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Comparative Scoreboard and Performance Indicators in NMP

Research Activities between the EU and Third Countries

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EXECUTIVE SUMMARY

This document is the final report of the study "Comparative Scoreboard and Performance Indicators in NMP (Nanotechnology and nanosciences, knowledge-based multifunctional Materials, and new Production processes and devices) Research Activities between the European Union (EU) and Third countries".

The study aims to compare, assess and monitor the progress of European NMP research vis-à-vis Third countries (Associated States and other Third countries), and establish the position of the EU in the international context, in the fields of NMP research and its industrial applications, to support policy making.

The specific objectives of the study are to:
- Identify, compare and assess the NMP research portfolios at the EU Member State and key Third country (involved or not in FP7) level;
- Map the different main areas, sectors and sub-sectors where NMP applies, covering both research and industry;
- Design, collect, analyse and compare indicators, enabling comparison between National/EU initiatives on inputs, outputs and impacts;
- Make recommendations on further development of indicators to support policy-making in this area;
- Develop recommendations to support the achievement of the EC's overall objectives for the NMP theme: To improve the competitiveness of European industry and generate knowledge to ensure transformation from a resource-intensive to a knowledge-intensive industry.

Synthesis of NMP research strategies and actions

Desk research was conducted to provide an overview of the key NMP research strategies and actions in the 18 selected countries covered by this study (EU Member States: Austria, Finland, France, Germany, Italy, The Netherlands, Poland, Sweden, and the United Kingdom (UK); Third countries, including Associated States: Brazil, The People's Republic of China (China), India, Israel, Japan, Republic of Korea (South Korea), Switzerland, Russia, and the United States of America (US)). This allowed the identification of the political structure, important policies and major funding programmes for NMP research in each country.

The evidence suggests that entities from Member States and Third countries do not generally organize their activities under the subject of NMP. Instead, individual countries tend to outline their national strategic priorities for Science and Technology (S&T), and allocate funding as appropriate to their Research and Development (R&D) objectives.

The countries studied each had diverse approaches to defining their science and technology priorities, and the support mechanisms that underpin these. None of the selected countries has developed an overarching "NMP strategy" as such, but rather NMP themes are included in the strategic R&D programmes of all countries. Moreover, specific sub-themes within the scope of NMP are sometimes identified as key areas for a given country. The importance given to nanotechnology programmes in a number of sub-themes (such as electronics and health) in many of the selected countries serve as an example of this.

Public-private partnerships are becoming more common as part of public support to R&D. Instruments supporting aspects such as access to technology and general business are also increasing, with a recognition that more needs to be provided to support demonstration and exploitation activities. Infrastructure is also a significant part of several countries' R&D budgets. Much of this is specifically related to NMP.

It should be stressed that the full scope of a country's programme is often not clear, in particular concerning the allocation of funding to each sub-programme and/or theme. Many countries have very large research programmes, in which NMP is included. However, these extensive programmes often also include sub-programmes, causing a risk of double counting when identifying NMP targeted funding. It should also be noted that complete information about programme funding is often not publicly available.

There are two main patterns viewed with transnational and international cooperation within the areas of NMP. First, the majority of national funding is only available for national entities, namely industry and academia. It is somewhat rare that foreign organizations are selected and/or allowed to apply for this funding. In many countries, foreign applicants can be considered if the funding body recognizes the added value of this candidate (*i.e*. if it would not be possible for any national applicant to perform a given task). Second, there is evidence of extensive collaboration between countries in areas of common interest through bilateral programmes.

Overview of indicators

This study covers twelve indicators, which are grouped under the following Input-Output-Impact framework:

- <u>Input</u>: This dimension includes the external drivers of innovation. They are represented by four indicators measuring external influence over NMP R&D and Innovation: *Education; Public finance; Venture Capital; Industrial R&D expenditures; and Infrastructure*.
- <u>Output</u>: This dimension refers to the outputs from firms and research organizations. They are represented by four indicators: *NMP scientific publications (in both quantitative and qualitative aspects); NMP patents; Research intensity; and Open Innovation Schemes, Linkages and R&D Collaborations*.
- <u>Impact</u>: This dimension tries to capture, on the basis of data availability, the impacts of NMP activities. They are represented by the following three indicators: *Numbers of institutions and firms in NMP; Employment; and Sales and Market Shares*.

Comparison of EU and Third Countries

Below we provide a summary of the results obtained for each of the twelve indicators, using them as the driver of the comparison analysis between the EU and Third Countries.

Education

Education is widely recognized as an important driver of R&D and Innovation. This input indicator is not only a measure of high-skilled labour supply, but also a measure of continuous knowledge in-flow into institutions and firms, either by enabling the ability to attract graduates, or by strengthening the in-house knowledge base through training and life-long-learning.

We found that, the number of S&T graduates as a percentage of the population aged 20-29 generally increased in the EU over the period 1998 – 2009. In 2008 and 2009, this sub-indicator was higher in the EU than both in Japan and in the United States (Member States such as Finland, France and the United Kingdom had significantly higher values than the latter two countries). This suggests that there should be a pool of suitably qualified individuals to meet the needs of industry. However, these needs are varied both in terms of quantity of graduates and in terms of specific skill sets. One of the key aspects of the education indicator (graduate destination), which would answer this (albeit retrospectively), was not available from most universities. It is thus not clear whether these graduates were eventually employed in an industry related to their field of study or not. The survey performed within this study and the results of another study (Gelderblom et al., 2012) suggest that industry forecasts an increased need for specialized personnel within 5 years from 2012 (see Employment indicator below).

Public finance

National investment in R&D can be measured by GERD (gross domestic expenditure on R&D), which comprises some public (government and higher education), business, and not-for-profit private investment. The EU has consistently invested in R&D in the public sector at a high level compared with other countries (information from EUROSTAT indicates an average of 0.68% GDP in the EU compared with 0.6% in the United States and 0.64% in Japan, over the period 2001-09). Member States who invest more than this include France, Germany, Finland, Sweden, and the Netherlands. In contrast, the United Kingdom, Italy, and Poland invest lower than average amounts. South Korea is the only Third country covered by this study to invest more (0.76%).

Funding schemes, in the 18 countries covered by this study, were examined for their relevance to NMP, and were found to vary considerably from one country to another. It is extremely difficult to correlate NMP funding instruments in the EU (primarily the Framework Programme) with instruments in Member States and Third countries. What we were able to do was to identify the presence of specific NMP themes within funding programmes and sub-programmes in each country.

NMP themes are an important part of public research funding programmes in each of the countries covered by this study. Most countries are focused on thematic or grand challenge areas, and therefore use NMP as necessary to address these issues. Nanotechnology, as the relative newcomer to the fold, has perhaps more dedicated programmes, although this is not always the case (*e.g*. United Kingdom). With the exception of some of the broader nanotechnology programmes (*e.g*. those of the United States, Israel, Germany), most technology-focused programmes are narrow in scope and contribute directly to the larger priorities of the particular country, including advanced energy, sustainable manufacturing.

Venture capital

Venture capital is an essential part of the growth cycle for new enterprises. In this study, venture capital was investigated at both early and growth stages. Within the NMP arena, perhaps only venture capital investments in nanotechnology can be specifically identified appropriately, partly due to the intense focus that nanotechnology has received over the last decade or more, with many high profile investments being widely publicized (*e.g.*, A123 Systems (a US company) and Oxford Nanopore (a UK company)). However, this identification is mainly limited to looking at the large investments of those firms specializing in investment in nanotechnology (*e.g.*, Nanostart and Nanodimension) (Crawley *et al*. 2012).

Overall, venture capital is important for the commercialization of new R&D, however, it is difficult to disentangle the value of the technology aspects from other aspects that are common to all venture capital investments, and, therefore, it is not easy to relate this indicator to specific aspects of NMP (with the exception of nanotechnology, as explained above).

Industrial R&D expenditures

EU business invests relatively less in R&D than its counterparts in Third countries (an average of 1.19% of GDP in the EU-27 versus 1.89% in the United States, 2.52% in Japan, and 2.19% in South Korea, over the period 2001-2009). That said, business investment in R&D makes up the largest part of GERD in the EU (and in most other countries surveyed). The developing economies of Brazil, India and China have all exhibited the largest relative growth rates (over 25%, in the period 2005-2010), but still remain below others in terms of total investment in R&D. Between 2001 and 2009, South Korea increased its relative business investment in R&D some 39% (In 2009, South Korea was only behind Japan and Finland in terms of GERD in the business sector, expressed as percentage of GDP). Considering absolute levels of business investment in high-tech R&D, we see that the United States continues to dominate, with the EU taking second place, followed by Japan.

In conclusion, this is a useful indicator to examine the differences in investment trends between different types of organization, or different countries, but poor in terms of specific thematic areas.

Infrastructure

Infrastructure use is an enabling factor of R&D and innovation. This study aimed to construct a composite indicator for infrastructure, made up of three sub-indicators: Geo-distribution of institutions and firms in NMP; Laboratories and research facilities for NMP; Use of funding, capabilities and capacities in NMP. Although a large amount of data was obtained, much of this was qualitative and, as such, a full indicator on infrastructure was not developed.

The extensive collection of secondary data on available infrastructures in the selected countries showed that the larger countries have significant infrastructures in a number of different sectors. It appears that linkage between these infrastructures is happening with increased frequency to create virtual networks that add value to the capabilities and capacities of each one.

We have observed different strategies regarding the positioning of these infrastructures. Most are clearly aligned along specific technology themes (*e.g.,* electronics, biomedicine). However, some of the newly funded infrastructures are challenge-led (*e.g.,* the United Kingdom's Catapults), which bring together a number of different capabilities to address the needs of a specific challenge (*e.g*., sustainable energy production).

Concluding, infrastructure is a key aspect which provides a measure of the health of R&D innovation within a country and how embedded this is.

Scientific publications

Scientific publications are an often used indicator to measure the quality and quantity of output from different organizations, regions and countries. Comparing countries with each other we can see that no single European country can match the output of the United States or China. It is notable that China has increased its output dramatically in all aspects of NMP, and particularly in nanoscience, nanotechnology, and material sciences. In terms of publication quality, we observe that China has improved in the period 1998-2010 in all aspects of NMP (apart from nanoscience and nanotechnology), while European countries have either increased at a more modest level or stagnated. China is now second to the United States in terms of publication quality in material sciences. In terms of other areas of NMP, European countries continue to perform well, and are leading in nanoscience and nanotechnology.

