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Europe's competitive

technology profile in the globalised

knowledge economy

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INTRODUCTION

Since the early 1980s, the production of goods has been increasingly organised into networked firms with delocalised production chains. These new business models have grown as a response to falling productivity growth in the 1970s and the new opportunities presented by information and communication technologies.[1] Initially, the strategies concerned mainly the lower end of the value chain driven by cost-related factors. However, over the last decade the internationalisation process has moved up the value chain to also cover the higher end of the value chain, including research and innovation activities. International competition for goods and services in the upper parts of the value chain is increasingly tougher.

This process of networked production coupled with complementary services is backed by increasingly fungible capital. Foreign direct investments are growing and are pushing countries to compete in terms of attractiveness and specialisation profile. With the economic crisis in Europe and the US, activities for incremental innovation are increasingly located close to the more dynamic Asian markets. In the medium-term, what is at stake is productivity growth, which relies on a larger part of the economy producing knowledge-intensive and high value-added goods and services. (Porter, 1990)

This paper presents an overview of technology development in Europe in this context of a global knowledge economy. It presents the latest data on the process of global technology development and future prospects based on strategic knowledge assets. Special emphasis is placed on the differences in technology profiles of the world's major knowledge producers. The underlying hypothesis is that periods of deep economic crisis have historically accelerated technological change, at the same time transforming the broader economy.[2] An evidence-based approach is important for going beyond simplistic concepts, and the results indeed show a more multifaceted picture of Europe.

1 Castells, 1996; Expert group to the European Commission, 1997.

2 Schön, 2009.

1. Europe's position in the globalised knowledge economy

The total amount of knowledge produced every year grew remarkably in the first decade of the 21st century. Comparing total expenditure on R&D in PPS in 2010 with the same investments in 2000 shows a 77 % increase in real terms. The total number of PCT patent applications in the world in 2010 was 57 % higher than in 2000 and the number of S&E graduates grew by 51 % from 2 430 000 in 2000 to 3 679 000 in 2010. This opens the door to new opportunities of international cooperation and to world progress in research and innovation addressing societal challenges. In economic terms, it also means stronger rationale for Open Innovation strategies in increased competition for knowledge-based and high value-added goods and services.

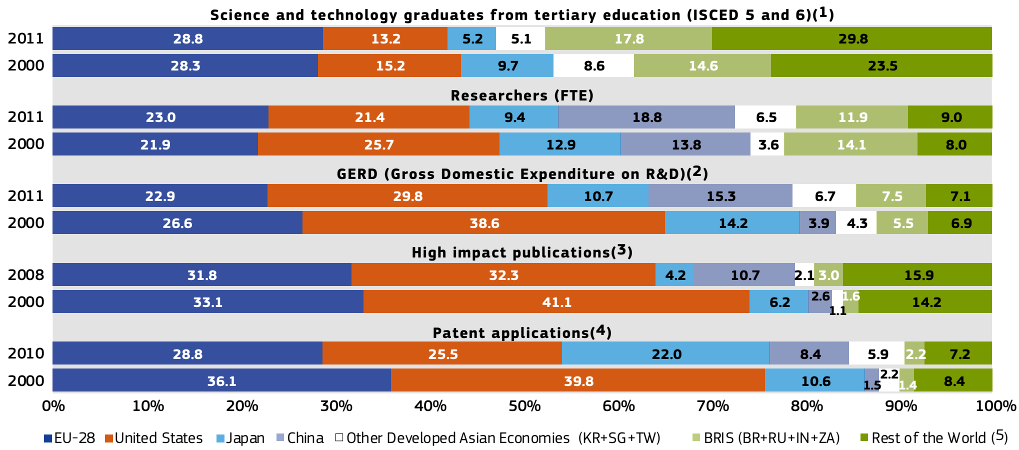
Capacities to produce knowledge are increasingly distributed around the world. The EU is a major knowledge centre but is losing ground to Asia in technology development

The process of a broader geographic distribution of knowledge creation in the world continues. Emerging powers in science, technology and innovation, in particular China, BRIS countries (Brazil, Russia, India, South Africa) and other developed Asian countries, are challenging the triad of the US, EU and Japan. Today, 70 % or more of knowledge creation takes place outside the EU, and around 50 % of the world's human resources for research and innovation live outside the triad. Figure 1 below illustrates that for science and engineering graduates, the largest increase of the world share has been among the BRIS countries and in other knowledge-growth countries in the world, possibly the first significant signs of the rising importance of these countries in the global knowledge economy.

The worrying trends for Europe are more in R&D investments and PCT patents,[3] as illustrated in the graph below. The change in the world share of PCT patents highlights in particular that both the EU and the US are losing ground to the more dynamic Asian technology powers. Overall, the increasing geographical spread of world science and technology production has had a larger impact on the US and Japan than on the EU. The EU's world share of PCT patent applications has fallen by 16 %, which is clearly a larger decrease than for the other dimensions of its R&I system. However, the US' world share of patent applications has fallen even more, by 31 %. The main expansion is found in Japan, China and other developed Asian economies.

Figure 1: World share of S&E graduates, researchers, GERD, high-impact publications and patent applications, 2000 and latest year

Participation in global R&D — % shares



Source: DG Research and Innovation — Economic Analysis Unit.
Data: Eurostat, OECD, Unesco, Science Metrix / Scopus (Elsevier).
Notes: Estimates were sometimes used when compiling the data.
(1) Tertiary graduates in science and engineering:
(i) Data is not available for China;
(ii) Other Developed Asian Economies does not include SG and TW;
(iii) BRIS does not include India and South Africa.
(2) GERD: Shares were calculated from values in current PPS€.
(3) (i) Top 10 % most cited publications — fractional counting method. Scientific publications 2008: citation window 2008-11;
(ii) Other Developed Asian Economies does not include SG and TW;
(iii) BRIS does not include South Africa.
(4) Patent applications under the PCT (Patent Cooperation Treaty), at international phase, designating the EPO by country of residence of the inventor(s).
(5) The coverage of the Rest of the World is not uniform for all indicators.

3 PCT: Patent Cooperation Treaty. 'International' patent application seeking patent protection for an invention in several countries. A PCT application does not in itself result in the grant of a patent, since there is no such thing as an 'international patent'. It must be followed by a standard national or regional patent application.

The growth in total world production of knowledge and the geographically more distributed knowledge is only part of the picture. A third and related trend is the more fungible nature of capital. Foreign investment dynamics and the increased pattern of sourcing parts and components from dispersed Global Value Chains indicate the globalisation of technology and production driven by large multinational corporations. It is relevant to follow this evolution closely, since it increases the competition between knowledge centres, triggering specialisation profiles. It can also be the base for complementarities and networked specialisation, based on related variety and overcoming sub-criticality.[4]

The globalisation of high value-added products and services can be measured by the composition and direction of overall foreign direct investment (FDI) flows, as well as by international financial flows oriented predominantly towards R&D.[5]

The EU remains the most attractive market for FDI, although investments have fallen with the current economic downturn

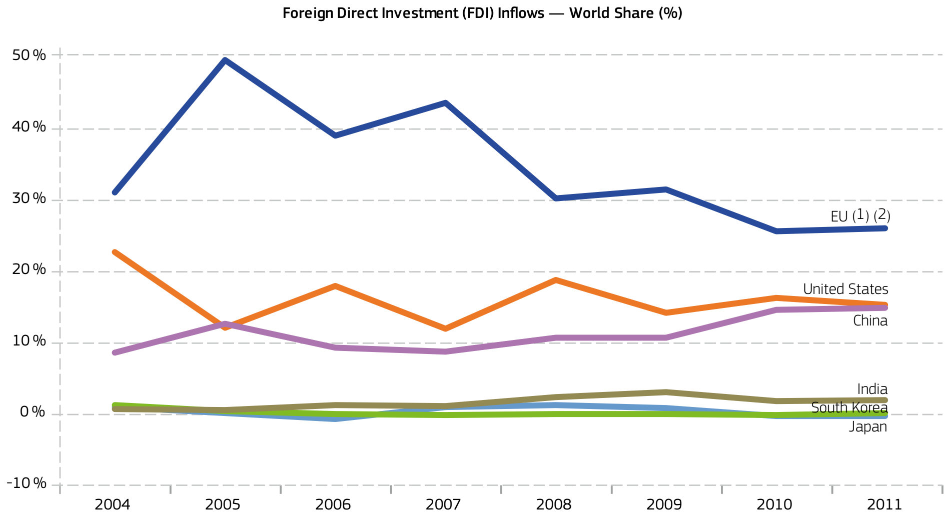
Concerning FDI, the data shows that the EU is still the main destination in the world, representing 1/4 of FDI inflows worldwide, twice the level of the US or China. However, the EU's share has been eroding in the past decade. At the same time, emerging economies such as China and India have increased their share of total world FDI inflows.

US firms are still the dominant foreign direct investors in the EU. However, firms from emerging economies are increasingly acting as FDI investors

Even though non-EU firms increasingly consider comparative advantages for investment in geographical areas other than the EU, the EU remains the major destination for foreign direct investments of US firms. In 2011, €242 billion of foreign direct investments were made in the EU from non-EU firms. With the exception of the peak in 2007, this represents a recovery to the pre-crisis situation.

