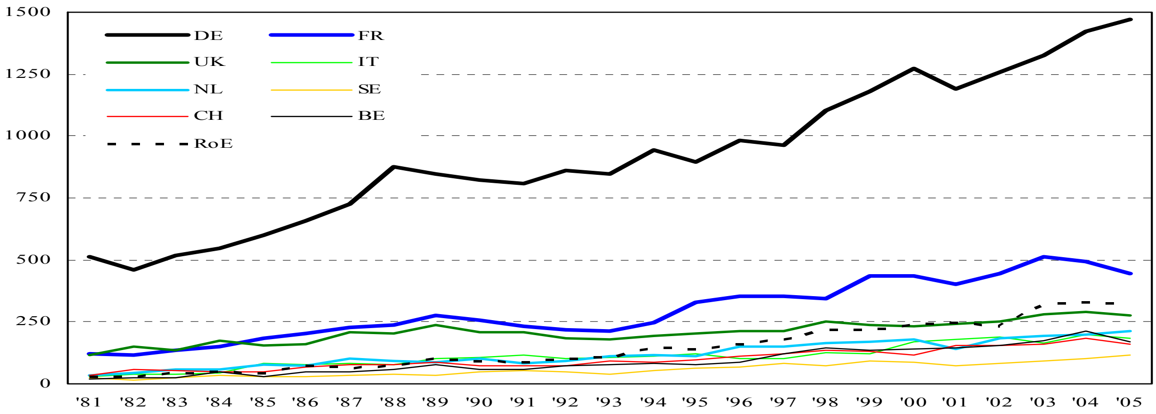
Figure 4.15: Advanced materials patent application intensity (number of EPO/PCT patents per trillion of GDP at constant PPP US dollars), 1991-2005



Source: EPO Patstat; OECD (2009*b*); background study.

Applicants from Germany account for almost half of all European patent applications in advanced materials and as Figure 4.16 suggests, Germany strengthened its position in recent decades. In relation to Europe as a whole, German applicants are over-represented in macro-scaled materials. French applicants account for around 14 percent of all European applications and are over-represented in high-performance materials, alloys and energy-efficient materials. UK applicants, who tend to submit more applications in layered materials, energy-efficient materials and nanomaterials than the European average, are responsible for 10 percent of all European EPO/PCT applications concerning advanced materials.

Figure 4.16: Photonics patent applications (EPO/PCT) by country, 1981-2005



Source: EPO Patstat; background study.

4.5.5.2. Advanced materials applications

Advanced materials, being a true general purpose technology, can be applied widely across industries as well as in service sectors such as health, software, architecture and construction, telecommunication and engineering services. Moreover, thanks to recent advances and new priorities, the average number of applications per new advanced material is now three times higher than in previous decades (Moskowitz 2009).

The most important application areas for advanced materials change over time due to shifting priorities and scientific progress. Right now semiconductors, automotive and aircraft, energy and environment, medicine and health, construction and housing, and various process technologies (including mechanical engineering and automation, packaging and logistics, textiles and clothing) are the main application areas. Other major applications are in defence and security.

Turning to future applications, Schumacher et al. (2007) have surveyed technological foresight studies and have concluded that the main priority will be to develop new applications of advanced materials in medicine, ICT and entertainment, textiles and smart materials. Another priority concerns security, where new applications such as nanomaterials and smart materials for protection, identity authentication and alarm systems will be needed. A third priority concerns energy and addresses applications such as solar materials, fuel cells and materials for energy efficiency.

It is clear that advanced materials are essential for the further development of many other key enabling technologies, in particular nanotechnology, micro and nanoelectronics including semiconductors, and photonics.

4.5.6. Advanced manufacturing technologies

Advanced manufacturing technologies comprise all technologies that significantly increase speed, decrease costs or materials consumption, and improve operating precision as well as environmental aspects such as waste and pollution from manufacturing processes. It is not a single technology but a combination of different technologies and practices that aim at improving manufacturing processes. Material engineering technologies (including cutting, knitting, turning, forming, pressing, chipping), electronic and computing technologies, measuring technologies (including optical and chemical technologies), transportation technologies and other logistic technologies are some of the many technologies that come together to form advanced manufacturing technologies.

The importance of promoting the development of advanced manufacturing technologies was highlighted in all four scenarios presented in FutMan (2003) and a recently launched U.S. study on the creation of new industries through science, technology and innovation is expected to pay particular attention to advanced manufacturing technologies (STPI 2010).

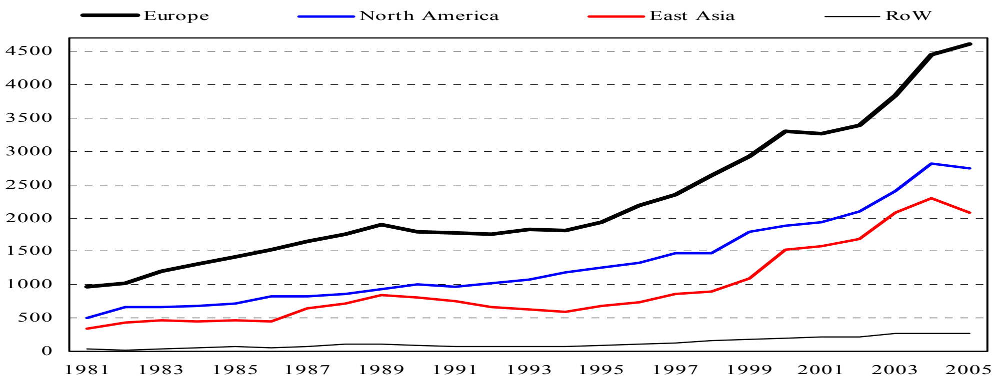
4.5.6.1. Background and current state

It could be argued that advanced manufacturing technologies are the oldest key enabling technology known to man, as the never-ending quest to do things in a better way is as old as human civilisation. This quest is usually rewarded in incremental steps, in the form of innovations and method improvements, but disruptive changes do occur from time to time, usually as a result of a new general purpose technology emerging (examples include the steam engine, electrical motor, and computing). Another peculiarity of advanced manufacturing technologies is that progress and innovation stem not only from technology producers but also from the users. In fact, in some specialised manufacturing industries there are no external providers of advanced manufacturing technologies, forcing manufacturing firms to develop on their own the skills needed to advance manufacturing methods.