The difficulty with this indicator is cleaning data sufficiently to unambiguously assign to specific technology domains. This has been performed for some technology themes such as nanoscience and nanotechnology. For others, the thematic area can be so broad that there are issues in excluding non-relevant information.

Patent applications

Patent applications are another indicator often used to benchmark different countries. However, their use comes with several caveats. Firstly, patents may be applied for in a different country from the one in which the intellectual property (IP) was developed – essentially, the country where the market is. For this reason, many patent applications are lodged with the United States Patent Office. Secondly, many patents never lead to commercial products (and likewise many commercial products are not patented, but instead subject to trade secrets). In this context they do not always provide a strong correlation with economic value. They do however represent a direct link to applied R&D as the first publicly visible outcome of R&D activities.

When investigating patent activity across all NMP domains, we observed that Europe continues to perform poorly against the United States, and that the BRIC countries (in particular China) are continuing to improve their relative ranking. The performance of South Korea is of significant interest. In nanoscience and nanotechnology South Korea now ranks as world´s top country, and in materials it has substantially increased its share over the period 1998 to 2009. In 2009 it ranked third behind the United States and Japan. Furthermore, in contrast to a decline in patenting activities in the manufacturing field of the world leaders (United States, Japan, and Germany), South Korea has also experienced an increase in annual output (from 303 in 1998 to 866 in 2009). All of these observations correlate well with the increased funding invested in R&D (GERD) throughout this period in South Korea. The strong academic and industrial ties (presented in the network analyses and discussed further below) also support this outcome.

Research intensity

The research intensity indicator is essentially a composite indicator drawn from publications and patents levels in R&D. For this indicator, we calculated the output *per* capita and observed that many EU Member States actually outperform the countries that have the highest number of publications and patent applications. The trends are also interesting. In terms of NMP publications, all countries are increasing or at the very least maintaining their *per* capita level over the period 1998 to 2009. In contrast, most have seen a stable or declining rate of patenting over the same period. An interesting observation is again with South Korea, which has seen NMP patent levels rise almost 250% *per* capita over this period. BRIC countries have also seen an increase: Brazil (138%), Russia (372%), India (289%) and China (209%), although in absolute terms these are at least an order of magnitude lower than South Korea.

Open innovation schemes, links and R&D collaborations

This is a powerful indicator to measure the strength of linkages between different organizations (private and public) and from that be able to infer the impact this has on different outputs. We performed network analyses using the co-authoring of patenting as an indication of collaborative innovation. This provides a means of measuring information flow between different organizations and determining who is important (in terms of overall output) as well as who has access to knowledge (and networks of other organizations). This was an intensive exercise and we focused the analysis on those countries with organizations demonstrating the highest degree of collaboration: France, Germany, South Korea, Japan, and the United States. The importance of different organizations within each of nanoscience and nanotechnology, materials, and manufacturing and processing was assessed by the prominence of an organization within that technology area and country (measured in this case by the number of different co-applicants it has on its patents). This is known as Degree Centrality. Each organization's importance was also assessed in terms of connections within that network, the Betweenness Centrality, which assesses the importance that the organization has as the link between two other organizations, and thus its control over access to knowledge.

This indicator thus provided a number of useful insights, particularly identifying existing networks that have evolved through collaborations, and are therefore the foundations of an innovation culture, allowing knowledge to flow effectively out to industry which can then turn it into commercial products.

Sales and market shares

The United States dominates the net sales of high-technology companies, followed by Japan, and then, at some distance, by Germany (at approximately half the value). Japan has seen the most dramatic increase in overall sales values (up some 500 B€ between 2005 and 2010). The BRIC countries, while having a more modest overall sales Figure, have seen dramatic growth rates of more than 20% *per* annum. From our survey, 64% of respondents provide commercial products or services based on NMP. Of these, 81% have launched a new product or service within the last 5 years.

This is perhaps the most important socio-economic impact indicator for governments. However, it is probably one of the most difficult to measure, if it needs to be assigned to a specific thematic area or technology and linked with an earlier intervention. Such socio-economic impacts have multiple causalities, not just technological interventions and specific funding schemes, but also other diverse aspects including the regulatory environment, consumer demand, licensing agreements, and other upstream economic inputs and outputs. Only by addressing the various interconnectivities of upstream elements, can there be a true appreciation of the effects.

Companies and institutes

Regarding the location of the top high technology companies in 2010 we observed that the United States continues to dominate with 487 of the top 1,000 non-EU companies (followed by Japan with 267). In contrast to its high level of output (in terms of publications, and more recently patents), China performs poorly in this ranking (19 of the top 1,000 non-EU companies). In Europe the situation is more evenly distributed with 244 of the top EU high technology firms in the United Kingdom, 206 in Germany and 134 in France.

This indicator provides a useful measure of the capacity a country or region has to perform in a particular thematic sector. However, given that most organizations are involved in multiple sectors it can be difficult to determine the true capacity in a particular thematic area. It is also important to correlate such analysis with the quality of the output and impact indicators (and the level of additional support, e.g. infrastructure).

Employment

In general, there is a mixed picture in Europe for employment in high-technology sectors with declines for France and the United Kingdom, but increases for Germany, Italy, the Netherlands and Poland over the period 2000-2008. The Scandinavian countries and Switzerland continue to dominate in terms of numbers of high technology employees per capita.

As previously noted, there is a lack of information regarding graduate destination, which makes it difficult to predict whether the correct types of graduate are being produced, and thus whether successful NMP outputs will lead to increased employment of European graduates.

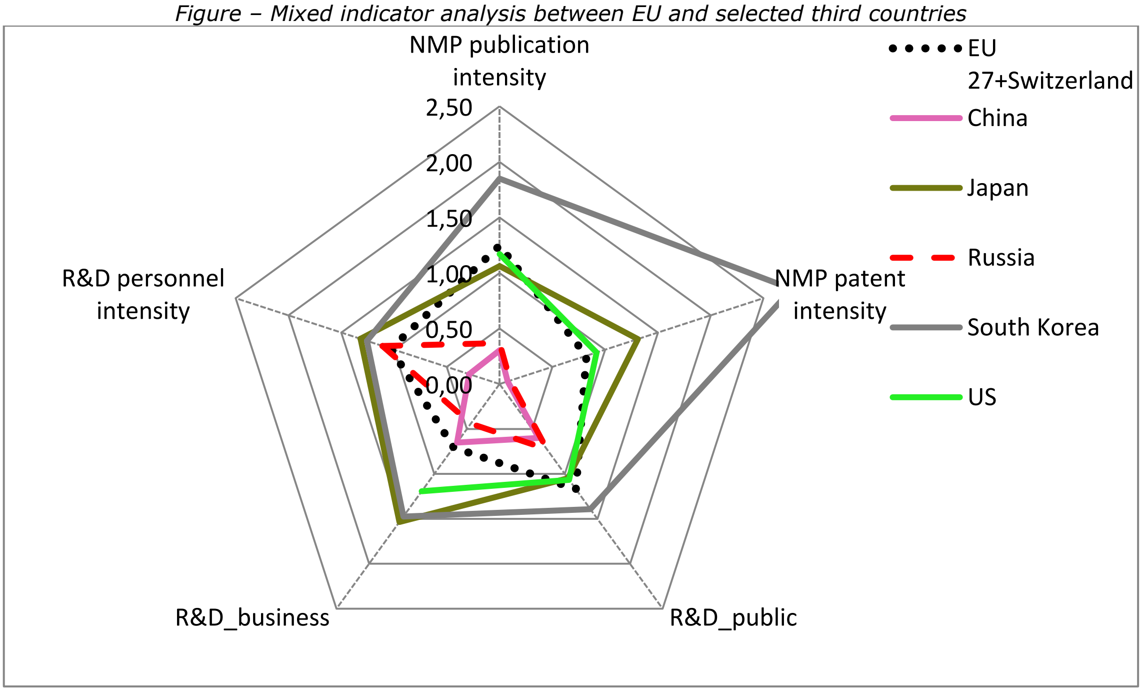
This is however a useful indicator as it provides information on the capacity of different organizations to effect change. It also provides information on employment trends which can feedback globally to universities allowing them to make informed decisions regarding course content. The main issue is providing data on a sufficiently large number of organizations with enough detail to distinguish between thematic and skill needs.

General conclusions: Mixed indicator analysis

The analyses performed within this project support the view that the EU is doing well in terms of input factors: it leads the way in terms of graduate numbers, investment in the public sector and several Member States are performing well in terms of business investment and venture capital for NMP. In terms of output it continues to perform well for publications (in terms of quality, if not quantity), however it lags behind Third countries with regards to patents (particularly, regarding patents in nanoscience and nanotechnology).

However, mixed indicator analysis linking input (funding, R&D personnel, and tertiary education) with output (publications, and patents) for the EU and for selected Member States and Third countries revealed that the EU is not as efficient at either the Member States level or as a collective as the best Third country (South Korea) (see Figure below). We also observe that European countries, such as Germany and Switzerland, publish and apply for patents relatively efficiently, based on funding input and level of R&D personnel, compared with countries such as the Netherlands and the United Kingdom. The EU as a whole has a lower patenting intensity than South Korea, Japan, and the United States; and a lower publication intensity than South Korea (it has a similar level to the United States for publication intensity). Interestingly, South Korea has a very high patent activity compared to its input factors (several times that of Japan, the next intensive).

Figure – Mixed indicator analysis between EU and selected third countries



Source: Authors' own analysis
Note: The number for R&D personnel intensity in the United States is lacking in this Figure

Our focused network analyses would suggest that the EU model does not include sufficient industry involvement in knowledge generation and exploitation. Increasing such involvement would further improve the efficiency of public funding. Comparing the situation in Germany with France, German institutes are patenting less, but networking more with industry than their French counterparts. German networks also appear to be more international in their membership. The level of patents held by the two key French institutes (CNRS and CEA), and the lack of connectivity of the CEA in particular (as measured by the Degree Centrality and Betweenness Centrality), both suggest that knowledge could be more efficiently distributed.