Investment flows coming from North America to the EU have been by far the largest. Although investments coming from emerging markets are still low in absolute terms, a gradual increase could be seen specifically from Asian and Central American investors, with investments from the former amounting to 19% of total FDI investment flows to the EU.

Figure 2: World share of Foreign Direct Investment (FDI), 2004–11

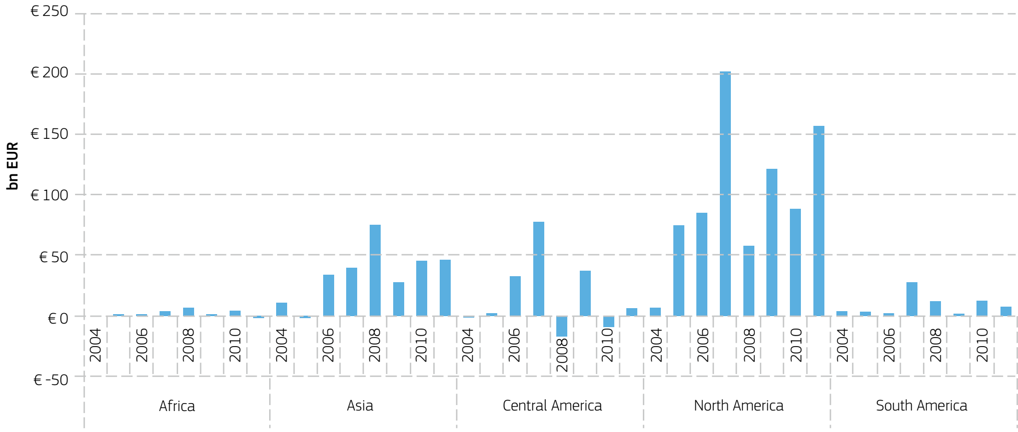


Source: DG Research and Innovation — Economic Analysis Unit.
Data: OECD.
Notes: (1) Bulgaria and Romania are not included for 2004, 2005 and 2007.
(2) EU does not include Special Purpose Entities (SPEs) for Luxembourg, Hungary, the Netherlands and Austria.

4 Expert group to the European Commission, 2008.
5 The globalisation of production can also be measured by input-output tables on trade, indicating income generated from the global value chains. The most recent data (2011) is consistent with the overall finding of FDI data, namely of the EU's slightly falling but persisting world lead. However, China is rapidly increasing its global value chain income and is competitive at both the lower and the higher end of the value chains. (Stehrer, in the upcoming Innovation Union Competitiveness report 2013)

Figure 3: Foreign Direct Investments in Europe by firms from other continents

EU-27 inward flows by partner



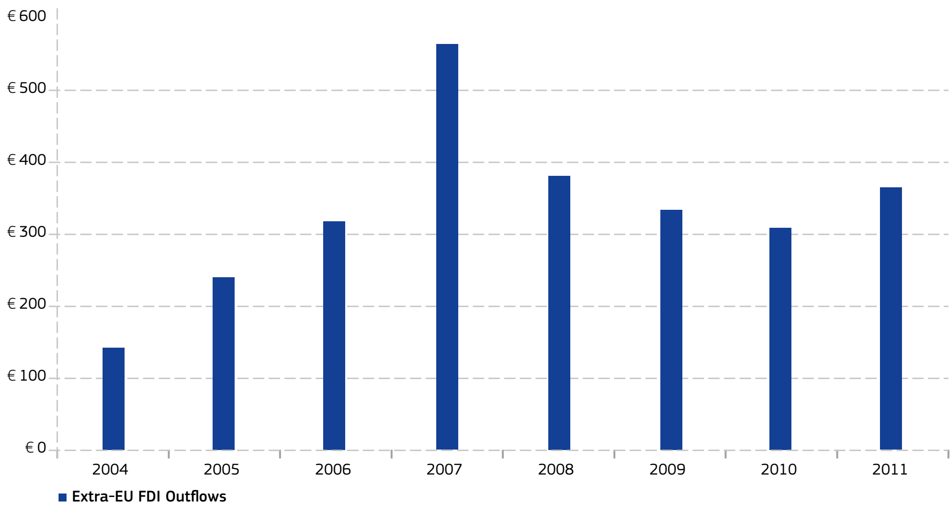
Source: DG Research and Innovation — Economic Analysis Unit.
Data: OECD, Eurostat.

This signals a shift from the traditionally perceived position of emerging countries as capital-receivers to one of investors, a change that does not seem to be intuitive. Indeed, emerging nations have served developed markets through exports by building on their low-cost competitive advantages. Thus the motives for establishing themselves in the developed world should be sought elsewhere. Looking at the recent take-over deals such as Geely (China) and Volvo (Sweden), Tata (India) and Corus (Netherlands/UK), etc. an increasing interest from emerging economies is seen in investments in technology and knowledge-intensive fields.

With the economic crisis, outward foreign direct investment flows of European firms have reached the level of FDI flows inside the European Union

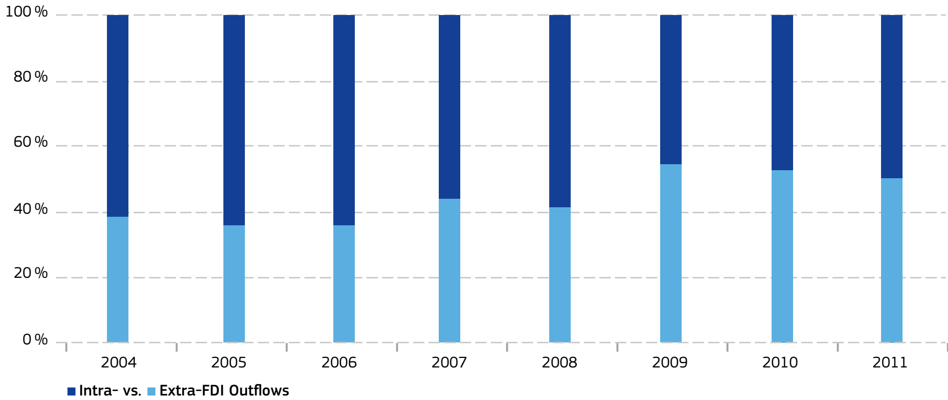
In 2008, FDI of EU firms fell sharply. Since then, there has been a progressive increase in FDI outflows both within the EU and to countries outside the EU. In 2011, the decreasing trend was reversed with extra-EU FDI outflows reaching € 365 billion. Although the level is far below the peak of 2007, outward direct investments have returned to their pre-crisis values. The intra-EU FDI outflows have been following a similar trend, however with a lag of one year, with the biggest decrease felt in 2009.

Figure 4: Foreign Direct Investments of European firms outside the EU



Source: DG Research and Innovation — Economic Analysis Unit.
Data: OECD, Eurostat.

Figure 5: Foreign Direct Investments inside the EU compared to extra-EU FDI outflows



Source: DG Research and Innovation — Economic Analysis Unit.
Data: OECD, Eurostat.

Traditionally, intra-EU FDI flows have been higher than extra-EU FDI outflows. This could easily be explained by the integration process amongst the EU countries and thus the reduced costs of access to markets, increased economies of scale and agglomeration benefits. However, a closer look at the share of intra versus extra-EU outward FDI flows reveals a gradual increase in the importance of extra-EU FDI outflows. For the first time in 2009, total extra-EU FDI was on par with total intra-EU FDI outflows.

This is clearly a reflection of the very strong internationalisation strategies of many EU firms, driven by the greater dynamics of markets outside Europe. Although the rising importance of certain developing nations as FDI destinations for European investors could be noticed even before the start of the crisis, the latter seems to have accelerated this trend and led to an increased importance of these countries as FDI destinations.

Investments in science and technology represent a very significant part of the foreign direct investments of EU firms

Investments in manufacturing activities for petroleum, chemical, pharmaceutical, rubber and plastic products still have the highest share of the EU outward investment flows. However, these are closely followed by investments in professional, scientific and technical activities (financial services are not taken into account). In 2010, the EU invested over €50 billion in professional, scientific and technical activities in extra-EU countries, which represented 17 % of all extra-EU FDI that year.