In recent decades there has been a clear trend away from traditional engineering technologies to the integration of computer technology into manufacturing processes and to enabling the vertical integration of planning, engineering design, control, production and distribution processes. Another trend, automation, allows increasingly complex manufacturing processes to be performed without any manual intervention. Robotics, automation technologies and computer-integrated manufacturing are the keywords in this context.

Figure 4.17 shows the number of EPO/PCT patent applications over time from Europe, North America, East Asia and the rest of the world. The increase in patent applications in all three main regions over the last three decades reflects the growing importance manufacturing firms attach to advanced manufacturing technologies and the opportunities that advances in other fields have offered in recent years.

Figure 4.17: Number of advanced manufacturing technology patent applications (EPO/PCT) by region of applicant, 1981-2005

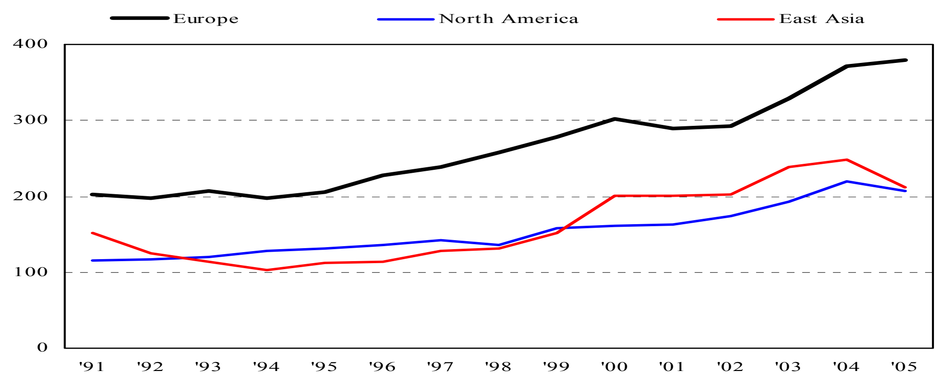


Source: EPO Patstat; background study.

It is also clear from Figure 4.17 that European applicants dominate, representing nearly half of all EPO/PCT applications. North American applications represent less than 30 percent of the total and East Asian applications around 20 percent. The four leading EPO/PCT applicants in the world in the period 2000-2007 were all from Europe: Siemens (Germany; 1847 applications), Robert Bosch (Germany; 1348 applications), Continental (Germany; 635 applications) and Endress+Hauser (Switzerland; 589 applications), followed by Fanuc (Japan; 574 applications) and Honeywell (USA; 573 applications).

Europe is where most EPO/PCT applications originate even after differences in GDP have been factored in, as Figure 4.18 illustrates. The application intensities of North America and East Asia are very similar, whereas the European application intensity has always been more than 50 percent higher.

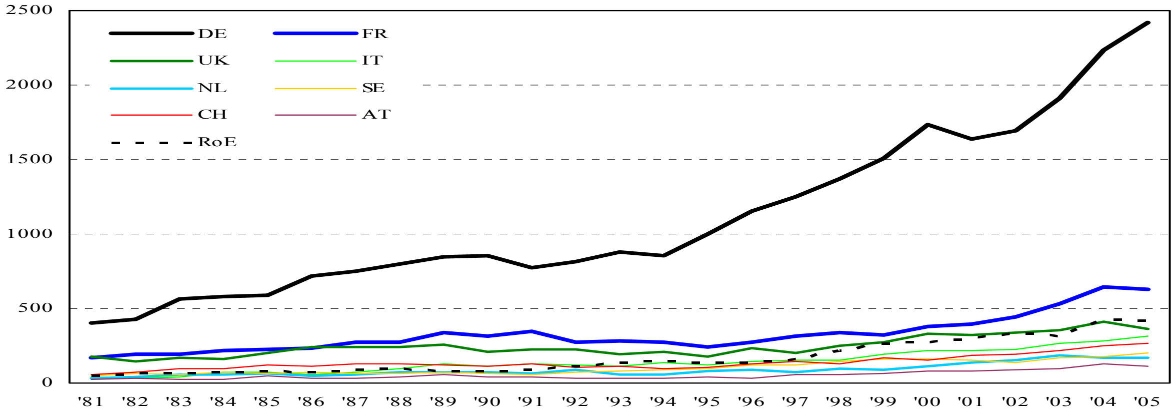
Figure 4.18: Advanced manufacturing technology patent application intensity (number of EPO/PCT patents per trillion of GDP at constant PPP US dollars), 1991-2005



Source: EPO Patstat; OECD (2009 *b*); background study

Germany is by far the most active European country in terms of EPO/PCT applications, with almost half of all European patent applications in advanced manufacturing technologies, due mainly to Germany's strong performance in tools, measuring and control. As Figure 4.19 shows, there was a particularly strong increase in German patent applications from 1993 to 2000, and again from 2002 onwards, which was not replicated in other European countries. French applicants account for 14 percent and UK applicants for 10 percent of all European patent applications. When adjusted for differences in GDP the application intensities of Germany and Switzerland are very similar, the Swiss intensity being slightly higher.

Figure 4.19: Advanced manufacturing patent applications (EPO/PCT) by country, 1981-2005



Source: EPO Patstat; background study.