Putting this altogether, there appears to be some key lessons that the EU can learn from other countries. Funding should be focused on innovation, which needs industry as its final recipient. Government funded organizations should therefore link effectively with industry to ensure that knowledge transfer occurs. This cannot work in an ad-hoc manner through the creation of new projects and short-lived consortia, but should be anchored in something long-lasting, i.e. infrastructure. The networks we observe through the patent co-applications suggest, but do not prove, that the success being enjoyed by the economies of Japan, South Korea and the United States could, at least partially, be due to this strong embedded collaboration between different public and private entities. Policy in these countries, both in terms of public funding and other fiscal support, helps focus this collaboration towards industrial output. Importantly, the collaboration is not restricted to that country, but looks outwards to where the best opportunities lie. Comparing France and Germany, who invest comparable amounts of public R&D funding, we see evidence of a different model for industrial collaboration in the two countries, which can be used as a basis to explain the differences in NMP impact, given the relative strengths of both countries' public research and infrastructure.

Main recommendations

Policy recommendations from the study, to support the EC's objectives for the NMP theme, include the following:

- Targeted support to EU organizations demonstrating strong industrial and international networks who would be expected to lead the way in distributing knowledge, and thus improve exploitation.
- Improved assistance to and coordination of infrastructure between EU Member States, to ensure complementarity and reduce the potential for duplication with industry needs as the driving force behind future knowledge generation, dissemination and exploitation.
- Longer term funding strategies for industrial R&D, which take into account existing structures, and allow the organizations to be able to attract high levels of industry collaboration and distribute knowledge, to grow and deliver stronger impacts (resulting in more comprehensive support throughout the whole innovation cycle).
- Larger focus on supporting and measuring longer-term impacts within R&D programmes. This might include new funding models to improve support to demonstration and exploitation (for example working with Venture Capital and other types of private investment) and measurement of the growth and composition of important players.
- Stronger links between EU and Member State funding; in the short term to add value to the Member State funding (which is the primary source of funding for most organizations), and in the longer term to move more organizations towards the use of European funding to realize their core R&D objectives.

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1. INTRODUCTION

This document is the Final Report of the study "Comparative Scoreboard and Performance Indicators in NMP (Nanotechnologies, Materials and new Production Technologies) Research Activities between the EU and Third Countries".

1.1 Context and objectives of the study

The study focuses on the situation of NMP research and its industrial applications in the EU compared with Third countries (Associated States to FP7 and other third countries). The study is thus aimed at comparing, assessing and monitoring the progress of European NMP research vis-à-vis Third countries (Associated States and other third countries) and establishing the position of the EU in the international context, in the fields of NMP research and its industrial applications.

The study will thus help to understand and explain the reasons underlying the position of the EU research in NMP, as well as its strengths and weaknesses, in order to anticipate future trends and policies required.

It is part of the European Commission (EC)'s evidence-based policy making and implementation - and will be used to inform and legitimise future policy and funding orientations.

Hence, the study aims to:

- Identify, compare and assess the NMP research portfolios at EU, Member States and key Third countries (involved or not in FP7) level;
- Map the different main areas, sectors and sub-sectors where NMP technologies apply, covering both research and industry;
- Design, collect, analyse and compare indicators, enabling comparison between National/EU initiatives on inputs, outputs and impact.

1.2 Understanding of NMP

NMP has a complex nature and covers a range of different themes and sectors. One of the issues encountered since the start of the study has been how to ensure that the stakeholders understood the concept of NMP and thus the scope of the project.
In particular, the complexity of NMP was a challenge with regard to the data collection process, as the term NMP is not widely understood at a national level. Further, to the extent it is understood at the national level, the scope of what are regarded as NMP activities differs between and within countries. This created problems in ensuring consistency of responses across stakeholders, especially with survey respondents. It was thus decided to use a formal definition of NMP, mainly based on the European Commission definition, and provide this to stakeholders in the questionnaire and in other communications.

The definition used is as follows: "Nanotechnology and nanosciences, knowledge-based multifunctional Materials and new Production processes and devices (NMP) (or Industrial Technologies) is one of the ten thematic priorities within the

Cooperation theme of the EU's Seventh Framework Programme (FP7) for Research and Development (2007-2013). It was also a priority in the previous Sixth Framework Programme, which ran from (2002-2006)".

NMP is defined under FP7 as:

- Nanosciences and nanotechnologies – studying phenomena and manipulation of matter at the nanoscale and developing nanotechnologies leading to the manufacturing of new products and services.
- Materials – using the knowledge of nanotechnologies and biotechnologies for new products and processes.
- New production – creating conditions for continuous innovation and for developing generic production 'assets' (technologies, organization and production facilities as well as human resources), while meeting safety and environmental requirements.
- Integration of technologies for industrial applications – focusing on new technologies, materials and applications to address the needs identified by the different European Technology Platforms."

It is believed that providing this definition for NMP allowed the stakeholders to understand the nature of NMP and the project, whilst also allowing the stakeholders to draw upon their own understanding of what activities they undertake under the scope of NMP.

It should be noted that for analytical (and in particular quantitative) purposes, the project team required the more detailed mapping of NMP. This mapping is described in Section 2.4 and in more detail in Annex 3.

1.3 Objectives and structure of the report

This report aims to present the final results and analysis of the work undertaken in the project. After the current section it provides:

- An overview of the methodology;
- Synthesis of the key NMP research strategies and actions in the EU and in the main Third countries;
- A comparison of the EU with Third countries based on the data collected, including suitable graphical and tabular presentations. This comparison has been done by area of NMP research and industrial activity;
- An analysis of the data collected, providing explanations about the EU situation and recent evolution, as well as the EU strengths and weaknesses by NMP area;
- The findings, conclusions and policy recommendations.

The report has been structured to allow the reader to first comprehend the methodology, in particular the construction of the indicators and, importantly, the definitions and scope of the project team´s understanding of NMP (Section 2). The current strategies and actions in the relevant countries (Section 3), and the results of the indicators (Section 4) are then provided. The final conclusions and recommendations of this study are presented (Section 5) and the bibliography (section 6).

2. METHODOLOGY

This section provides an overview of the methodology used to collect and analyse the required information for this study. Relevant issues encountered during the data collection process are also addressed.

2.1 Literature review

A literature review provided the basis for the development of the indicators, by examining past contributions towards measuring research and innovation, and allowed the collection of important reports and strategic documents relevant to NMP research and innovation. It supported initial activities for the development of the indicators, country selection, and mapping of NMP. The bibliography relevant to these activities is provided by the end of the report.

2.2 Construction of indicators

2.2.1 The framework

When defining the indicators to use for the assessment of NMP research and innovation, we tried to adhere to two principles set forward by Hollanders and Van Cruysen (2008):

- Simplicity – using a limited number of robust indicators, composed of quantitative and descriptive data supplying not only content but also context.
- Transparency – based on a detailed explanation of the methodology, needed to allow simple calculation.

The main premise from which we departed was that, although quantitative methods are interesting for cross-section comparisons of industrial sectors and across countries, qualitative methods are indispensible both to probe causalities (Chambers, 2007) and to explore those issues that cannot be approached using quantitative methods. The indicators were grouped into an indicator framework, which aids in the understanding of the relationships between them, and facilitates their interpretation. We have selected, and slightly revised, the framework used for the 2008-2010 European Innovation Scoreboard (EIS) reports (Hollanders and Van Cruysen, 2008), because of its focus on R&D and Innovation measurement and in line with the EC guidelines developed (Hullmann, 2006), as well as satisfying the objective to measure inputs, outputs and impacts.

The framework we used is in line with the Input-Output-Outcome-Impact framework described by Segnestam (2008); however it was slightly modified to encompass some of the indicators used in the EIS. The EIS's methodology does not directly call for the measurement of short-term results and, as such, the Outcome dimension has been dropped in their "EFO" framework (Enablers, Firm activities, and Outputs). Because of the even stronger focus on R&D, and the possibility for dual interpretation of indicators, we have also taken out the Outcome dimension, merging the indicators which could possibly belong there with those of other dimensions, as Segnestam (2008) also proposed. Some of the indicators used in the EIS's Enablers dimension (human resources and finance) can then be translated to Inputs; Firms' activities (firm investments, linkages and throughputs) can be translated into Outputs; and the Outputs in the EIS (innovative companies and economic effects) can be translated into Impacts. We also considered the likely probability to obtain comparable data.

2.2.2 Definition of indicators

Taking into account these considerations, the study aimed to develop twelve indicators grouped under the following Input-Output-Impact framework (see also the Table 1). A more complete description of the indicator construction is provided in Annex 6:

- Input: This dimension includes the external drivers of innovation. They are represented by four indicators measuring external influence over NMP R&D and Innovation: Education; Public finance; Venture Capital; Industrial R&D expenditures and infrastructure.
- Output: This dimension refers to the outputs from firms and research organizations. They are represented by four indicators: NMP scientific publications (in both quantitative and qualitative aspects); NMP patents; Research intensity; and Open Innovation Schemes, Linkages and R&D Collaborations.
- Impact: This dimension tries to capture, on the basis of data availability, the impacts of NMP activities. They are represented by the following three indicators: Numbers of institutions and firms in NMP, Employment, Sales and Market Shares.

Table 1 – Indicator overview

Name of indicator	Further information on indicator type / construction	Relevance to NMP R&D and innovation
Input indicators	*Focus on the supply of highly qualified human resources, researchers, external funding and infrastructural influences*	
Education	Graduation numbers from tertiary education in the EU; No. of students in tertiary education /100,000 inhabitants; Annual graduation from tertiary education as a % of the population aged 20-29 years; Tertiary graduates in S&T/ 1,000 of population aged 20-29 years).	Education is an enabler or driver of R&D and Innovation. Also a measure of continuous knowledge in-flow into institutions and firms.
Public Finance	Total intramural expenditures on R&D (as % of GDP) in the government sector, business enterprise sector, and higher education sector; and Public funding data from the NMP primary data collection (survey). Sectoral expenditures on R&D, as a % of GDP, can be used to compare the EU with the selected Third countries. Survey data was used to help understand in which areas the public funding is mainly focused.	Public spending on R&D is seen as one of the major drivers of economic growth. Trends in public spending on R&D will then indicate the direction of competitiveness in the NMP sector for the selected countries.