The internationalisation of the economy has moved to cover the higher end of the value chain, where the investment flows between the EU and US dominate

Globally, the internationalisation of business R&D is the result of relations between a small number of countries. Figure 7 below illustrates these relationships for the manufacturing sector of the EU, the US, Japan, China and Switzerland. The service sector is excluded due to missing data. The size of the pie chart for each country indicates the total amount of R&D expenditure of foreign-owned firms in this country, while the pie slices represent the R&D expenditures of foreign-owned firms from one particular country. The data presented illustrates the pre-crisis period.[6]

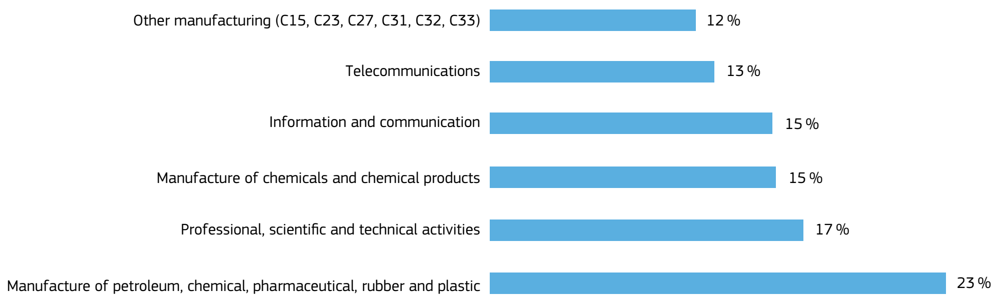
As for the investments in research and innovation, the figure below reveals the extreme importance of the relationship between the US and the EU. R&D expenditure of US firms in the EU and of EU firms in the US taken together account for 2/3 of R&D expenditure of foreign-owned firms in manufacturing worldwide.[7]

The US is also the largest investing country in the majority of the EU Member States. EU firms account for more than 65 % of the total manufacturing R&D expenditure of foreign-owned firms in the US, or more than 90 % once other European countries which are not members of the European Union (mainly Switzerland and Norway) are added. However, the figure also shows a deficit in the EU's R&D investment flows to the US.

6 'Internationalisation of business investments in R&D and analysis of their economic impact', Innovation Union Competitiveness paper 1/2012 http://ec.europa.eu/research/innovation-union/index_en.cfm?pg=other-studies
7 The European Union is considered as one entity, and intra-EU relationships (for example, R&D of German firms in France) are not taken into account.

Figure 6: Breakdown of Foreign Direct Investments by sector

% of all extra-EU NACE sectors



Source: DG Research and Innovation — Economic Analysis Unit.
Data: OECD, Eurostat.

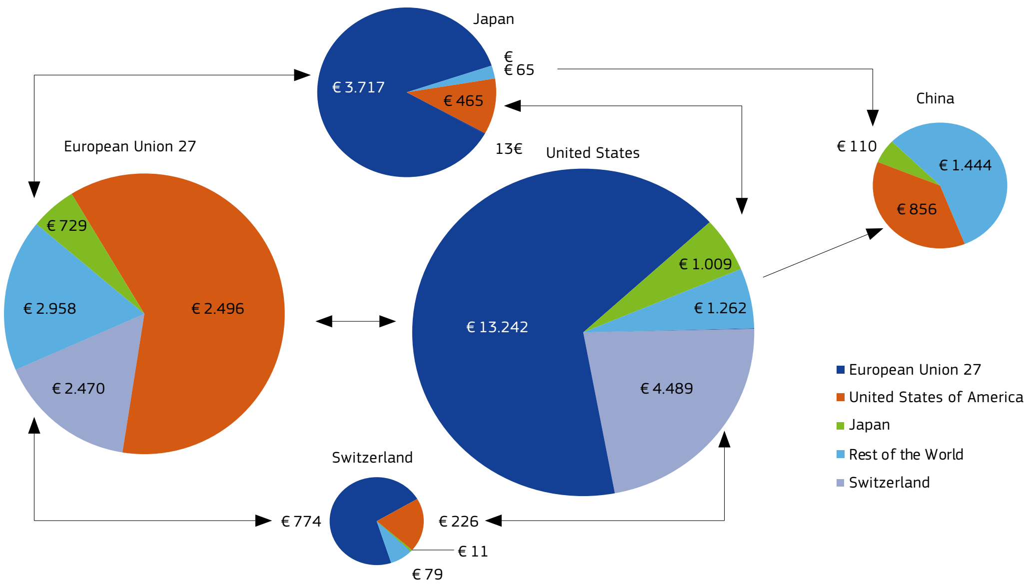
While EU firms invested € 13.2 billion in the US, the US firms invested only € 9.5 billion in the EU. Such a deficit of almost 40 % is a sign that the US is more attractive for R&D than the EU.

The EU remains an attractive place to perform R&D but Asia is rising and gaining ground

In recent years, China has emerged as a new location for R&D of foreign-owned firms. However, Chinese data is incomplete and has some methodological issues, which makes a comparison with data from OECD countries difficult. The R&D expenditure of wholly foreign-owned companies in China was € 2.4 billion in 2007. A breakdown of this amount into different countries of origin is not available.

In absolute terms, overseas R&D expenditure of US firms in the EU more than doubled between 1994 and 2008. However, the Asian countries' rise as R&D locations for US firms is leading to a shift in the distribution of US overseas R&D expenditure. The EU's share of US overseas R&D expenditure decreased from around 75 % in 1994 to around 60 % in 2008, with corresponding increases for Asian countries and non-European countries. Much of the decrease in the EU share occurred during the 1990s. From the early 2000s up until the crisis, the EU share has remained stable at around 60 %.

Figure 7: Overseas business R&D expenditure in manufacturing between the EU, the US, Japan, China and Switzerland, 2007 (in million euro)



Source: DG Research and Innovation — Economic Analysis Unit.
Data: OECD, Eurostat, National statistical offices, DG RTD study calculations.
Notes: 1) Firms from the European Union spent € 774 million on R&D in Switzerland in 2007; Swiss firms spent € 2.47 billion on R&D in the EU-27 in 2007.
2) Swiss data also includes the service sector; data for China is estimated based on national sources and US and Japanese outward data.

EU firms expect to further expand their worldwide R&D investments, impacting mainly the most knowledge-intensive Member States

Overall, businesses in the EU increased their expenditure on R&D as a share of GDP from 2007 (1.18 %) to 2011 (1.27 %). This is in part due to sustained R&D investment by European firms, which expect their worldwide investments in R&D to grow further by an average of 4 % annually over the period 2012–14.

Figure 8 below shows that this evolution affects mainly the knowledge-intensive Member States. The figure depicts the investments of R&D-intensive firms in absolute numbers as a share of total national R&D investments financed by businesses in absolute numbers. The numerator is based on firm-level data by headquarter and the denominator on national data (firms operating in the country independently of the location of their headquarter).[8] When a country has several large multinational corporations investing in R&D worldwide (in the country and abroad), these investments can be larger than the sum of R&D investments financed by the businesses registered in the country (BERD data). The values for the country in Figure 8 are in this case larger than 100. Given the methodological differences

Figure 8: Share (%) of Firm R&D investments in R&D financed by businesses (in brackets, number of firms in the population)

Shares of top companies' R&D investments compared to BERD

	2005	2006	2007	2008	2009	2010	2011
EU [(1)]	108.5 (1 000)	106.9 (1 000)	105.5 (1 000)	104.4 (1 000)	106.9 (1 000)	110.7 (1 000)	: (1 000)
BE	58.6 (37)	63.5 (33)	70.3 (40)	65.1 (39)	62.3 (40)	: (39)	: (34)
CZ	1.7 (2)	5.2 (4)	7.8 (4)	2.1 (1)	3.0 (2)	8.8 (3)	6.3 (2)
DK	72.0 (37)	: (38)	82.8 (42)	84.5 (47)	85.9 (46)	93.3 (45)	73.8 (35)
DE	108.1 (167)	107.6 (167)	105.6 (189)	106.8 (209)	105.6 (206)	110.2 (206)	88.0 (235)
IE	34.6 (12)	39.0 (12)	37.2 (11)	42.7 (12)	100.0 (16)	156.6 (17)	208.3 (14)
EL	17.8 (6)	: (3)	20.5 (5)	: (4)	: (5)	: (5)	: (1)
ES	26.8 (22)	25.9 (23)	23.9 (21)	24.1 (21)	50.5 (27)	62.5 (25)	: (22)
FR	117.3 (112)	120.9 (114)	128.0 (113)	127.5 (125)	113.5 (116)	111.9 (125)	: (126)
IT	76.6 (40)	75.1 (48)	73.7 (51)	77.4 (57)	77.6 (53)	80:1 (54)	: (50)
LU	81.9 (6)	: (5)	128.5 (6)	: (10)	138.7 (8)	225.9 (9)	175.7 (13)
NL	207.6 (44)	: (50)	199.0 (49)	: (53)	242.3 (52)	: (54)	: (52)
AT	: (28)	18.3 (31)	18.6 (30)	: (32)	22.5 (31)	: (29)	: (27)
PL	5.1 (2)	7.4 (2)	12.1 (4)	: (6)	12.7 (5)	18.1 (7)	1.7 (2)
PT	3.6 (2)	.6 (1)	7.6 (3)	12.5 (4)	33.2 (8)	27.1 (6)	: (6)
SI	19.4 (1)	21.4 (2)	23.9 (2)	24.7 (2)	26.3 (2)	24.5 (2)	19.2 (2)
FI	148.7 (70)	136.5 (67)	164.4 (60)	145.5 (58)	143.0 (56)	140.5 (52)	136.1 (46)
SE	103.2 (81)	: (75)	107.6 (78)	: (70)	107.7 (76)	: (74)	121.5 (85)
UK	170.5 (327)	160.9 (321)	134.5 (289)	141.3 (247)	162.2 (246)	171.3 (244)	189.8 (247)
IS	30.5 (1)	25.3 (1)	20.2 (1)	29.9 (1)	37.5 (1)	: (1)	: (1)
NO	25.3 (5)	30.3 (7)	34.2 (8)	32.8 (9)	44.0 (11)	42.8 (9)	: (9)
CH	: (37)	: (39)	: (42)	255.7 (38)	: (38)	: (40)	: (40)
TR	9.0 (1)	11.3 (2)	8.1 (3)	13.8 (2)	22.1 (3)	15.6 (4)	: (5)

Source: DG Research and Innovation — Economic Analysis Unit.
Data: Eurostat, OECD, EU R&D industrial scoreboard.
Notes: (1) EU average does not include Croatia.