4.5.6.2. Applications of advanced manufacturing technologies

Given the current focus on increased automation and integration of computers, it is natural that most applications of advanced manufacturing technologies are in robotics, computer-assisted design and computer-integrated manufacturing. Furthermore, robots are expected to become much more flexible and easy to use over the next few years, paving the way for a new era of robotics, improving the quality of life by delivering efficient services and, in so doing, combating an expected shortage of skilled labour of up to 6 million people by 2020. In addition, high labour costs are a particularly compelling reason for European manufacturing firms to use robots more in the interest of productivity and competitiveness. The miniaturisation of robotic technologies and the development of sophisticated sensors are important trends in this context as they will enable robots to be used in small-batch production facilities. Similarly, new developments in robotic technologies mean that they can assist in operations under hazardous conditions, for example in space, deep sea, or mining and mineral extraction.

Another feature of applications of advanced manufacturing technologies is the emergence of multifunctional 'platform technologies' with a range of manufacturing applications. This includes technologies such as plastic electronics, silicon design, renewable chemicals and carbon fibre composites capable of replacing various metals. Such platform technologies offer the potential of substantial economic opportunities.

Advanced manufacturing technologies are linked to most other key enabling technologies. In particular, progress made in advanced materials, microelectronics, biotechnology and nano-technology will profoundly affect manufacturing and help manufacturers master the challenges ahead (FutMan 2003), while STPI (2010) refers specifically to photonics, nano-materials and industrial biotechnology as having a crucial impact on advanced manufacturing technologies.

4.6. Market potentials

Estimating market potentials is notoriously risky, even in the case of established products on stable markets. For key enabling technologies it is even more difficult as the technologies and products for which market potentials are estimated often do not yet exist on the market. Most of the potential applications are at a pre-commercial or even conceptual stage, driven by technological opportunities rather than the likely preferences of users. Demand is largely unknown and it may well be that there will be no market at all for some of the concepts. Historical experience with new technologies shows that many of the most important application areas were not envisaged at the early stages of technological development but emerged later through interaction of users and producers, and sometimes just by chance.

Furthermore, products based on key enabling technologies often serve as inputs into more complex products. For instance, nanomaterials may be used in a wide variety of manufactured products from different industries. Semiconductors can be applied to a range of instruments, machinery and equipment. Biotechnologically-produced enzymes may be found in a number of food or chemical products. New photonic applications such as OLED displays can be used in electronic, automotive and telecommunication devices. Advanced materials and advanced manufacturing technologies can be used to produce virtually any kind of commodity. As a consequence market potential estimates will vary depending on the underlying definition of key enabling technologies (as there is no universally accepted definition or agreed list) and also depending on which sections of a value added chain are considered.

All this complicates any attempts to predict future market development and often results in poor forecasts. Instead of trying to do this, the background study contains several detailed compilations of existing estimations of future market volumes (of which there are many, not always pointing in the same direction). The results in terms of current and future market sizes as well as implied annual growth rates are set out in Table 4.3 (more detailed tables can be found in the background study).

Table 4.3: Estimated global market potentials of key enabling technologies

	Current market size (around 2006/08; USD)		Expected size in 2015 (around 2012/15; USD)		Expected compound annual growth rate	
	lower bound	upper bound	lower bound	upper bound	lower bound	upper bound
Nanotechnology	12 bn	150 bn	27 bn	3100 bn	16%	46%
Micro and nanoelectronics	250 bn		300 bn	350 bn	5%	13%
Industrial biotechnology	90 bn		125 bn	150 bn	6%	9%
Photonics	230 bn		480 bn		8%	
Adv. materials	100 bn		150 bn		6%	
Adv. manufacturing techn.	150 bn		200 bn		5%	

Source: Background study; Confindustria (2009).

Bearing in mind the above caveats, as well as the fact that the six technologies in Table 4.3 have no intrinsic market value unless they can be commercialised in the form of marketable products for which there will be a demand, it is possible to get a rough idea of the size of the current and future market for applications of key enabling technologies by adding the volumes of the six technologies (some market volumes are likely to be counted twice, for instance the market for nanomaterial applications). Such an exercise results in a current market volume of USD 830-970 billion which is projected to grow to USD 1.3-4.4 trillion around 2015. The spread of the latter interval reflects genuine uncertainty and is predominantly due to widely differing expectations about the future market for nanotechnology applications, which in a cautious scenario is expected to double from 12 to 27 billion and in the most optimistic scenario grow by 2000 percent, from 150 to 3100 billion. These differences reflect not only different levels of optimism and uncertainty but also the lack of definitions of key enabling technologies. A case in point is the lower estimate of the current market volume for nanotechnology applications, which is clearly based on a much more restrictive definition of nanotechnology than the higher estimate of 150 billion.

It is interesting to note that only two markets, for nanotechnology and photonics applications, are expected to outperform the overall market for goods. In the case of advanced materials and advanced manufacturing technologies, the market for applications is expected to grow by 5 to 6 percent per year, similar to the expected medium-term growth rate for the goods market as a whole, and in a conservative scenario this also applies to industrial biotechnology and micro and nanoelectronics including semiconductors. At least as regards advanced materials and advanced manufacturing technologies, substitution effects may be part of the explanation for the seemingly low growth rates.

Market volumes and growing demand should not however be the main drivers for a policy on key enabling technologies. Growth in market volumes for a particular technology says little about the effects on macroeconomic net growth. Although key enabling technologies make it possible to develop entirely new applications in many fields of manufacturing and help to establish new markets, many of the new applications will result in demand shifts between sectors and markets and cause declining demand in sectors less affected by such technologies. Policies should therefore focus on stimulating the productivity and innovation impacts of key enabling technologies, even though such impacts are difficult to quantify. Productivity impacts tend to be higher the faster the technologies diffuse across industries and the higher the number of different industries in which they are applied. Innovation impacts can be manifold and are not limited to technology producers. Key enabling technologies can stimulate product and process innovation in several sectors, including innovative applications beyond the horizon of technology producers. Exploiting the innovative potential of key enabling technologies often requires close interaction between their producers and users, taking into account the specific needs of those users. Examples of indirect innovation effects of key enabling technologies range from medicine to environmental technologies.