Name of indicator	Further information on indicator type / construction	Relevance to NMP R&D and innovation
Venture Capital	Venture capital investment as a % of GDP, by number of employees, as a % of GDP- early stage, as a % of GDP- expansion and replacement; as a % of total funds raised; % of high-tech and non-high tech venture capital in 2006 and also in 2007. Data for the EU and United States only.	Another key link in the "innovation support chain"
Industrial R&D expenditure	Intramural R&D expenditure (GERD) in the business enterprise sector; Business enterprise R&D expenditure by NACE high-tech groups (all NACE activities); R&D investment and growth rate (in top companies) by country; R&D investment intensity (R&D/net sales) by country.	Measures innovative knowledge creation in business. Important for the science-based sector.
Infrastructure	Geo-distribution of institutions and firms in NMP; Laboratories and research facilities for NMP; Use of funding, capabilities and capacities in NMP.	Enabling factor & important indicator of competitive advantage of high-tech, and high-value, knowledge-based industries.
Output indicators	*Measure the outputs from firms and research organizations*	
NMP scientific publications	No. of scientific publications by field, per year and per country for Nanoscience and technology; Material science; Chemical engineering; Construction and building; Machine tools; Mechanical Engineering; Production and processing; Textiles. Publication quality for by country is measured using journal impact factors and citations.	Scientific publications are an accepted measure of basic R&D output. Thus, the total number of Scientific publications in NMP is an output indicator of R&D activities in the fields covered by NMP.
NMP patents	No. of patents in NMP applied for at the EPO, by year and country, as a % of the total country population for applications as per fields in indicator "NMP scientific publications", except manufacturing replaces Production and processing.	Patents in NMP are an important indicator of applied R&D output.
Research intensity in NMP	Publication intensity – No. of publications (aggregated from indicator "NMP scientific publications") /million inhabitants; and Patent intensity – No. of patent applications (aggregated from indicator "NMP patents") /million inhabitants are calculated.	Relates to the two previous indicators, but provides them per capita to place them in their population context.

Name of indicator	Further information on indicator type / construction	Relevance to NMP R&D and innovation
Open innovation schemes, linkages and R&D collaborations	Cooperation networks are constructed using the assignee data from the patent applications or the affiliation data from publications. These are provided for: Public-private publication cooperation; Public-private patent cooperation; Comparison of collaboration activities between EU and non-EU countries (further descriptive information from the NMP survey).	First two sub-indicators measure basic and applied R&D cooperation, third sub-indicator other collaborative activities between innovative organizations e.g. sharing of (knowledge) resources.
Impact indicators	*Impacts of NMP activities including employment, sales and market shares*	
Number of institutions and firms in NMP	Includes: Number of top firms by country (2005-2010); Number of top institutions and publication numbers by country - Nano science and technology (1998 and 2010); Number of top institutions and publication numbers by country - Material science (1998 and 2010).	NMP innovation and production takes place in institutions and firms, so the total number of such organizations can be an indicator of the economic competitiveness of the NMP sector.
Employment in NMP	Annual employment in high-technology sectors; Intensity of annual employment in high-technology sectors /1,000 inhabitants; Skill shortages by organization type and by received funding type; Expected changes in different skill categories in the next 5 years by organization type and by received funding type. Organization types included are large enterprises, SMEs, university and higher education, and research institutes. Skill levels investigated include: technician, ST/Eng graduate, ST/Eng PhD, and others. Funding types are public funding and venture capital funding.	High-tech employment reflects an increasingly knowledge-based economy. Theory suggests that technological innovation has a positive effect on employment.
Sales and market shares	Net sales of top companies by country (EU and non-EU) – top companies in each country appearing the EU Industrial R&D Investment Scoreboards are aggregated.	Commercialization represents the tangible results of R&D, process & production technologies.

2.3 Choice of countries for study

Since one of the objectives of this study is to benchmark the EU against Third countries in terms of their NMP Research and Innovation performance, as well as ensuring the inclusion of countries known to have a sufficient level of NMP activity to have defined some strategic and policy activities at national level, it is important to choose countries with differing overall innovation performance.
Within Europe, the Innovation Union Scoreboard (IUS) (European Commission, 2011) has compared Member States in this respect, as well as the EU to its main competitors (United States, Japan, and the BRIC countries). The OECD has also analysed country's innovation performance in a series of reviews (OECD, 2008, 2009, 2011). Furthermore, the FP7 NMP thematic priority has the objective "to improve the competitiveness of European industry…", and thus it might also be useful to look at the competitiveness ranking of countries. For this, the study used the World Economic Forum Competitiveness Ranking (Sala-i-Martin, 2009). The aim was to achieve a selection that included a range of different conditions, to ensure that there is coverage of all main regions in Europe, and to provide a selection of major third countries.

In total, 18 countries were selected. The countries are as follows:

- EU: Austria; Finland; France; Germany; Italy; The Netherlands; Poland; Sweden; and the United Kingdom (UK).
- Third countries (including Associated States): Brazil; The People's Republic of China (China); India; Israel; Japan; Republic of Korea (South Korea); Switzerland; Russia and United States (US).

2.4 Mapping of NMP

NMP relates to a specific thematic priority of an EU funding programme (FP7), supporting research related activities. It is necessary to clearly define the fields and sectors in regard of the main areas funded by the NMP theme. This is important so that these fields and sectors can easily be identified in different national contexts in a comparable way. The use of international classifications for fields of science and industry sectors was examined to support data comparability. The Field of Science and Technology (FOS) classification in the Frascati manual was chosen for examining the research fields to which NMP applies. This most recent classification was used since NMP contains a number of newer/emerging technology fields and this version was developed to reflect these latest changes and aims at achieving a minimum level of comparability of R&D data at the international level. The NACE system used in the EU to classify economic activities for statistical purposes was implemented as the basis. The NACE system is directly linked to the International Standard Industrial Classification of all economic activities (ISIC) Rev. 4, as adopted by the Statistical Commission of the United Nations. Previously funded topics were compared with these two classifications. Verification was also made with national programmes for the countries selected. Additionally, the conclusions of the NMP Expert Advisory Group presented in its Position paper of November 2009 regarding the future research and technological directions of the NMP programme for the period (2010-2015) were taken into consideration.

Overall, the FOS analysis shows that there are certain core areas in which all the R&D would be relevant (e.g. Materials engineering, Nanotechnology and biomaterials) and other areas such as the Physical sciences or Electrical engineering, Electronic engineering and Information engineering where a considerable proportion could be relevant. However, the analysis also indicated that there were many other fields in which there could be relevant research, but for which it is not possible to accurately estimate the proportion of R&D activities that would be relevant for NMP.

This indicates a particular difficulty in setting the boundaries for statistical data collection and leads to the conclusion that NMP cannot adequately be disaggregated from the different fields of science. Hence, some of the indicator analysis developed in this study must necessarily be at a more general level of Science and technology. The assessment of NACE sectors showed that R&D activities in NMP are of most interest to the manufacturing sector. While there are also some overlaps also to the energy and water supply sectors, with water purification and remediation, and with the building/ civil engineering sectors, in the main it can be concluded that NMP R&D and Innovation relates mainly to the manufacturing sector.

The eventual breakdown aimed to allow the study to extend beyond the level of S&T in general as much possible in the context of research fields, but also be possible to relate to the different manufacturing sub-sectors. The overarching aim is to ensure that the data gathering and construction of indicators would be able to provide substantial input to research and innovation policy-making. Thus, the eventual breakdown needs to be able to amalgamate sub-fields and sectors appropriately. Therefore, a theme-based classification that could be used for primary data classification was developed. It has the advantage of relating to both international classifications of both Fields of Science and industry sectors, whilst breaking down broad areas such as the Chemical Sciences, Materials Engineering and Nanotechnology by application area and allowing the capture of areas of NMP overlapping with other themes. The final result is a suitable breakdown for policy-making applications, which also relates to international Field of Science and industrial sector classifications. It includes the following themes: Agrifood; Construction; Electronics; Energy; Environment; Health and medicine; ICT; Manufacturing and process technology; Materials; Measurement and analysis; Photonics; Security; Space; Transport.

The mapping of NMP is described more fully in Annex 3.

2.5 Primary data collection/analysis

Primary data was collected via an online survey, interviews and a questionnaire provided via email.

2.5.1 Online Survey

The purpose of the online survey was to collect information relevant to each of the indicators, that would be specific to NMP, and which was not available from other statistics. The online survey targeted senior decision makers in funding / policy-making bodies, research institutions, and industry participants. This targeting towards individuals in senior management (CEO, Director, Head of Department or Unit, or equivalent) was provided to ensure that responses were received from those who could provide a strategic insight on their organization. They were identified through desk research encompassing a variety of sources including:

documentation from funding bodies, both regarding programme contacts as well as receivers of funding from national programmes within the scope of NMP; and reports on research intensive or innovative manufacturing companies, such as those listed, for example, in the R&D Industrial Scoreboard and other such reports.[2] Care was taken to include a balanced geographic as well as thematic specialization.

The survey was completed between April 2011 and December 2011. Overall, a total of 1,318 invitations were sent out, and a total of 176 responses were received, distributed across the 18 selected countries. This represents an overall response rate of 13%. However, while this response rate is slow, the results are of significant value due to the level of the respondents selected, and provide some valuable inputs to supplement the quantitative data collected in the study. The precise data on the distribution of respondents by country can be found in Annex 1.

2.5.2 Interviews

The project team undertook a substantial interview process, in order to obtain further details on aspects related to the NMP indicators and to the final mapping and synthesis of NMP in the EU and third countries. The interviewees were selected from the desk research and the survey, and the overall list was agreed with the European Commission before the interviews were completed. The selection criteria for the interviews were the same as for the survey (see above). A total of 101 interviews were completed. The make-up of the interviewees includes 27% policy makers/funding agencies; 40% academia (include national research institutes); and 34% industry/industrial associations. Further information about the interviewees is provided in Annex 2.

Significant issues were found with obtaining responses from the selected universities. To attempt to make the process simpler for the targeted respondents, the project team identified specific courses at each of the universities that were likely to have NMP content, and sent these lists of specific courses to the targeted respondents. However, after email requests and follow-up phone calls, only a few replies were received from the targeted respondents, with many of the replies received only providing partial information.

[2] These reports are listed in the bibliography for each country

2.6 Desk research and secondary data collection/analysis

Desk research was completed to provide the initial basis of the analysis in the study. The sources for this desk research include publicly available information from national science bodies and funding agencies; previous European, country and sector reports; and other sources. Details of the sources used are presented in a bibliography provided by the end of the report and in Annex 4.

Of significant importance to this study are the collection of information on NMP infrastructures, publications and patents.