8 For a more extensive methodological note, explaining the differences between BERD and Industrial Scoreboard datasets, see Azagra-Caro, J. and Grablowitz, A., 2008.

between the two data sets, these shares are only proxies of the extent to which a country is affected by the internationalisation of business R&D investments. The number of firms in each country is indicated in brackets.

Figure 8 shows that it is mainly knowledge-intensive countries which are most affected by the internationalisation of business R&D. Switzerland has the highest ratio, followed by the Netherlands, Ireland, the United Kingdom, Finland and Sweden. Germany and France are also affected, but in these countries, business R&D investments in the country seem to have grown more than French and German firms' worldwide R&D investments. The data for the United Kingdom is particularly interesting, since the overall R&D intensity in the country is much lower than in other EU Member States. The table seems to indicate that British businesses do indeed invest considerably in R&D but on a worldwide scale.

2. Technology profiles of the world's major knowledge centres

With the globalisation of investment in research and innovation, different locations compete to attract investments but also to develop new and innovative products and services for the global market. The competitive position of Europe depends in this context not only on its accumulated knowledge assets overall but also on its relative technology profile being relevant for emerging world growth markets. The EU has broadly maintained its dynamics in technology production, even surpassing the US following the economic crisis. Technology production in the US, when measured in PCT patent applications, was more heavily affected by the economic crisis, although there has also been a clear recovery trend since 2010. Even though both the EU and the US have increased their PCT patent applications, the main change over the last decade has been in Asia, with the continued rise of Japan and South Korea and the acceleration of China's growth from 2009 onwards. Figure 9 shows this evolution by thematic sectors. World technology production is divided into the three major blocks of countries: the EU, North America (including the US and Canada) and Asia (including Japan, China and South Korea). The table breaks down PCT applications by sector in terms of world share, absolute numbers and change over time (2008 is the latest available year for full counting of sector-specific PCT data).

Technology-intensive countries in North America and Asia are more strategic than the EU, focusing on key enabling technologies and transformative technologies linked to societal challenges

Figure 9 presents a very tight and even distribution of strengths in several technology areas, following the clear rise of Asia in all of them. Consistent with the findings from Figure 1, it has been mainly North America that has lost its share and Asia that has gained. The EU has in broad terms kept its world technology share in most areas.

However, the table below also shows clear differences in technology profiles between the three major blocks of countries. Countries in North America and Asia seem to be more strategic and selective in their approach, focusing technology development on key enabling technologies and transformative technologies linked to societal challenges. This is particularly true when considering the potential of converging technologies, a necessary step in addressing more comprehensive societal challenges. North America, headed by the US, stands out in technologies for health, biotechnology, energy, nanotechnology and security; Asia is taking the lead in ICT (partly linked to FDI) and has reached a technology position on par with the Western blocks in green energy, environmental technologies, materials and space. For the EU's transformative capacity, the only clear exception is environmental technologies, green energy and materials, where the EU was the world leader in 2008. This could be explained by the fact that Europe, in comparison to the US and certain countries in Asia, has less traditional energy resources and has thus focused on developing alternatives. As highlighted by Porter, the developments in the industry could be attributed to the existing factor conditions and focused policies.

These sectors, coupled with the EU's lead in construction technologies, provide a strong foothold for converging technologies for sustainable buildings and cities (see more in section 4). However, Asia is catching up rapidly in these fields as well as in automobiles and other transport technologies. The EU presents a broader but less specialised technology profile, keeping its strengths in more traditional and established industry sectors (transport, construction, food and agriculture). However, with the rise of Asia, the EU is also losing world share in these sectors.

Figure 9: PCT applications, world share; absolute numbers in major world regions (world leaders in bold)

	EU-27		North America		Asia	
	2000	2008	2000	2008	2000	2008
Health	32.7 % 6015	30.9 % 7207	49.4 % 9068	**47.9 %** 11172	14.5 % 2661	17.3 % 4035
Biotechnology	28.0 % 2787	32.0 % 2415	49.0 % 4885	**44.4 %** 3346	20.7 % 2068	20.8 % 1566
ICT	37.7 % 8354	25.8 % 9960	40.0 % 8864	35.0 % 13486	20.5 % 4552	**37.9 %** 14613
Energy	29.8 % 1624	31.6 % 1744	48.2 % 2467	**46.9 %** 2591	19.7 % 1007	19.2 % 1059
Green energy	32.7 % 3196	**33.3 %** 3806	43.6 % 4258	32.5 % 3687	21.2 % 2075	31.7 % 3624
Environment	34.7 % 3970	**34.5 %** 4839	42.0 % 4815	31.8 % 4456	20.8 % 2386	31.1 % 4363
Nanotechnology	31.5 % 256	34.1 % 478	45.6 % 371	**37.0 %** 552	19.8 % 161	26.5 % 389
Materials	41.7 % 7091	**35.5 %** 8070	34.4 % 5850	29.4 % 6691	21.0 % 3566	32.1 % 7296
New Prod. techn.	36.0 % 4978	**36.8 %** 5664	45.1 % 6236	36.33 % 5596	15.8 % 2185	23.8 % 3670
Security	38.7 % 2200	34.8 % 2934	45.5 % 2585	**37.6 %** 3171	12.6 % 717	24.9 % 2098
Automobiles	60.0 % 1642	**50.2 %** 2213	24.5 % 670	17.3 % 763	14.3 % 391	31.2 % 1378
Other Transport	58.0 % 449	**47.5 %** 625	25.6 % 198	22.3 % 294	9.8 % 76	24.2 % 318
Aeronautics	42.8 % 112	**65.7 %** 460	50.0 % 131	26.7 % 187	5.0 % 13	6.1 % 43
Space	27.7 % 28	**35.4 %** 28	50.5 % 51	34.2 % 27	18.8 % 19	30.4 % 24
Construction	54.8 % 1532	**44.2 %** 2183	28.2 % 787	35.6 % 1757	11.0 % 307	15.4 % 759
Food, Agriculture, Fishery	43.4 % 1641	**36.8 %** 1902	36.0 % 1362	37.7 % 1949	15.4 % 582	21.1 % 1091

Source: DG Research and Innovation — Economic Analysis Unit.

Data: WIPO PCT applications; data processed by the University of Bocconi, Italy.

Economic transformation addressing societal challenges may come from Asia

Figures 10 and 11 below highlight the accelerating progress of Asia in transformative technologies linked to major societal challenges and expanding world markets. Contrasting with the slow move from the traditional technology leaders of the US and the EU, the figures below outline a major geographic strategic shift in the world's knowledge economy in the decade to come.

Figure 12 presents a further step in disaggregation, in this case in the field of energy. It focuses on sub-sectors in the field of renewable energy. The trend of an increasing world technology share of Asian economies is also clear at this level. Already in 2008, Asia took the world lead in technology development for energy efficiency and it also had a very comparable level of technology production in solar energy.

The strengths of the EU are in recycling and waste, wind energy, geothermal energy, solar energy development and more broadly in environmental technologies (although Asia has most probably taken the lead in this field considering the evolution illustrated in Figure 11). The US holds the lead in technology development for biofuels.