4.7. European competitiveness by subsector

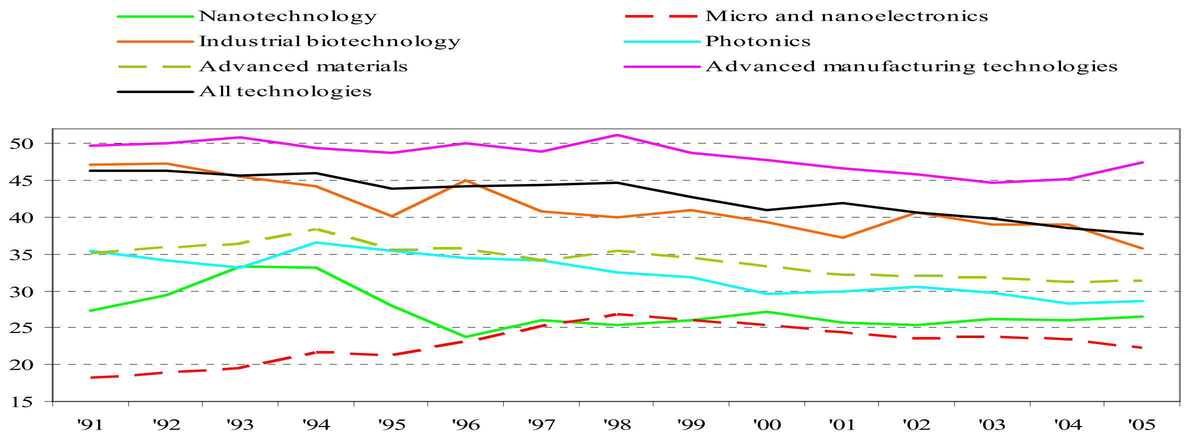
Analysing Europe's international competitiveness in key enabling technologies is not a straightforward exercise as there are no data on sales, costs, prices or profitability for the type of pre-market products, or in some cases mere concepts or not even conceptualised ideas, with which this chapter deals. One possible approach to take is to base the competitiveness analysis on patent data, using patent applications within a particular technology as a proxy for the competitiveness of an applicant in that technology. However, using patent data for analysis is potentially more problematic than using such data for illustration purposes, as in Section 4.5. Potential pitfalls range from definition problems — assigning classification codes to the right technology, making sure that no relevant classification code is left unassigned while keeping to a minimum the number of cases in which classification codes are assigned to more than one technology — via the skewed value distribution of patents (few patents are valuable and most are economically irrelevant) to the fundamental question whether the number of patent applications is a good proxy for competitiveness or not. An illustration of the latter question is given in PCAST (2010), which notes that even though the USA is the world's leading producer of nanotechnology patents, in terms of scientific publications in the field of nanotechnology it has been second to the EU since 1995 and has recently been surpassed by China as well.

The arguments for and against patent analysis are set out in the background study, which also contains an explanation of the methodology used to assign patent classification codes to technologies, as well as several examples of the effect on results of using data on patent applications made at the European Patent Office (EPO), the U.S. Patent and Trademark Office, the Japanese Patent Office, or filed at all three patent offices jointly.

The analysis in this section will be based on applications made at the EPO or under the Patent Cooperation Treaty (in this chapter referred to as EPO/PCT applications), bearing in mind that the data are probably biased in favour of European applicants and therefore likely to exaggerate Europe's strengths. EPO/PCT applications are, however, preferred as they are likely to represent greater economic value since they are more expensive than applications made at a single patent office.

As illustrated in Figures 4.2, 4.5, 4.8, 4.11, 4.14 and 4.17, patent applications from Europe have generally increased in tandem with applications from the rest of the world, enabling Europe to more or less hold on to its share of overall applications in each of the six technologies. As Figure 4.20 shows, the European share of all EPO/PCT applications is particularly high in advanced manufacturing technologies and industrial biotechnology but lower in micro and nanoelectronics owing to a preponderance of applications from East Asia in recent years.

Figure 4.20: European share (%) of total patent applications (EPO/PCT), 1991-2005



Source: EPO Patstat; background study.

Across all six technologies, German applicants make the single most important contribution to the European share, with more than 43 percent of all European applications being made by German applicants, followed by France (15 percent) and the UK (11 percent).

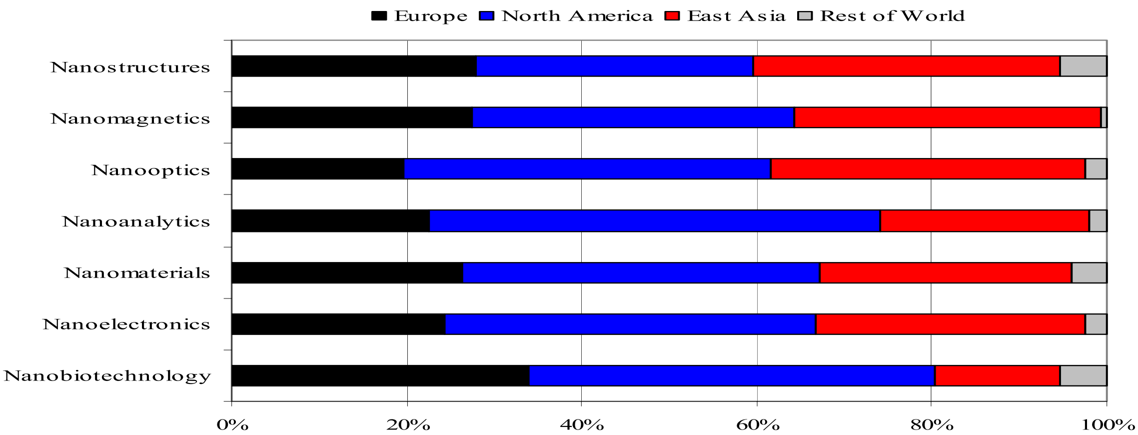
Assuming that the shares indicated in Figure 4.20 remain stable at their 2005 levels and that they can serve as proxies for market share, combining them with the global market volume estimations in Table 4.3 gives a rough idea of the expected contribution of the technologies to the European economy around 2015. In the conservative scenario in Table 4.3, the market for European products applying key enabling technologies could be worth USD 400 billion, or 31 percent of the 1.3 trillion world market. In the more optimistic scenario the market value for Europe would be considerably higher, USD 1.2 trillion, or 27 percent of the world market of 4.4 trillion.