2.6.1 Infrastructures

From publicly available information, a series of main infrastructures in each of the 18 selected countries was identified. These were chosen based on a number of criteria including: turnover, critical mass and uniqueness of facilities, accessibility to external users, and support for external users. For large countries (with total population exceeding 50 million), between 15 and 20 infrastructures were identified and analysed, whereas for small countries (total population lower than 50 million) between 5 and 15 infrastructures were identified. The information obtained is presented in Annex 5.

The identified infrastructures include only those which are accessible to external users. Thus, for instance, university infrastructures that are only accessible to the university users are not included. This criteria, whilst important to ensure that the identified infrastructures are those which can be accessed by a range of entities, resulted in some data collection issues as the actual accessibility arrangements differ between infrastructures and can be subject to confidentiality clauses.

For ten countries, however, we could discern several pieces of information that can be analysed using quantitative methods. These countries are Austria, Finland, Germany, Japan, UK, France, Switzerland, Israel, Sweden and the Netherlands. The most interesting piece of data we were able to extract is the employment Figures reported by the individual (laboratory) facilities. All ten countries have reported, for at least three facilities, employment data. A second piece of data that has been reported is the annual budgets for each of the facilities. Seven countries have provided for at least three of their (laboratory) facilities budgetary data.

2.6.2 Publications and Patents

The process for selection of the publication and patent data needed to be precisely defined in order to guarantee agreement between the selected data and the classifications set out in the Frascati Manual (OECD, 2002), in this case the revised FOS (OECD, 2007).

The publication data in the area of nanotechnology was sourced from the existing database on this sub-field available at UNU-MERIT. This database is based on the Web of Science records retrieved using a specific keyword based algorithm (Huang, Notten and Rasters, 2011).

The use of a solely keyword based algorithm was justified in this particular case due to the interdisciplinary nature of fundamental nano-scale research (Porter et al, 2007). For nanotechnology patents this is not the case, as patent offices worldwide have already reacted to this shifting frontier in research by adding nanotechnology specific classes in their classification schemes.

For all other publication data, the Elsevier's Scopus database was used. Within Scopus, the data is indexed into subject areas which can be used as an initial starting point to define the categories on which this study focuses. In some cases, such as for Materials Engineering (FOS 2.5), it could be directly translated to a complete Scopus subject category. For others, the subject categories were used as a starting point to predefine the area of interest while further narrowing down, if necessary, or complementing these with keyword based algorithms.

2.7 Synthesis of NMP research strategies and actions

Desk research was conducted to provide an overview of the key NMP research strategies and actions in the selected countries. A template for the initial data collection for the synthesis was developed, and the template gathers data on initiatives, strategies, programmes and funding related to NMP.

In terms of reliability it is important to note that the project used in the first case, sources such as Era WATCH and Trendchart in which data was collected in a consistent way, but also due the incompleteness of these sources supplemented these with direct analysis of national data. The partners also tried to verify data with programme officers where possible.

In terms of consistency, it should be pointed out that applying NMP definitions to other programmes is highly subjective (both for the researchers in this project, and for those who are being interviewed and managing funding programmes) – this is the result of its broad nature, and the fact that each component has significant overlaps with the others, and with other KETs. While funding levels and dedicated programmes for nanotechnology can be more easily identified, this is less so for materials (which are included in many R&D programmes) and for manufacturing – related to aspects of materials and nanotechnology (as well as in its own right). Especially considering that ICT and biotechnology are excluded from the NMP definition, it can become very problematic indeed. This issue makes it difficult to disaggregate funding data, which is presented by national bodies according to their national strategies, and not according to NMP definitions.

2.8 Validation of study results

The main qualitative methods used to arrive at the analysis and formulate the policy recommendations included the organization of online workshops and a workshop at the European Commission premises in Brussels. Quantitative methods of each indicator and the construction of the mixed indicators is described in section 4.

2.8.1 Online workshops

The objective of the online workshops was to allow selected experts to review different aspects of the study's findings, provide an opportunity to debate the analysis and support the formulation of useful policy recommendations.

In this respect an online workshop "*NMP research and the path forward - issues and challenges for funding agencies in Europe and third countries*" was organized on 14th June 2012 to look at particular issues faced by funding agencies with the objectives of cross-referencing the findings from the interviews and survey, and of supporting the formulation of recommendations for NMP research.

A second online workshop "*NMP Indicators - an efficient research tool for better understanding?*" was held on 25th of June 2012, with the aim to address and discuss development of indicators for scientific purposes and measurement with a focus on NMP areas. The workshop also discussed whether it is possible to improve the methodology for indicator development and comparison including how to ensure that the indicators are used at a political level.

The workshop gathered different indicator development experts to discuss these issues with the consortium. The participants were invited through a personalized e-mail that included a guidelines document with detailed information about the event and a brief description of the project.

2.8.2 Workshop in Brussels at the European Commission

A workshop was held on the 28th of June 2012, at the premises of the EC Representation at Brussels in Belgium.

Experts and other relevant stakeholders within the NMP research and indicator development, including representatives from the European Commission, participated and discussed the main findings of the project. They provided comments and suggestions on an initial draft of the final report and a presentation of the current status of the analysis of the indicators, which were then used to update the report and further the analysis.

3. SYNTHESIS OF NMP RESEARCH STRATEGIES AND ACTIONS

3.1 Introduction

This section describes the main tendencies and observations made within NMP research initiatives and strategies in the selected countries.

The term NMP is not widely used at a national level, and the scope of what are regarded as NMP activities differs between and within countries. Indeed, none of the selected countries in the study has developed what can be regarded as "NMP strategies". However, nanotechnology, materials, and new production processes are clearly present, and have a significant role, in the R&D programmes of all of the selected countries. The objective of this section is therefore to provide an outline of the main national R&D policies, and identify the strategies and actions that are related to NMP.

More detailed information about policies, strategic areas, programmes and funding is provided in Annex 4. It should be noted that the main contents of this section, as well as those from Annex 4, were drawn from secondary data. Primary data from the project surveys and interviews was also used in order to provide specific examples, as well as to complete and update the information obtained from desk-based research.

3.2 Programmes and strategies

The national programmes relevant to NMP were initially identified from desk research, using the principal sources of a country such as ministries, departments, funding bodies, policies and strategies documents. The information was then updated in line with results from the project survey and interviews. The identified programmes can be divided into two main categories:

- Broad scope programmes;
- Narrow scope programmes.

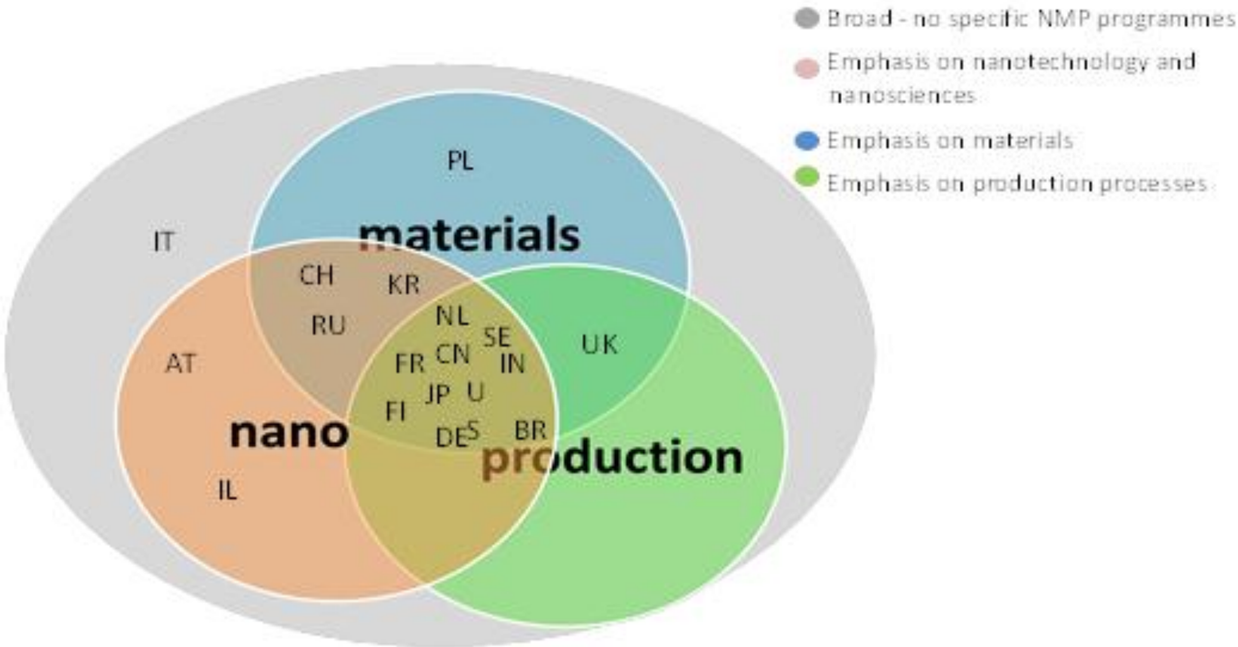
The broad scope programmes cover a range of themes/areas, although are not necessarily those having the highest budgets. These programmes tend to have a number of sub-programmes. Examples of broad scope programmes are the MAGNET programme in Israel (30 M€, annually), which includes the NOFFAR programme - Nanotechnology and biotechnology, and finances new generic technologies that will lead to advanced products; the National Key Technologies R&D Programme in China, involving a range of themes such as health, medicine, energy, security and materials (3 B€ to be divided between 5 years 2007-12); The Research and Development in Priority Development Directions of the Russian Technology Complex, that includes themes such as health, biotechnology, energy, security, and materials (1217 M€ for 2007-2012); and the SERC R&D programme in India, including themes such as biotechnology, health, electronics, photonics, ICT, energy, security and materials (25.8 M€ for 2009-10).

Narrow scope programmes tend to focus on one theme, for instance ICT, energy or transport. Examples of such programmes include the Strategic Development of Technology for Efficient Energy Utilization (1.08 B€ 2008) in Japan, the MNP

Neurological and Psychiatric Diseases programme (19 M€) in France, the Pharma-Initiative für Deutschland (800 M€ for 2007-2011) in Germany, or the Energy Research Capacity (71 M€ for 2008-2009) in the UK.