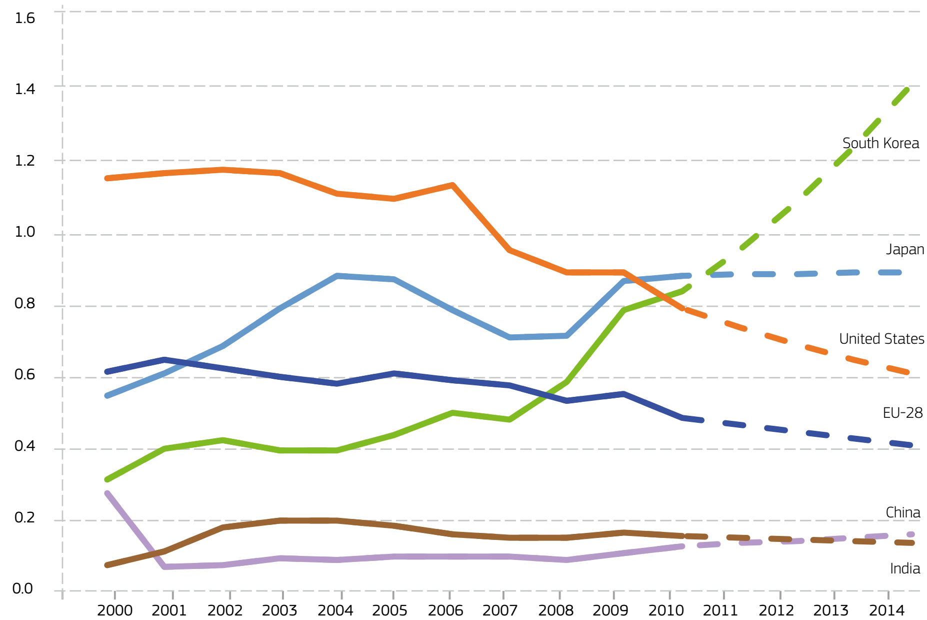
The US and Asia are specialised in transformative and pervasive technologies while the EU's technology development is specialised in its established industries

The previous analysis of the EU's scientific production revealed a mismatch between the specialisation and the quality and relative world strength. The major technological areas of specialisation and de-specialisation of Europe can be illustrated by the Revealed Technological Advantage, which compares the relative importance of a given technological area in all patent production in Europe[9] to the relative importance of this technological area in all patent production worldwide.[10] Figure 13 below provides an overview of the technology specialisation (RTA index) of the EU, the US and the major Asian technology powers. The arrows indicate the trend over the period 2000–10 and the green colours technology areas of specialisation.

The broad diversification of the EU's technology profile contrasts with the highly specialised technology profile of the Asian countries. The US is in an intermediate position. The EU is characterised by its technology specialisation in established industries, such as aeronautics, automobiles,

Figure 10: PCT patent applications addressing societal challenges — Health

Health related technologies — PCT patent applications (1) per billion GDP (PPS€), 2000-14 (2)

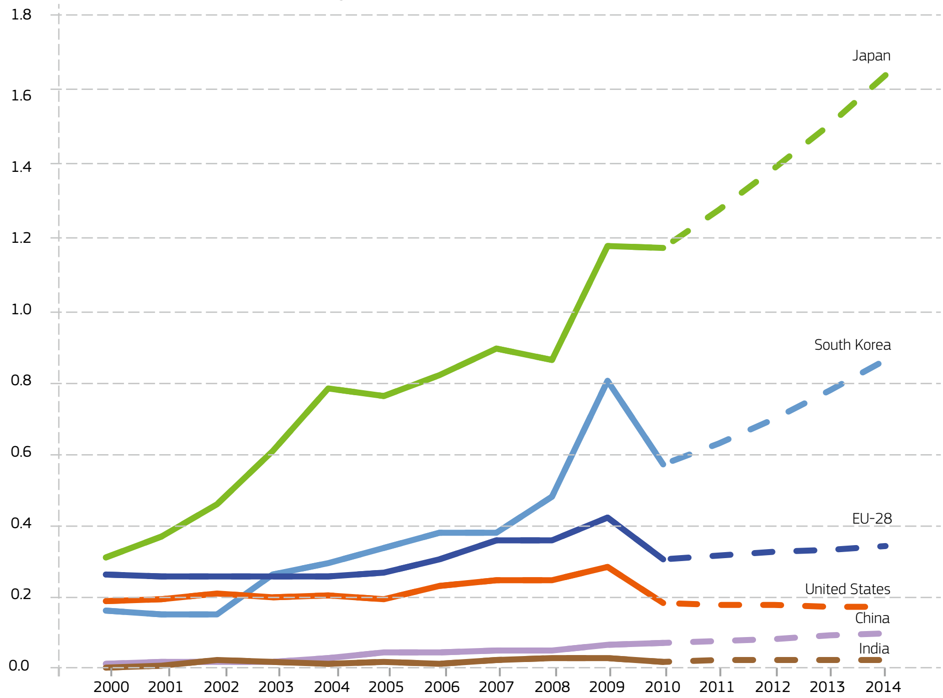


Source: DG Research and Innovation — Economic Analysis Unit.
Data: Eurostat, DG ECFIN, OECD.
Notes: (1) Patent applications under the PCT (Patent Cooperation Treaty), at international phase, designating the EPO by country of residence of the inventor(s).
(2) The estimation for the period 2011-14 is based on the annual average growth rate calculated for the period 2005-10.

9 EU and Associated Countries.
10 Four patent systems are considered: EPO patent applications, USPTO grants, PCT patent applications and triadic patents.

Figure 11: PCT patent applications addressing societal challenges — Environment

Environment-related technologies — PCT patent applications [1] per billion GDP (PPS€), 2000-14 [2]



Source: DG Research and Innovation — Economic Analysis Unit.
Data: Eurostat, DG ECFIN, OECD.
Notes: (1) Patent applications under the PCT (Patent Cooperation Treaty), at international phase, designating the EPO by country of residence of the inventor(s).
(2) The estimation for the period 2011-14 is based on the annual average growth rate calculated for the period 2005-10.

Figure 12: Renewable energy in world regions (world share of PCT patents; absolute numbers)

	EU-27		North America		Asia	
	2000	2008	2000	2008	2000	2008
Biofuels	27.1 % 1 809	29.3 % 1 111	50.1 % 3 344	**42.7 %** 1 621	20.7 % 1 379	26.3 % 997
Recycling & Waste	45.7 % 966	**40.0 %** 1 336	33.2 % 711	30.4 % 1 015	19.3 % 414	27.3 % 912
Energy efficiency	46.8 % 553	32.6 % 960	28.8 % 340	24.3 % 715	21.2 % 251	**40.1 %** 1 179
Solar energy	44.2 % 303	**33.0 %** 816	28.1 % 193	33.0 % 814	24.8 % 170	30.2 % 745
Wind energy	62.0 % 124	**52.1 %** 399	21.5 % 43	21.7 % 166	6.5 % 13	21.2 % 162
Geothermal energy	38.3 % 49	**36.8 %** 105	30.5 % 39	27.7 % 79	25.0 % 32	29.8 % 85
Environment	34.7 % 3 970	**34.5 %** 4 839	42.0 % 4 815	31.8 % 4 456	19.8 % 2 386	26.5 % 4 363

Source: DG Research and Innovation — Economic Analysis Unit.
Data: WIPO PCT applications; data processed by the University of Bocconi, Italy.

other transport technologies and construction technologies. The specialisation profile in the US and even more so Asia is quite the opposite. They have a much clearer specialisation profile in transformative and pervasive technologies. The US is positioning itself in health, biotechnology and nanotechnologies, while Asia has already achieved revealed technological advantage in ICT, nanotechnologies, materials, energy and environment technologies. Overall, Asia is expanding its relative specialisation in all technology areas.

Figure 13: RTA index, WIPO by applicants, 2000–10

Thematic priority	EU-27	US	ASIA
Health	0.9 ↓	1.25 ↑	0.61 ↑
Biotechnology	0.94 ↑	1.20 ↓	0.71 ↑
ICT	0.84 ↓	1.04 ↓	1.29 ↑
Energy	1.15 ↓	0.74 ↓	1.22 ↑
Environment	1.04 ↓	0.88 ↓	1.15 ↑
Nanotechnologies	0.83 ↓	1.16 ↓	1.07 ↑
Materials	1.05 ↓	0.86 ↓	1.16 ↑
New Production techn.	1.02 ↑	1.10 ↓	0.78 ↑
Security	0.97 ↓	1.09 ↓	0.81 ↑
Automobiles	1.59 ↑	0.54 ↓	0.96 ↑
Other Transport techn.	1.45 ↓	0.70 ↑	0.69 ↑
Aeronautics	1.52 ↑	1.03 ↓	0.21 ↑
Space	1.02 ↑	1.25 ↓	0.64 ↑
Construction technologies	1.40 ↓	0.82 ↑	0.53 ↑
Food and Agriculture	1.12 ↓	0.91 ↑	0.81 ↑

Source: DG Research and Innovation — Economic Analysis Unit.
Data: WIPO PCT applications; data processed by the University of Bocconi, Italy.

The EU is not focusing on these transformative technologies. The trend of the EU is to reinforce technologies in its established transport and production sectors while it loses ground in all areas of transformative and pervasive technologies, including technologies addressing societal challenges, which have a potential for transformative structural change.

The EU's technology specialisation is well matched with its technology strengths

Comparing the EU's specialisation profile with its technology strengths at the world level, there is higher matching than for its scientific production profile. The specialisation in transport and construction reflects the technology areas where the EU has the largest world share of PCT patent applications. At the other end of the scale, the lower and falling world technology shares in health and ICT match the low and decreasing RTA index for these areas. Only in a few technology areas does the EU present a mismatch between its world position and its specialisation efforts. The lower and decreasing specialisation in energy, environment and materials may in the medium term endanger the EU's world technology lead in these areas, if not already (the latest patent statistics are only up to 2008). This would also create a mismatch between the EU's scientific strengths in these areas and its technology position.