In the following subsections patent analysis and cluster analysis will be used to explore each of the six technologies in greater detail.

4.7.1. Nanotechnology

European applicants accounted for one in four EPO/PCT nanotechnology patent applications in 2005, compared to 39 percent for North America and 30 percent for East Asia. These aggregate figures can be subdivided into nanostructures, nanomagnetics, nanoanalytics, nano-optics, nanomaterials, nanoelectronics and nanobiotechnology. The share of EPO/PCT applications for each of these fields is shown in Figure 4.21, for the three main regions and for the rest of the world. It is clear that in most of the fields North America accounts for more applications than Europe or East Asia. Europe's strength is in nanobiotechnology and its weakest fields are nanoanalytics and nano-optics. In all seven fields Europe is behind one or both of the other main regions in terms of EPO/PCT applications.

Figure 4.21: Composition of nanotechnology patent applications (EPO/PCT) in 2005



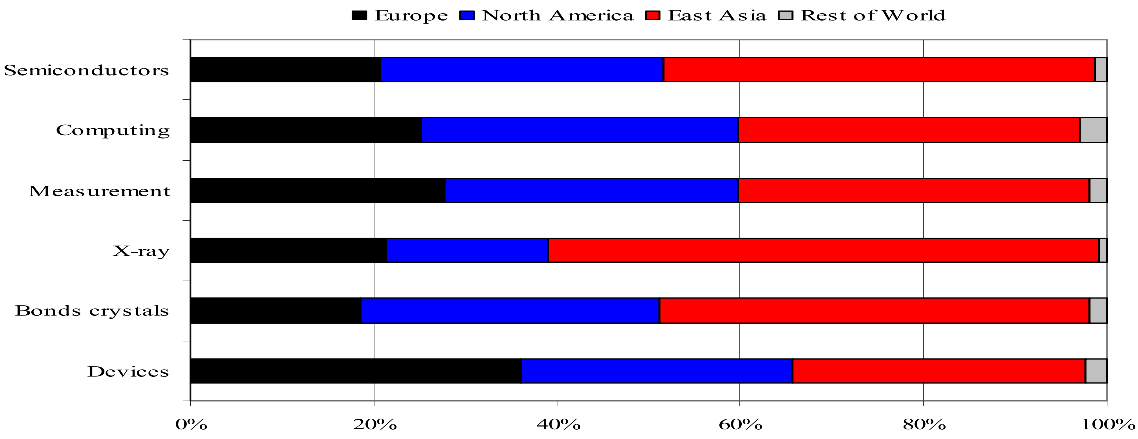
Source: EPO Patstat; background study.

In Europe there are more than 240 nanotechnology research centres and around 800 companies specialising in nanotechnology research (Afsset 2008; Conseil économique et social 2008). Both figures are slightly higher than the corresponding U.S. numbers. In terms of its research base Europe has a particularly strong position in nanomaterials, nano-optics and nanobiotechnology, whereas its position in nanoelectronics, nanoanalytics and nanomagnetics is less prominent. In 2008 public funding for European nanotechnology research amounted to USD 2.6 billion, ahead of the U.S. (1.9 billion) and comparable to East Asia (2.8 billion), but private investment in nanotechnology research fell short in Europe: USD 1.7 billion compared to 2.7-2.8 billion in the U.S. and East Asia (Confindustria 2009; PCAST 2010).

4.7.2. Micro and nanoelectronics including semiconductors

In 2005, European applicants accounted for 22 percent of all EPO/PCT patent applications in micro and nanoelectronics, compared to 30 percent for North America and 46 percent for East Asia. The applications can be divided into semiconductors, computing, measurement, x-ray, bonds and crystals, and electronic devices. The market volume for semiconductors is far greater than the market volume of the other five segments combined.

Figure 4.22: Composition of patent applications (EPO/PCT) in micro and nanoelectronics including semiconductors in 2005 (%)



Source: EPO Patstat; background study.

As Figure 4.22 demonstrates, European applicants dominate the market for devices patents but are weaker in bonds/crystals and semiconductors. It is striking that East Asian applicants made almost half of all EPO/PCT applications in the important semiconductor field.

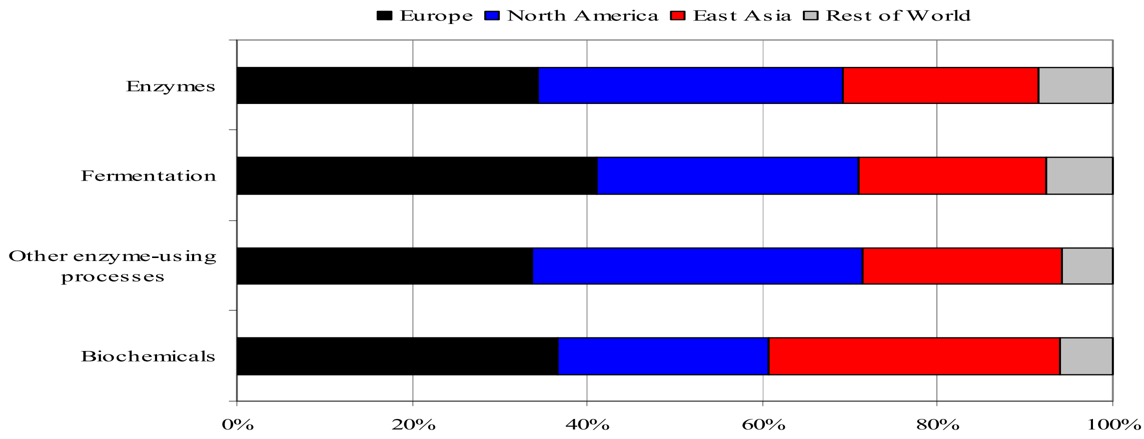
Returning to the aggregate level, Europe attracted only 10 percent of overall investment in micro and nanoelectronics in 2007, compared to 48 percent in East Asia (Confindustria 2009).