In the analysis we have attempted to identify whether different countries have funding programmes focusing on any of the three broad aspects of NMP and also whether there are specific NMP themes within programmes (e.g. related to electronics, or health). While we can identify the importance of NMP within different countries' R&D funding programmes, a number focus on one or two of the broad NMP themes (rather than all). Figure 1 indicates the relative importance of nanotechnology and nanosciences, knowledge-based multifunctional materials, and new production processes and devices, as measured by the presence of dedicated R&D programmes for each within different countries (identified as described above). This varies from inclusion in a number of programmes (without specific large dedicated programmes, as found in Italy); to a number of large programmes specifically looking at different NMP themes. Countries such as Germany, France and the US all have large programmes dedicated to each of N and M and P.

Figure 1 – Importance of N, M or P in selected countries



Source: Authors' own analysis

It should be noted that the inclusion of a country within a certain sphere, does not mean that it lacks funding activity in another, but rather it reflects whether there are any specific programmes focusing on this area. So for example the UK strategy has changed in recent years away from funding specific nanotechnology programmes. Instead nanotechnology is now funded as part of wider material and manufacturing programmes.

Furthermore we observe that a number of countries have specific sub-programmes dedicated to an NMP theme and addressing specific challenge areas or industrial sectors. In most cases these are nanotechnology related (*e.g.* nanoelectronics, nanomedicine). The major findings for each of the 18 selected countries are described in Annex 4.

3.3 Funding schemes

Each country has its own tailored funding system, with government funding agencies and different types of private sector funding. The funding systems of the selected countries differ quite significantly in terms of clarity and in terms of degree of centralization. The responsibility of funding for science and technology is sometimes very centralized within a few major government bodies. In other cases the funding system is decentralized, with a myriad of institutions, each provided with core funding (sometimes from a number of sources) to be allocated according to its own remit and assigned to a number of areas/themes. It is thus important to consider a range of information sources, in order to try to obtain a complete characterization of the funding system of each country and identify the most recent/accurate data.

Another issue that makes it difficult to determine the overall budgets for NMP programmes is the risk of double-counting. Given the complexity of some (public) funding programmes, some of the same available funds can appear in a number of different programmes. In addition, some of the broad scale programmes are applicable to areas that are not within the scope of NMP, and it is not possible to know which part of the funding is actually used for the areas related to NMP. It is thus not clear that a fully accurate and complete identification of funding for NMP activities can be obtained.

Nonetheless, some important information could be obtained from the interviews that were performed in this project. The recipients of funding were selected based on their involvement in NMP sectors. Thus, during the interviews they were asked about their sources of funding, and in particular recipients from Member States were questioned about their participation in European programmes. It was interesting to observe that all of the research companies active in the NMP areas participated in these European initiatives, some more than others, but the programmes FP6 and FP7 were particularly very well-known.

Another striking comment is that the majority of the companies interviewed used FP7 funding to establish/improve their value chain and network, as well as to fund specific research. Many relatively small companies also highlighted the fact that these European initiatives allowed them to explore areas which they would not have done themselves due to limited resources. Even though some did note that the funding from these programmes was not a crucial part of their business, a general sense that the funds were very useful has been expressed.

Some stakeholders in the selected Third countries were familiar with the European initiatives. The Marie Curie programme, focused on improving the mobility of researchers, was well recognized and used by these countries. Some key actors (both funding agencies and recipients of funding) in the US expressed an interest in increasing the collaboration with the EU, but also highlighted the fact that due to legal constraints between the EU and the US, it was often very difficult for researchers to participate in these initiatives. However, it was emphasized that specific bilateral agreements were deemed beneficial, e.g. between Israel and Germany, and between US and China.

Most of the public funding for interviewees was received from national sources - often in the form of public-private partnerships, in which there is some government contribution that is matched by academia or companies. Often, the contribution from academia was through the provision of research facilities and staff, and the industry partner determined the main research interest. Venture capital in NMP areas seems to be increasing globally, but according to the interviewees this is especially so in Israel, UK, US and Germany.

Overall, we observed that private investment in public research is becoming more important, and that funding programmes are beginning to look at bridging the gap between public funding of R&D and Venture Capital investment in start-ups. In particular, countries such as France are focusing public funding for industry away from grants and subsidies and more towards investment models (loans and guarantees, [3] which may also lead to royalties).

Table 2 shows the main sources of funding for public R&D in NMP, and indicates that many countries now have strong private public partnerships and private investment in public R&D. A few still focus largely on public investment in public R&D (such as the UK).

Table 2 – Overview of sources of funding

Mainly public	*Mix PPP and public*
AT, FI, IL, PL, UK, BR, CN, JP, KR, US	FR, DE, IT, SE, CH, NL, IN, RU

3.4 Final remarks

It has been observed that each country has its own approach to both establish its science and technology priorities, and to define the most suitable research programmes to be implemented. None of the selected countries has developed an "NMP strategy" as such, however NMP themes are included in the strategic R&D programmes of all countries. Moreover, the areas within the scope of NMP are sometimes identified as the key areas for a given country. One example is the importance given to nanotechnology in the majority of the selected countries.
It is often the case that if a country recognizes its strength in a given sector, for instance manufacturing (which is the case of, for example, China, the UK and India), then programmes and actions are directed towards research in that sector. Thus, the strengths (and also the needs) of a given country are a major factor in determining the R&D priorities and, consequently, the allocation of funding to the areas within the scope of NMP.

Concerning some of the innovation indicators, as identified through the Innovation Union Scoreboard, the EU is performing slightly below other main players, such as

[3] Speech by the President of the French Republic, Press Conference on the Investments in the Future Programme, Élysée Palace – Monday 27 June 2011 http://www.elysee.fr/president/root/bank_objects/110627_Press_Conference_on_the_Investments_in_the_Future_Programme.pdf

the US, Japan and South Korea [4]. The interviews performed in this project were used to attempt to understand reasons why this is the case. The recipients of funding from the EU (both industry and academia) indicate one possible reason for this relative poor performance as the fact that the overall funding schemes from the European Commission such as the Framework Programme (currently FP7) and similar initiatives are very valuable, but this kind of tailored funding is sometimes believed to be lacking at national level in Member States.

With regards to funding, there is an apparent increase in the use of private funding in public research programmes (with these tending to be in NMP areas). There is also greater support for companies in public funding schemes (including access to technology and general business support) and a recognition that more needs to be provided to support demonstration and exploitation activities (such as the investment models for companies observed in France and Brazil). Infrastructure is also a significant part of several countries' R&D budgets: France, Japan, South Korea, Russia and the US. Much of this is specifically related to NMP.

It should be stressed that it is often not clear or possible to understand the entire scope of a programme, in particular the allocation of funding to each sub-programme and/or theme. Many countries have very large research programmes, where NMP is well funded. However, often these extensive programmes also include sub-programmes, and therefore the risk of double counting when identifying funding is relatively high. It should also be noted that complete information about programme funding is often not publicly available.

With regard to transnational and international cooperation within areas of NMP, two main patterns seem to evolve. First, the majority of national funding is only available for national entities, namely industry and academia. It is rare that foreign organizations are selected and/or allowed to apply for this funding. In many countries, foreign applicants are only considered if the funding body recognizes the added value of this candidate (*i.e.* if it would not be possible for any national applicant to perform a given task). This has been identified from the interviews with the national funding agencies and in the eligibility criteria for each identified programme. Second, there is evidence of extensive collaboration between countries in areas of common interest.

[4] http://ec.europa.eu/enterprise/policies/innovation/files/ius-2011_en.pdf

4. COMPARISON OF EU AND THIRD COUNTRIES

This section provides the comparison of the EU and Third country activities in NMP, based on the indicators previously described. As such, the analysis included in this section can be considered as one of the central focuses of the study. The section is developed indicator-by-indicator, using both quantitative and qualitative data.

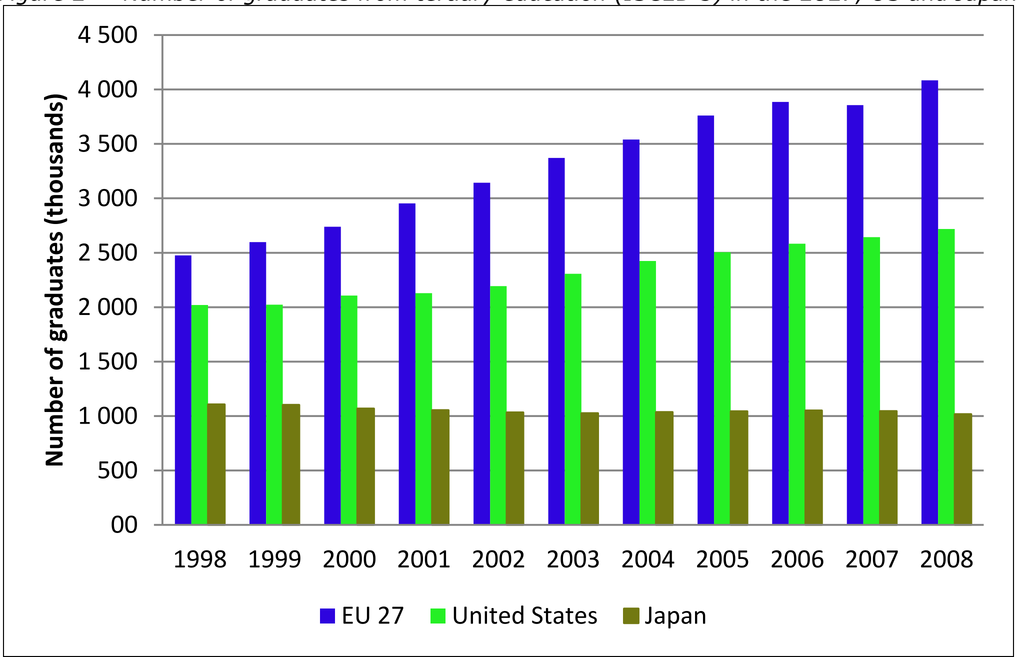
4.1 Input indicators

4.1.1 Education

The education indicator is regarded as a first specific step to assess the external drivers of innovation within the NMP domain.

The numbers of graduates from the first stage (ISCED 5) and second (ISCED 6) of tertiary education in the EU27, US and Japan, sourced from EUROSTAT, are shown in Figures 2 and 3. The educational attainment is based on the International Standard Classification of Education (ISCED, 1997)[5]. These Figures show an increasing trend in the number of graduates, although slightly levelling off in 2006 and 2007. It is hoped that the further increase in graduates and doctorates in 2008 will be sustained in further years, for which there is no data available currently.