3. Potential of European cooperation in converging technologies for emerging growth markets

Technology development is an important part of the supply side of innovation potential. A more strategic focus of supply measures for technology relevant for growth markets has strong potential to foster high-growth innovative enterprises if this supply is combined with demand-side measures and more general framework conditions for firm growth and entrepreneurship. Innovative firms operating in emerging growth markets benefit from first-mover advantages and growth potential as advanced followers or adapters.

The competitive advantage of a country depends in the end on the strengths and interaction of knowledge supply, home demand, firm strategies, competition, related industries, and their interaction. Advanced and sophisticated home demand is emphasised by Porter as an important factor for raising the national competitive advantage.[11] The existence of 'sophisticated' home consumers ultimately drives demand-side innovation as companies are forced to satisfy their needs to remain competitive.

In 2005, a high-level European expert group revisited and extended Porter's concept of lead markets. The geographical focus of sophisticated home markets was extended to the potential of the European single market and oriented towards a thematic approach identifying emerging global markets. The plea was for a bolder innovation policy combining supply and demand measures in growing business areas combining a large share of GDP with direct impact on the daily life of citizens.[12] The combination of supply- and demand-side measures in a single intervention can be more effective than one-sided policy measures as it ensures early technology adoption with large export potential. However, there is little empirical evidence of such initiatives in EU Member States, as market interventions are more risky and complex for policy makers.[13]

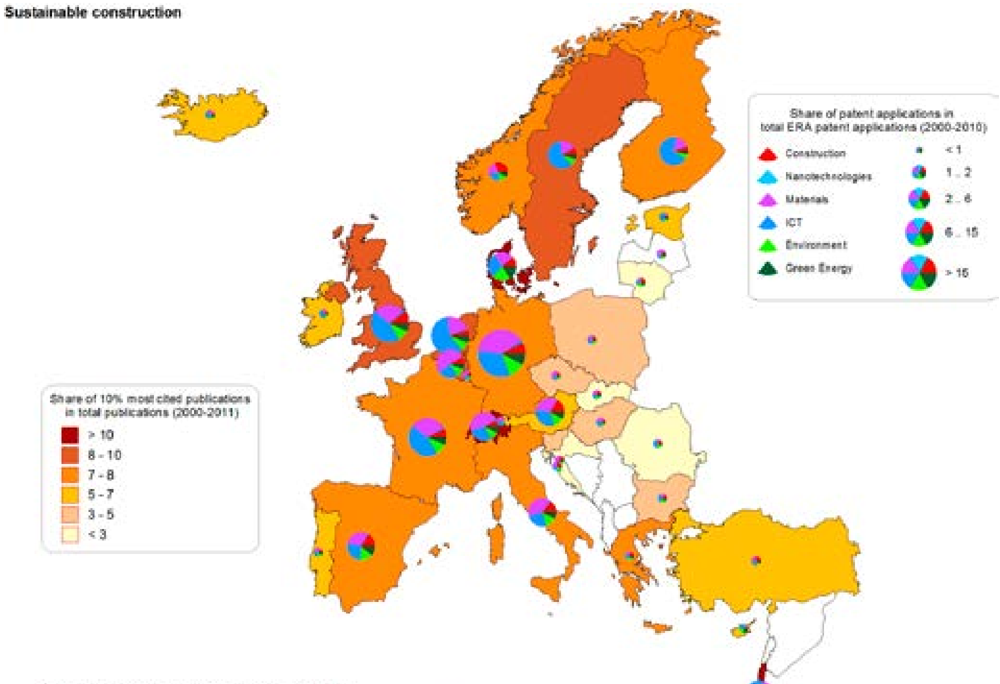
The following analysis of the technology supply illustrates some areas possibly linked to emerging growth markets: sustainable construction, clean transport and innovative medicine. The purpose of the analysis is to assess strengths in converging technologies inside Europe and the potential of using intra-European collaboration in networked specialisation benefitting from related variety.

Foresight studies have pointed at accelerating urbanisation, climate change and resource scarcity.[14] This evolution is forecast to raise global demand in more sustainable cities. A simultaneous and coordinated push of supply- and demand-side measures for innovative goods and services in sustainable construction has large potential for high-growth innovative enterprises in Europe. The construction sector is one of the largest manufacturing sectors in Europe and it has managed to update its R&D intensity over the last decade. Sustainable construction is the development of new solutions addressing the design and management of buildings for innovative use of resources (energy, materials, water and land use) and renewable energy for heating and cooling integrated in ICT-based management systems. Residential, non-residential and infrastructure construction are to be upgraded, pushed by demand-side measures such as standards, regulation for energy efficiency, impact on the environment, water and health, public procurement of construction and market mechanisms.[15] On the supply side, initiatives at the EU level include the public private partnership on energy-efficient buildings, the SET plan for renewable energy and smart grids, and funding to secure clean and efficient energy and to support climate action in Horizon 2020.

Figure 9 and the previous analysis reveal that the EU has a strong world position in several technologies relevant for sustainable construction. The maps below (Figures 14 and 15) provide an overview of the strengths and specialisation of individual European countries in technology and science relevant for integrated solutions for sustainable construction. Construction technologies can be integrated with S&T strengths in green energy, the environment, ICT, materials and nanotechnologies. Countries with the right mix of science and technology strengths are better positioned to take up the market opportunities in sustainable construction fostering high-growth innovative enterprises; countries with a specialisation in one or several key areas complementing the design of innovative goods and services have a clear value added to be integrated in specialised knowledge flows and value chains. The European Research Area and the knowledge dimension of the single market can facilitate this integration in networked specialisation strategies, therefore avoiding sub-criticality.[16]

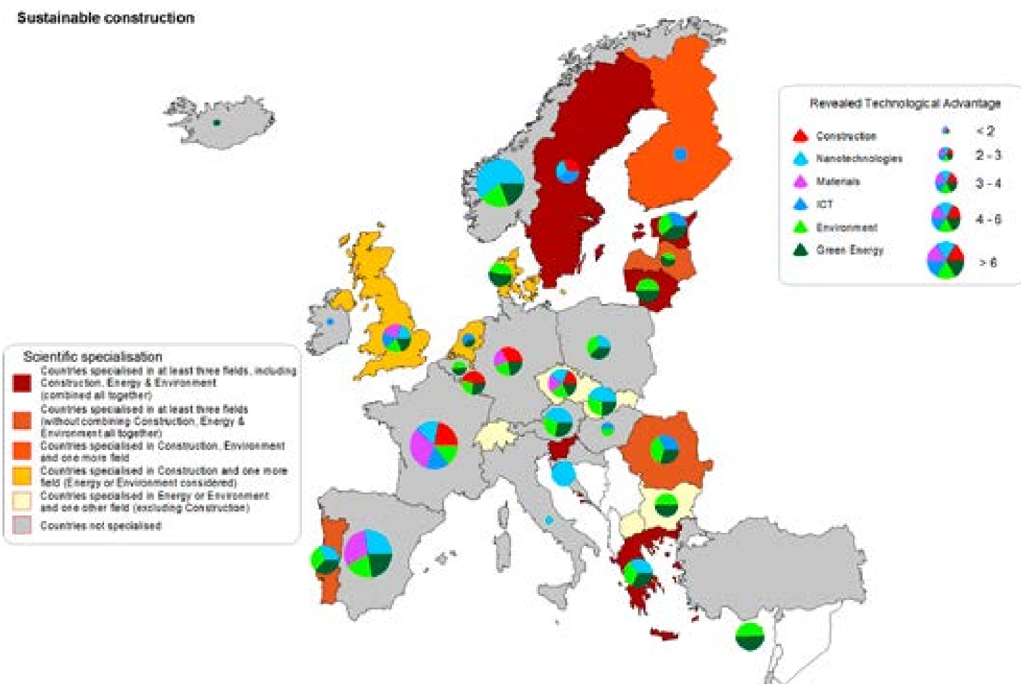
11 Porter, 1990.
12 'Creating an innovative Europe', report of an independent expert group chaired by Mr Esko Aho.
13 Tsipouri, L. Paper presented at the European Commission Mutual Learning seminar, 2012.
14 Expert group report to the European Commission, 2009, 'Le Monde en 2025. La montée en puissance de l'Asie et la transition socio-écologique'.
15 Expert group report to the European Commission, 2007, report of the taskforce on sustainable construction.
16 Expert group report to the European Commission, 2008, 'Challenging Europe's Research: Rationales for the European Research Area (ERA)'.

Figure 14: Sustainable construction — strengths (share of S&T in ERA), 2000–11



Source: DG Research and Innovation - Economic Analysis unit
Data: Science Metrix – Canada, based on Scopus data; Univ. Bocconi - Italy, based on WIPO-PCT applications
Notes: Thematic priorities with fewer than 5 patent applications over 2000-2010 are not displayed on the map.
Thematic priorities with fewer than 10 citations over 2000-2011 are not included in the calculations.

Figure 15: Sustainable construction — relevant specialisation of European countries



Source: DG Research and Innovation - Economic Analysis unit
Data: Science Metrix – Canada, based on Scopus data; Univ. Bocconi - Italy, based on WIPO-PCT applications
Note: The RTA value is calculated based on ERA countries only.
Thematic priorities with fewer than 5 patent applications over 2000-2010 are not displayed on the map.