4.7.3. Industrial biotechnology

Industrial biotechnology is one of the key enabling technologies in which Europe is ahead of North America and East Asia in terms of patent applications. In 2005, Europeans submitted the highest share of EPO/PCT patent applications in industrial biotechnnology (36 percent), followed by North American (34 percent) and East Asian (23 percent) applicants. Europeans are in fact world leaders in the production of enzymes and in fermentation: around 80 of the most important enzyme producers are located in Europe, with only 20 in North America (Confindustria 2009).

The competitiveness of the entire European biotechnology industry was the subject of a chapter in the 2001 Competitiveness Report (EC 2001). In the present chapter, however, the interest lies only in industrial biotechnology, which in turn can be divided into enzymes, fermentation processes, other enzyme-using processes, and established biochemicals except enzymes (such as organic acids, vitamins, proteins).

Figure 4.23: Composition of industrial biotechnology patent applications (EPO/PCT) in 2005



Source: EPO Patstat; background study.

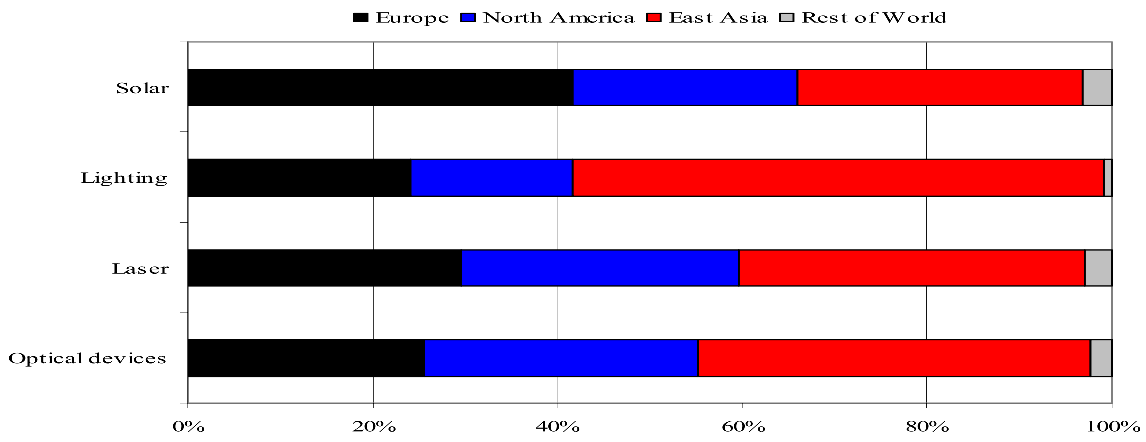
Figure 4.23 confirms Europe's strong position in all four fields, notably in fermentation. In enzymes and other enzyme-using processes North American applicants are about as active as their European counterparts.

4.7.4. Photonics

As in the case of micro and nanoelectronics, photonics is a key enabling technology in which East Asia has left Europe and North America behind in terms of patent applications. In 2005, European applicants accounted for 29 percent of all EPO/PCT applications in photonics, North American applicants for 27 percent and East Asian applicants for 42 percent. Even so, European producers maintain a strong position in many photonics applications such as data communication, healthcare, lighting (including inorganic and organic LEDs), solar cells, safety and security, and laser-assisted manufacturing. It is estimated that there are around 5000 photonics companies in the EU, mostly SMEs, employing around 300 000 people directly (Photonics21). In addition, the jobs of more than 2 million employees in the EU manufacturing sector depend directly on photonics products.

Photonics can be categorised as solar technology, lighting, laser and optical devices. Figure 4.24 shows the shares of EPO/PCT patent applications in each category, and it is clear that European applicants are strongest in solar technology. The largest field in photonics, however, is optical devices, where Europe is under-represented in terms of patent applications.

Figure 4.24: Composition of patent applications in photonics (EPO/PCT) in 2005



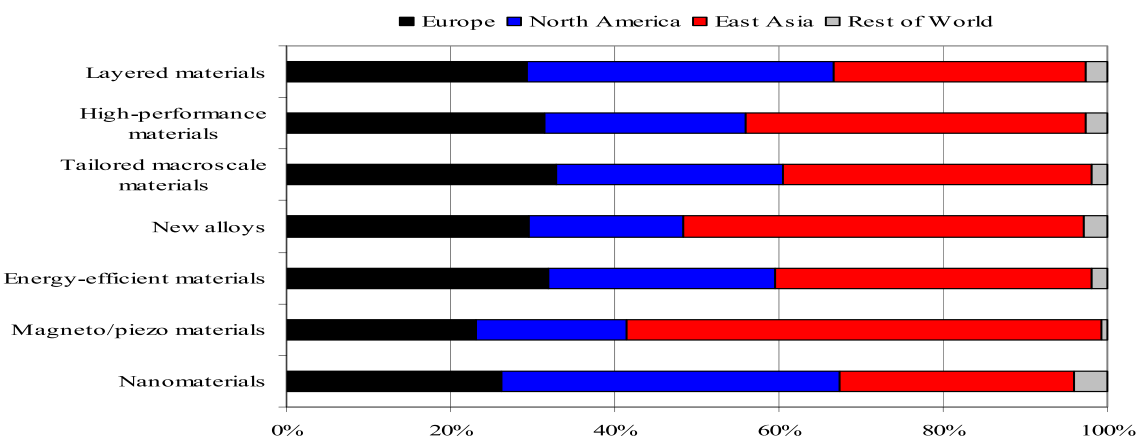
Source: EPO Patstat; background study.