Figure 2[6] – Number of graduates from tertiary education (ISCED 5) in the EU27, US and Japan

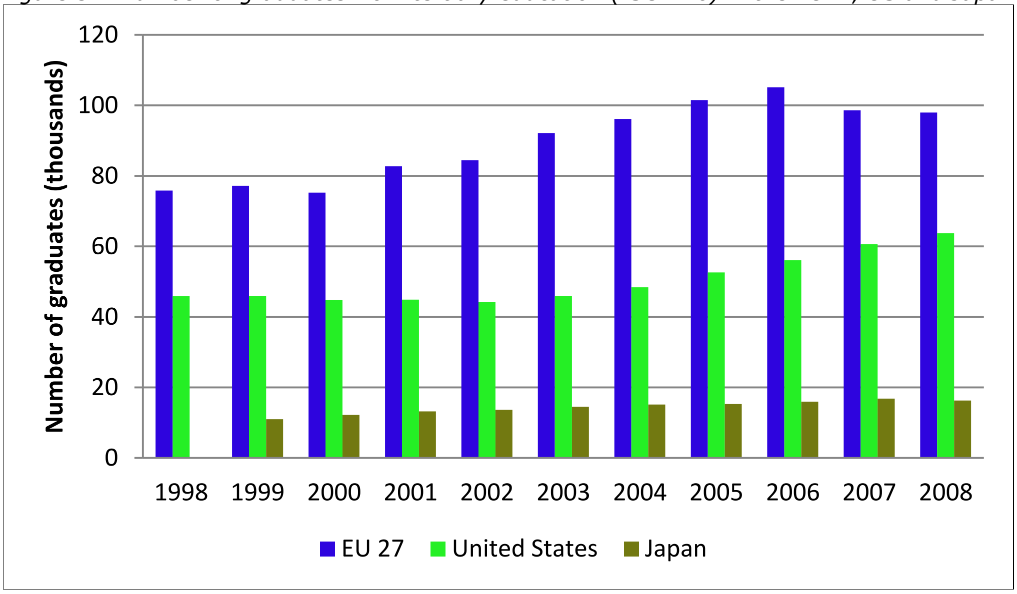


Source: EUROSTAT

[5] ISCED-5 is the first stage of tertiary education (not leading directly to an advanced research qualification). ISCED-6 is the second stage of tertiary education (leading to an advanced research qualification).

[6] All fields of study covered.

Figure 3[7] –Number of graduates from tertiary education (ISCED 6) in the EU27, US and Japan



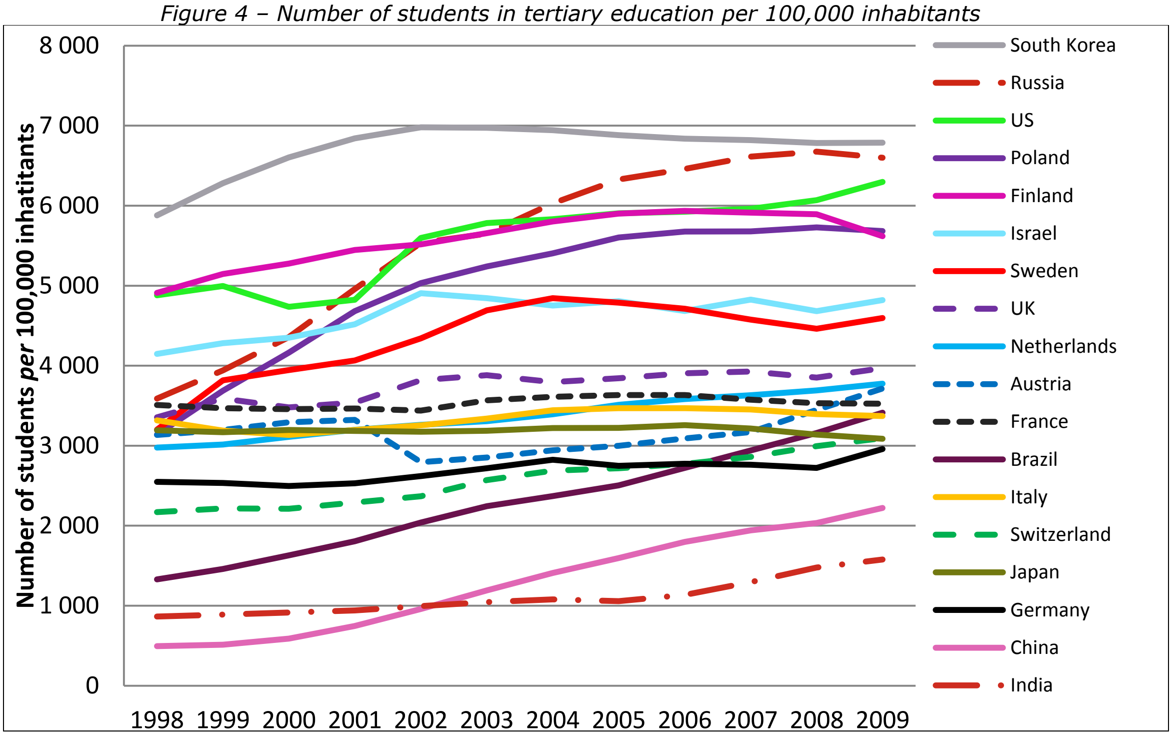
Source: EUROSTAT

Taking the population into account, two kinds of intensity indicators have been developed - one for "tertiary education" and one for "tertiary graduation". The former focuses on the number of tertiary students in colleges, universities or polytechnics, and the latter indicator is based on the number of graduates who have received tertiary education degrees, certificates or diplomas. These data are presented in Figures 4 and 5.

Figure 4 shows that South Korea has the highest ratio of number of students to total population during the period 1998-2009. Russia catches up rapidly and reaches almost the same level as South Korea in 2009. The US, Finland and Poland are also close to the top. Notably, China and India have the lowest intensity ratio.

[7]The coverage is all fields.

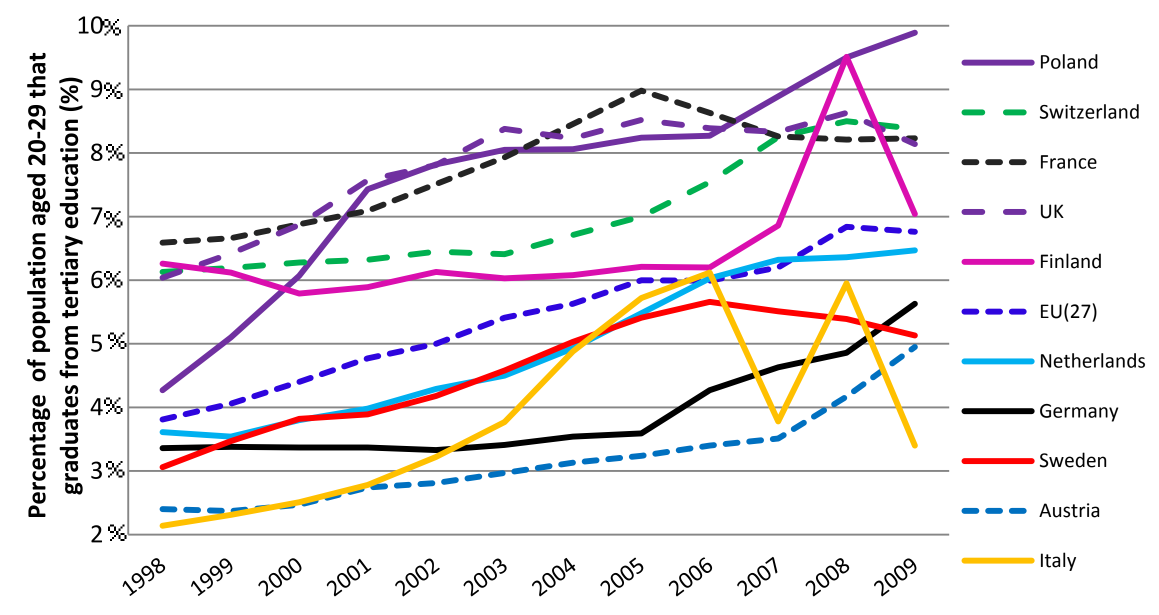
Figure 4 – Number of students in tertiary education per 100,000 inhabitants



Source:UNESCO (the tertiary education per 100,000 inhabitants), EUROSTAT (tertiary education) and United Nations (population).

Normalizing the number of students in tertiary education by the population of 20-29 years old, for some of the selected countries, a mixed picture appears (Figure 5) although most countries show a general increasing trend. Poland witnesses an outstandingly fast growth in the percentage of population aged 20-29 that graduates from tertiary education.

Figure 5[8] – Percentage of the population aged 20-29 that graduates from tertiary education



Source: EUROSTAT

To deepen the understanding of the S&T areas, the analysis is extended to tertiary graduates in S&T (Figure 6)[9]. This includes new tertiary graduates in a calendar year from both public and private institutions completing graduate and post graduate studies, compared to an age group that corresponds to the typical graduation age in most countries. It does not correspond to the number of graduates in these fields who are available in the labour market in this specific year.

The levels and fields of education and training used follow the 1997 version of the International Standard Classification of Education (ISCED, 1997) and the EUROSTAT Manual of Fields of Education and Training (1999). In addition to EU countries, Japan and the US are also included in the comparison.

In the S&T field France, Finland, Switzerland and the UK have the highest tertiary graduate intensity - above the average level of EU 27 countries. Compared with the non-EU countries, the EU 27 appears to be catching Japan up steadily, and increasingly higher than the US. In 1998, the EU 27 had a percentage of 0.88%, well below Japan (1.23%) and the US (0.92%). However, this situation gradually improved until 2009, with a percentage of 1.43% in EU, 1.42% in Japan and 1.03% in the US.