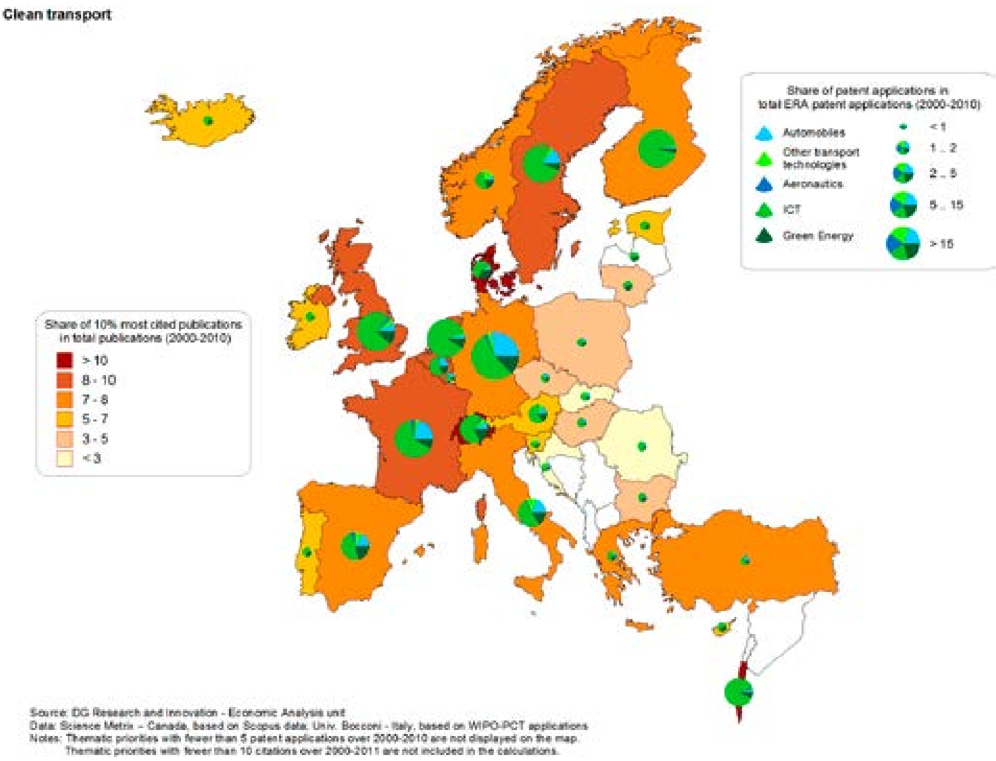
Figure 14 depicts a distribution of Europe's capacity for innovation in sustainable construction. Germany has a leading potential to converge technologies for construction, green energy, the environment and materials. Important technology potential can also be found in smaller countries, such as the Netherlands, Denmark, Switzerland, Sweden and Israel, all countries where the technology strengths are backed by strengths in the relevant science areas.

Figure 15 reveals potential for technology network links with Spain and Norway and scientific cooperation with Estonia, Lithuania, Slovenia, Greece, Portugal, Romania and Latvia. The Czech Republic presents a particularly relevant and broad science and technology profile covering a large range of technologies backed by focused scientific specialisation.

Another related growth market inside the overall solution for sustainable cities is clean transport. The EU produces around 20 million vehicles a year, employing more than 12 million Europeans directly or indirectly. The industry invests around 4 % of its revenues in R&D.[17] The cars Europeans drive are also responsible for 12 % of the EU's collective carbon footprint, and between 1990 and 2004 the CO_2 emissions from road transport increased by 26 %. Supply-side measures for R&D, such as the European green cars public private partnership, are combined with demand-side measures such as stricter EU regulations on passenger cars' CO_2 emissions.

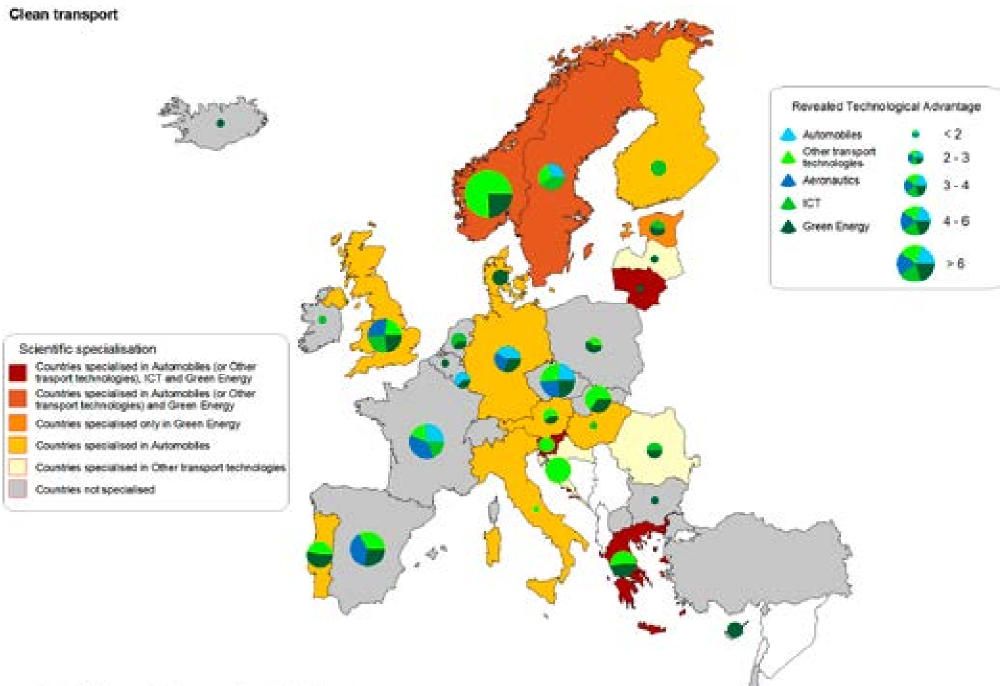
Figure 16 illustrates the science and technology strengths in areas related to clean transport, in particular combining capacities in automobiles, trucks and other transport technologies with strengths in green energy (electric and hybrid engines as well as second-generation biofuels). ICT as an enabling technology is also important for smart electricity grids and intelligent vehicle charging systems.[18] The aeronautic sector is also included, given the EU Joint Technology Initiative on Clean Sky aviation. However, in this field it is important to remember that many components in the value chain of airplanes are categorised under other transport technologies.

Figure 16: Clean transport — strengths (share of S&T in ERA), 2000–11



17 According to the European Automobile Manufacturers' Association (ACEA).
18 European Commission, Green Cars Initiative, http://ec.europa.eu/research/transport/road/green_cars/index_en.htm

Figure 17: Clean transport — relevant specialisation of European countries, 2000–11



Source: DG Research and Innovation - Economic Analysis unit
Data: Science Metrix – Canada, based on Scopus data; Univ. Bocconi - Italy, based on WIPO-PCT applications
Note: The RTA value is calculated based on ERA countries only.
Thematic priorities with less than 5 patent applications over 2000-2010 are not displayed on the map.

Building upon the technological profiles of countries in the EU opens the door to opportunities for network specialisation. Figure 16 shows that major centres for innovative combinations can be found in Germany, France and Sweden, where automobile and transport sectors are present together with capacity in green technology development and ICT. Switzerland, the United Kingdom and Denmark are also potential supply leaders for this emerging growth market since they combine technology capacity with a strong science base relevant for clean transport. Spain and Italy have technology profiles with large absorptive capacity converging transport and green energy technologies, and in the case of Spain this is also clearly reflected in their specialisation profile.

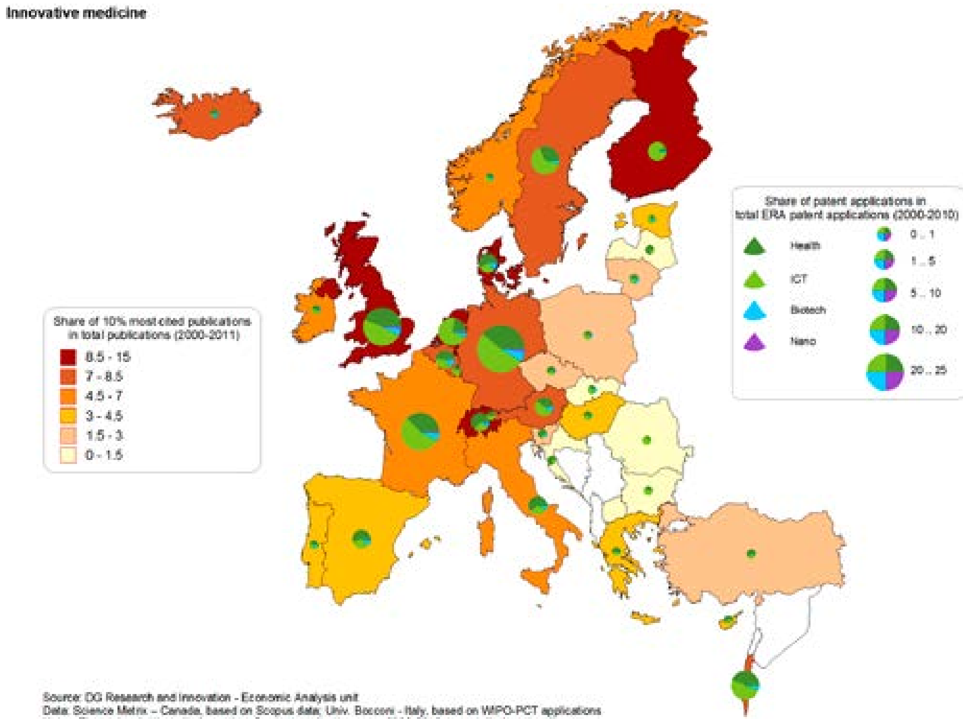
Figure 17 reveals that there are large opportunities for networked technology collaboration with Norway, combining specialisation in both green energy and other transport technologies. Scientific networking can also benefit from closer links with Lithuania, Slovenia and Greece, all with a parallel scientific specialisation in several fields relevant for clean transport. Estonia, with its clear specialisation in green energy, has potential to link into networked collaboration with the clean transport technology centres in Scandinavian countries and Germany. Germany notably has a lower level of specialisation in areas related to clean energy, while other European countries can complement efforts to further develop the joint objective inside the European Research Area.