4.7.5. Advanced materials

Despite a very strong research base in advanced materials, and public research spending to the tune of EUR 44 billion a year (around 75% higher than USA or Japan), European patent applications in advanced materials have lost momentum in recent years and represented 31 percent of all EPO/PCT applications in this field in 2005. North American applications have also petered out and stood at 30 percent of the total in 2005, whereas East Asian applications have continued to increase and had reached 37 percent by 2005.

Advanced materials can be divided into layered materials, high-performance materials, tailored macroscaled materials, new alloys, energy-efficient materials, magneto and piezo materials, and nanomaterials. Though currently quite modest, the latter category is expected to grow faster than any other category of advanced materials in the medium term.

Figure 4.25: Composition of patent applications in advanced materials (EPO/PCT) in 2005



Source: EPO Patstat; background study.

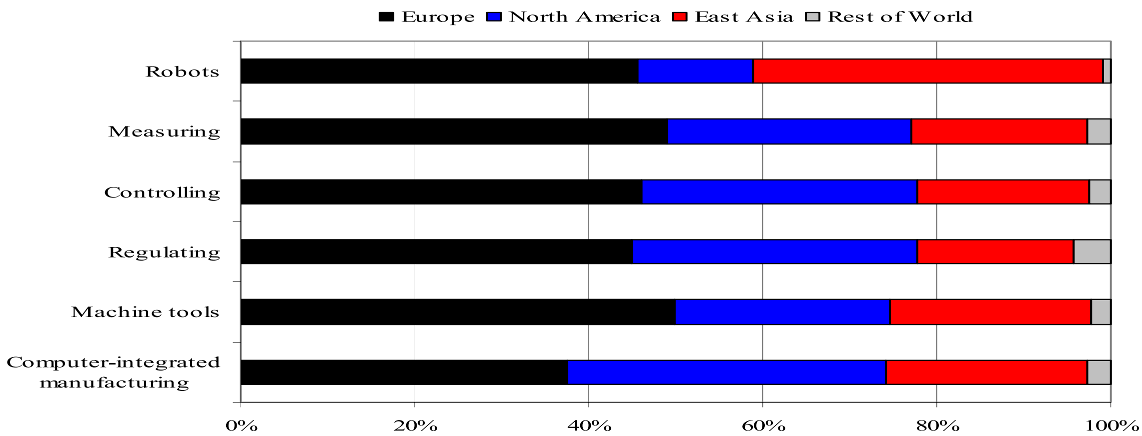
Figure 4.25 demonstrates that Europe is relatively strong in tailored macroscaled materials and in energy-efficient materials, albeit in both cases with a smaller share than East Asia. In magneto and piezo materials, on the other hand, European applicants appear to be falling behind. In all seven fields Europe is behind one or both of the other main regions in terms of EPO/PCT applications.

4.7.6. Advanced manufacturing technologies

Europe is the world leader in advanced manufacturing technologies and in 2005 accounted for almost half of all EPO/PCT applications, followed by North America with around 30 percent of all applications and East Asia with around 20 percent.

Advanced manufacturing technologies can be subdivided into robotics, measuring, controlling industrial processes, regulating industrial processes, machine tools, and computer-integrated manufacturing. Figure 4.26 illustrates how European applicants account for most EPO/PCT applications in all six categories, representing around half the applications in machine tools and in measuring industrial processes. After Europe, East Asian applicants are particularly strong in robotics, and North American applicants in computer-integrated manufacturing.

Figure 4.26: Composition of patent applications in advanced manufacturing (EPO/PCT), 2005



Source: EPO Patstat; background study.

4.7.7. Cluster analysis

As a complement to the patent data analysis on which preceding subsections are based, the background study also contains ten case studies of clusters. For each key enabling technology except advanced manufacturing technologies, a cluster in the EU and a cluster outside Europe have been analysed and compared. The results are summarised in Table 4.4.

Table 4.4: Main results of cluster analysis

Technologies	EU cluster	Non-EU cluster	Main findings
Nanotechnology	North Rhine-Westphalia (NRW)	Kyoto	Both clusters are relatively young. Both focus on integrating nano-technology with other sciences. Kyoto is better than NRW at private financing, commercialisation of results, lead or anchor firms, and entrepreneurial spirit.
Micro and nano-electronics including semiconductors	Grenoble	Ottawa	Stronger cluster identity in Grenoble than Ottawa. Strong research base in both. Stronger government incentives (e.g. tax credits) in Ottawa than Grenoble.
Industrial biotechnology	Cambridge	San Francisco Bay Area	Both clusters developed spontaneously and are now mature. Bay Area firms more commercially oriented than Cambridge, which is more closely linked to universities.
Photonics	Berlin-Brandenburg (OpTecBB)	Québec	OpTecBB geographically more concentrated, financially better equipped and with stronger cluster identity than Québec. Stronger government incentives (e.g. tax credits), greater dynamism, more access to venture capital in Québec.
Advanced materials	Wallonia (Plastiwin)	Changsha, China	Both clusters are young and both have a number of large firms. Stronger government role in Changsha. Cluster leads or anchors in Plastiwin are the larger firms, in Changsha universities.

4.8. Implications

Europe is an important source of technological progress in all six technologies considered in this chapter. It is the world leader in advanced manufacturing technologies, holds a top position in industrial biotechnology, has been able to maintain a strong position in advanced materials and is also building a strong position in photonics despite a rapid increase in technology output in East Asia. In nanotechnology and micro and nanoelectronics Europe contributes less than North America and East Asia.

4.8.1. Existing priorities

The European Union and its Member States have recognised the importance of key enabling technologies and, in many cases, adopted strategies for them in the medium to long term. There is, however, a lack of coordination between Member States.

France was the first Member State to publish a strategy for key technologies. Since 1995 it has published, every five years, strategy documents covering the next five years. The current strategy («Technologies clés 2010») is in the process of being replaced by a new strategy running until 2015.