While the US leads in most technologies relevant for health, Europe has potential to couple the determined matching of supply and demand with networked specialisation

The demographic evolution in developed economies is leading to an ageing population, with public health systems under increasing cost pressure. Europe is experiencing this growing demand particularly strongly, and therefore has large potential for 'lead users' reflecting increasing global market demand.[19] Figures 18 and 19 illustrate the strengths and specialisation profiles of European countries in technology and science relevant for the challenge of innovative medicine. Innovative medicine addresses key areas, including

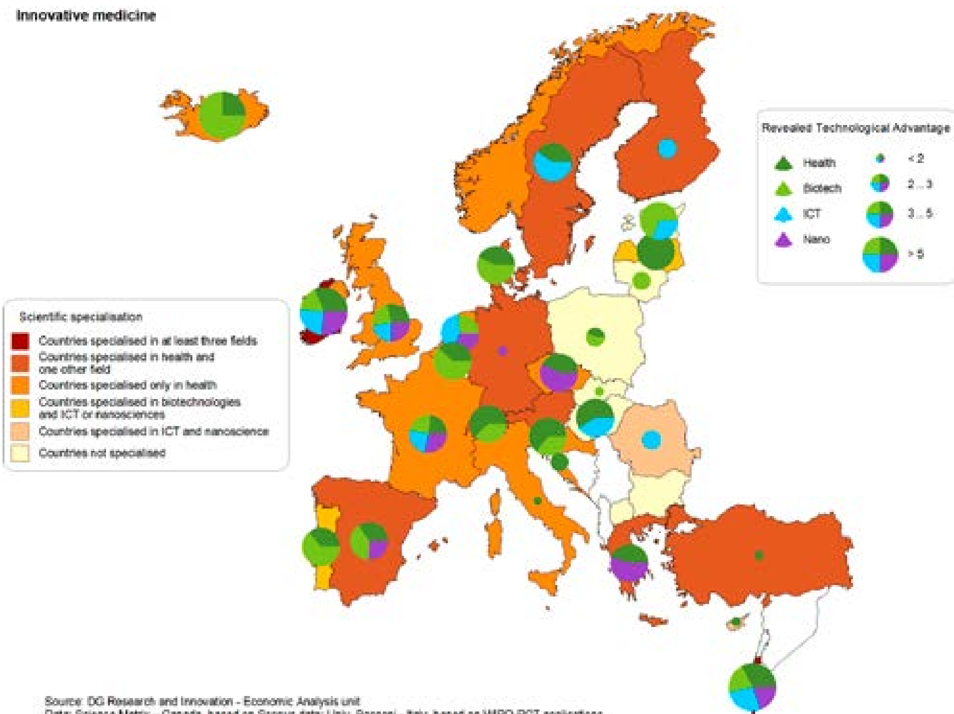
19 See the report of the independent expert group on R&D and Innovation chaired by Mr Esko Aho, 'Creating an Innovative Europe', 2005.

Figure 18: Innovative medicine — strengths (share of S&T in ERA), 2000–10



Source: DG Research and Innovation - Economic Analysis unit
Data: Science Metrix – Canada, based on Scopus data; Univ. Bocconi - Italy, based on WIPO-PCT applications
Notes: Thematic priorities with fewer than 5 patent applications over 2000-2010 are not displayed on the map.
Thematic priorities with fewer than 10 citations over 2000-2011 are not included in the calculations.

Figure 19: Innovation medicine — relevant specialisation of European countries



Source: DG Research and Innovation - Economic Analysis unit
Data: Science Metrix – Canada, based on Scopus data; Univ. Bocconi - Italy, based on WIPO-PCT applications
Note: The RTA value is calculated based on ERA countries only.
Thematic priorities with fewer than 5 patent applications over 2000-2010 are not displayed on the map.

cancer, immune-mediated diseases, infectious disorders and treatment through electronic health. This innovation challenge concerns principally science and technology in health and biotechnology, but their convergence with ICT and nanotechnologies also has large potential for innovative products. Figure 18 shows that Germany, the United Kingdom, France, Sweden and the Netherlands have relatively extensive technology development in all of these fields, while the United Kingdom and the Netherlands are also strongly backed by high-quality scientific research in most or all of these fields. Germany and Sweden also have strong scientific backing and would have additional scientific strengths cooperating with neighbouring countries such as Denmark and Finland, or Switzerland, Belgium and Austria.

Considering the potential for technology collaboration and networked specialisation within the European Research Area, Figure 19 identifies highly relevant technological specialisation in Estonia, Latvia and Iceland, but also in Ireland, Israel, Slovakia and Belgium (specialised in health and biotechnologies). The possibilities for scientific cooperation with other European countries addressing comprehensive solutions for innovative medicine is even broader, with Ireland and Belgium standing out. Other possible cooperation partners include Spain and Greece with a health research profile, and Portugal and Latvia with biotechnologies combined with nanotechnology specialisation. There are also many other interesting and potential cooperation partners for the S&T centres in these areas.

CONCLUSIONS

This article sets out to assess the technology profile of Europe in the context of increasingly tough international competition and fungible R&D investment moving from one country to another, depending on market opportunities and specific knowledge assets. Knowledge is increasingly important for the production of goods and services and this knowledge is becoming more widely distributed geographically. FDI flows and production organised around global value chains establish knowledge centres in relation to each other for collaboration in related fields, but also for competition in terms of attractiveness and specialisation profile. In this context, Europe is maintaining its strengths as a world centre of knowledge production. However, Asian economies are growing very swiftly and have already overtaken the technology lead of Europe and the US in certain sectors.

The analysis has also showed that technology-intensive countries in North America and Asia are more strategic than the EU, with a better focus on key enabling technologies and transformative technologies linked to societal challenges. The US stands out in technologies for health, biotechnology, energy, nanotechnology and security, while Asian economies have taken the lead in ICT and reached a technology position on par with the Western block in green energy, environmental technologies, materials and space. The EU presents a broader but less specialised technology profile, keeping its strengths in established industry sectors such as transport, construction, food and agriculture. The EU's specialisation profile matches its technology strengths well. This contrasts with the highly specialised technology profile of the Asian countries. The US is in an intermediate position. The specialisation profile in both Asia and the US is more focused on transformative and pervasive technologies. The US is specialised in health, biotechnology, nanotechnologies and space, while the Asian economies are specialised in ICT, energy and the environment.

However, Europe has the potential to strengthen its competitive position in these converging technologies relevant for societal challenges and emerging growth markets. Building on the European Research Area and the single market, there is large collaboration potential in key growth areas, such as sustainable construction, clean transport and innovative medicine. The cross-border technology drive inside Europe is in the hands of certain Western Europe countries which also have advanced framework conditions for innovation. However, many related technologies, as well as science, can be explored through collaboration with other European countries, including several countries in the Eastern and Southern part of Europe.

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This article analyses Europe's competitive technology profile in the context of a globalised knowledge economy and increasingly tougher world competition for the upper end of the global value chains. More geographically distributed world knowledge coupled with increasing international flows of foreign direct investment is pushing countries to think more strategically about their technology profiles. This is particularly the case when addressing comprehensive global societal challenges, which require converging technologies. A strategic supply of converging technologies relevant for emerging growth markets provides a strong supply position, which must be matched with a parallel development of advanced home demand. The article presents Europe's competitive position in the globalisation of knowledge and investment flows as background to a more detailed analysis of Europe's technology profile. A general conclusion is that while Europe remains an inevitable knowledge centre of the world, its technology profile is less strategic than its main competitors and less oriented towards converging technologies relevant for addressing societal challenges and emerging global growth markets. The analysis shows that Europe's competitive position could be strengthened through a more determined orientation of its technology development coupled with reinvigorated intra-European cooperation using the potential of networked specialisation.

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