Germany launched its high-tech strategy in 2006 with nanotechnology, biotechnology, micro-systems technology, ICT, optical technologies, material technologies, production technologies, and innovative services identified as key technologies (BMBF 2006).

In the ***United Kingdom***, a strategy document published in 2008 listed advanced materials, biosciences, electronics, photonics and electrical systems, nanotechnology, high-value manufacturing and ICT as key technologies for the UK (Technology Strategy Board 2008).

At ***EU*** level, following last year's communication (EC 2009*a*), a high-level group has been set up with the task of developing a shared longer-term strategy and action plan on the key enabling technologies identified in the communication. Furthermore, a study has been launched comparing the policies in different countries. The present chapter should be seen in the same context.

The priorities of the EU regarding key enabling technologies have also manifested themselves in other ways: the action plan for Europe on nanosciences and nanotechnology 2005-2009 which is being succeeded by a new action plan for the period 2010-2015; the strategy for Europe on life sciences and biotechnology; and the European nanoelectronics initiative advisory council (ENIAC) founded by the EU, its Member States and industry to take forward European research in nanoelectronics. As already pointed out, the framework programme for research, technological development and demonstration activities also reflects the priorities of the EU in the area of key enabling technologies.

4.8.2. Future directions

All in all, Europe is neither losing nor gaining ground in the six technologies, judging by its share of EPO/PCT patent applications and bearing in mind that patents are less relevant than future commercial applications based on the technologies. In all cases Europe is confronted with increasing competition from East Asia, which in the past decade has made considerable progress, whereas North America's share in global technology output has gradually diminished.

Europe's position tends to be stronger in chemicals-related fields than in technology areas linked to electronics. Another European peculiarity is the importance of the automotive sector as a source of technological progress in some key enabling technologies (micro and nanoelectronics, photonics, advanced manufacturing technologies) due to the high degree of technological competence in this particular industry in Europe.

Public research plays a more prominent role in Europe than elsewhere, although in some technologies (industrial biotechnology, nanotechnology) North America reports an even greater share of public research in total patent output. Dedicated technology start-ups are less significant in Europe compared to North America, but more prevalent than in East Asia.

The critical role of key enabling technologies for manufacturing calls for attention, regardless of the current technological competitiveness. A mix of generic measures and technology-specific interventions is most likely to accelerate the development, diffusion and use of key enabling technologies and increase their impact on the wider economy:

- Since key enabling technologies are research-driven it is essential to maintain a strong research base. Funding basic research with a long-term view is a key policy task. Basic research funding in key enabling technologies needs to strike a balance between setting thematic priorities (in order to obtain a critical mass of knowledge and promote cooperation among researchers working on similar subjects) and providing free space for explorative research into entirely new areas.

- Because these are technologies originating at the frontier between scientific research and industrial applications, the exchange between both groups of knowledge producers is essential as well. In particular, incentives need to be in place at public research institutions for actively engaging in technology transfer. This includes proper intellectual property management, promotion of spin-offs, acknowledging the importance of technology transfer in evaluations and funding and offering linkage programmes such as researcher mobility programmes.

- Industrial R&D on key enabling technologies is characterised by high knowledge spillovers and high technological uncertainty. There is a case for public co-funding of business enterprise R&D, as long as state aid rules are respected and case-by-case assessment criteria fulfilled. R&D programmes should follow a long-term perspective, align technology priorities with thematic priorities of basic research programmes and include incentives for cooperative R&D.

- Although key enabling technologies are characterised by particularly high investment in R&D and high technological and market risks, a generally favourable framework for innovation and commercialisation of new technologies can also be helpful. Policy measures that stimulate start-ups, including a culture of entrepreneurship and risk-taking, can be important, as can a favourable financial environment, including tax incentives for R&D and investment in new technologies.

- Key enabling technology actors should be encouraged to build up networks for joint technology development, particularly in areas requiring a high degree of cross-disciplinary and cross-technology fertilisation. Networking could take place at different geographical levels: global networks of the leading organisations from research and industry where appropriate; regional networks (clusters) to spur technology development wherever close and frequent cooperation among actors is needed. Clusters can be particularly helpful for linking R&D and commercial applications.

- Maintaining a competitive manufacturing base within each technology is critical in order to make full use of their productivity and innovation impact. While pure technology development could be spatially separated from production, direct interaction between R&D, manufacture and application in user industries is needed for creating new fields of application and developing efficient production facilities for new technologies.

- Boosting education and training in these technologies is essential in order to ensure a supply of skilled personnel. Strengthening cross-disciplinary education is a main challenge in that context. A likely shortage of skilled labour should be tackled through education and/or immigration policies.

- An active venture capital market is important for commercialising research results in key enabling technologies through spin-offs and other types of start-ups. Above all, venture capital needs a supportive regulatory environment. In case private venture capital markets in Europe are not fully capable of providing sufficient funds for start-up and early-stage financing, public programmes may have to fill the gaps.

- Addressing barriers to the adoption of new technologies is another important task. Extensive experience has been gained in promoting the rapid and broad diffusion of, for example, advanced manufacturing technologies (Baptista 1999; Link and Kapur 1994; Arvanitis and Hollenstein 1997; Shapira and Youtie 1998). These findings stress the need for consultancy, skills and training, access to external funding as well as cooperation and mutual learning among SMEs.

- There is also a need to acknowledge the role of lead firms and lead markets in the commercialisation of key enabling technologies. Early incorporation of large, globally active companies can help match research with global market prospects and thereby link technological advances to market needs. Venture capitalists can also play a part in this process.

- Balancing health, environment and safety issues against innovation incentives is a major challenge for regulation of key enabling technologies. Involving all the main stakeholders and focusing on legislation that is flexible enough to adjust to technological progress within each technology is a promising approach.

- In order fully to leverage the potential of key enabling technologies to increase productivity and wealth, an integrated, coordinated approach is required, linking actors from regional, national and international levels as well as from different policy domains, including research, innovation, education, competition, industry, taxation, health and environment.

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