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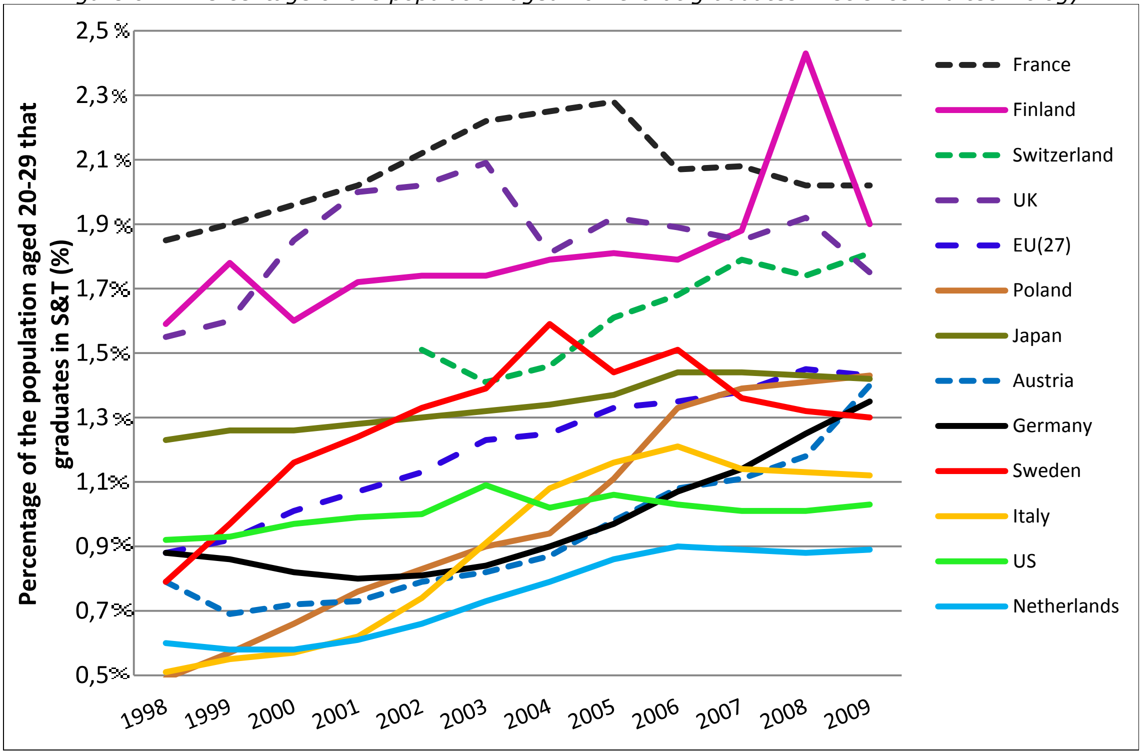
[8] Tertiary education is at levels 5-6, according to ISCED1997.

9 In Finland, the sharp increase in 2008 is in part due to the two-cycle degree structure adopted during 2005-2008. During those years, students could choose to finish their degrees according to either the old or the new system. This stimulated students who followed the old degree structure to complete their study before the termination of the old system by summer 2008.
(See more details on the two-cycle degree structure on the websites: http://www.science.gov.tm/projects/pes/en/finland.htm#s4 and http://www.helsinki.fi/studying/degree_system.shtml)

Figure 6[10] – Percentage of the population aged 20-29 that graduates in science and technology



Source: EUROSTAT

The project survey was also used to investigate this indicator - through responses on specific skills shortages and at which level the issue of skills shortages is most important.

The survey results showed that about half of respondents do not report any shortages in the categories of technician, graduates and doctorates. Of those that did report such shortages, 36% of these remaining respondents see a need for more technicians and doctorates, while 32% see a need for more graduate skills. Interestingly, over half of all respondents expect an increasing need for high-skilled R&D personnel in the next five years, with the scientific disciplines of Materials Science, Chemistry and Engineering being the top three most important predicted fields of interest. This indicates that the educational base of S&T and Engineering is of high importance.

Information was also obtained from various qualitative reports. The report "Assessment of impacts of NMP technologies and changing industrial patterns on skills and human resources" (Gelderblom *et al*., 2012) shows that the majority of literature available on skills, human resources and NMP technologies focuses on nanotechnology and nanosciences (N), rather than on materials (M) or new production processes (P). This is in accordance with the conclusion reached by this current project. The report also argues that most attention is devoted to university level studies within nanotechnology and nanosciences. What also became evident is a plea for inter-disciplinary curricula and supervision of students by different departments. Horn et al. (2009) found that nanotechnology degree programs are

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[10] Note: 1) Graduates (ISCED 5-6) in mathematics, science and technology. 2) Data for Switzerland between 1998 and 2001 are not available.

not concentrated in areas of high nanotechnology publication activity, but rather clustered in response to federal and state investments. The above mentioned report also identified an increased attention for nanotechnology and nanosciences at other education levels besides the university level, for instance nanotechnology and vocational education and training (including Lifelong Learning). In the same context, Yawson (2010) points out that vocational educational training (VET) in skill development for nanotechnology is getting more and more important. Stephan et al. (2007) observed that nanotechnology postsecondary education occurs more frequently in an informal manner, at university lab environments, rather than within formal degree programs. Another important aspect highlighted was the need of identifying skills demand, to avoid resource waste and imbalance (Malsch, 2008).

A number of reports from third countries discuss how other regions are tackling skills demand relevant to NMP. According to the report "Japan's Manufacturing Competitiveness Strategy: Challenges for Japan, Opportunities for the US" (Corwin and Puckett, 2009), Japanese firms are focusing on increasing productivity growth through skills upgrading. Furthermore, this report refers to a new program at Tokyo University that is designed "to transfer and preserve technical manufacturing know-how from factory floor workers and managers who have recently retired" in order to "avoid losing their unique skills and knowledge" and the government is trying to update the curriculum to meet the requirements of its high-tech manufacturing sector. Another recent initiative in the US, the Advanced Manufacturing Initiative, seeks to address the whole research and innovation environment to improve the performance of the advanced manufacturing sector. Education is mentioned in the report that lead to the creation of this initiative [11] and one of its elements is the dissemination of design methodologies for manufacturing.

4.1.2 Public Finance

The second input indicator is public finance - which is used to assess financial input enabling R&D at the national level. This indicator includes two types of information (i) The gross domestic expenditure on R&D (GERD), of which three sub-indicators are of interest; and (ii) Based on the survey, including the public funding received in different organizations and purpose of its use. The sub-indicators are as follows:

- Intramural R&D expenditures in the government sector, as a percentage of GDP;
- Intramural R&D expenditures in the business enterprise sector, as a percentage of the GDP;
- Intramural R&D expenditures in the higher education sector, as a percentage of GDP;
- Public funding data from the NMP primary data collection (survey).

GERD data includes data on R&D performed within a country and funded from abroad, but excludes payments for R&D performed abroad. GERD is not equal to public finance, although public finance is a main part of GERD, especially in the part of expenditure of government and higher education sections. GERD is constructed by adding together the intramural expenditures of the performing sectors – which are government, higher education, business enterprises and private non-profit. The

[11] Report to the president on ensuring American leadership in advanced manufacturing, June 2011.

private non-profit sector is not included, due to its relative insignificance and lack of data for a majority of countries.

The percentages of GERD in GDP by sector (*i.e*. government, higher education and business enterprise sector) are provided in Annex 6. The selected non-EU countries tend to have higher R&D intensity in the government sector but lower R&D intensity in education sector when compared with the EU-27 average values.

Overall, it was found that that the EU has consistently invested in R&D in the public sector (government and higher education sector) at a high level compared with other countries (information from EUROSTAT indicates an average of 0.68% GDP in the EU compared with 0.6% in the United States and 0.64% in Japan, over the period 2001-09). Member States who invest more than this include France, Germany, Finland, Sweden, and the Netherlands. In contrast the United Kingdom, Italy, and Poland invest lower than average amounts. South Korea is the only Third country to invest more (0.76%).

The NMP online survey (see Section 2.5.1) was used to investigate the public funding by receiver types and fields, as well as the purpose of use of the funding received. The survey respondents were targeted among senior managers (*e.g*. CEO, Director, Head of Unit). Their responses provided insightful information. The results of the survey (see Tables 3 and 4) are drawn mainly based on the level of respondents rather than the sample numbers. Some of the main findings of the survey are as follow:

- Private companies (both large companies and SMEs) who received public funding tend to have higher relevant percentages in Novel materials and Nanotechnology, which indicates that the public funding received in companies is more likely to be related to these two fields;
- Universities and higher education organizations who received public funding are highly relevant in all four fields, with Novel materials and Nanotechnology tending to assume a leading position.
- The main purpose of the received funding tends to be for applied research;
- Funded companies often have a higher percentage of investment in applied research than average;
- Surprisingly, SMEs who received public funding tend to have a higher percentage of doing basic research than large companies;
- University and higher education institutes have the highest percentage in basic research.

Table 3 – Sub-themes of NMP in private and public organizations that received public funding

Organization numbers	**Private organizations**				**Public organizations**			
	Large enterprises (18)		**SMEs (36)**		**Universities & higher education (56)**		**Research institutes (36)**	
	received public funding NMP R&D (14)		**received public funding NMP R&D (19)**		**received public funding NMP R&D (34)**		**received public funding NMP R&D (26)**	
	high relevance	**moderate relevance**	**high relevance**	**moderate relevance**	**high relevance**	**moderate relevance**	**high relevance**	**moderate relevance**
Biotechnology	2	1	5	3	21	3	9	8
Novel materials	8	4	11	3	25	5	15	7
Nanotechnology	7	3	10	4	26	5	15	7
Novel manufacturing processes	4	6	4	15	17	10	5	12
Percentages	**Private organizations**				**Public organizations**			
	Large enterprises (18)		**SMEs (36)**		**Universities & higher education (56)**		**Research institutes (36)**	
	received public funding NMP R&D (14)		**received public funding NMP R&D (19)**		**received public funding NMP R&D (34)**		**received public funding NMP R&D (26)**	
	high relevance	**moderate relevance**	**high relevance**	**moderate relevance**	**high relevance**	**moderate relevance**	**high relevance**	**moderate relevance**
Biotechnology	14.3%	7.1%	26.3%	15.8%	61.8%	8.8%	34.6%	30.8%
Novel materials	57.1%	28.6%	57.9%	15.8%	73.5%	14.7%	57.7%	26.9%
Nanotechnology	50.0%	21.4%	52.6%	21.1%	76.5%	14.7%	57.7%	26.9%
Novel manufacturing processes	28.6%	42.9%	21.1%	78.9%	50.0%	29.4%	19.2%	46.2%

Source: Project survey

Table 4 – Purpose of received funding (those who received public funding)

	Large enterprises (14)	SMEs (19)	University and higher education (34)	Research institutes (26)
Basic research	21.4%	31.6%	82.4%	65.4%
Applied research	85.7%	78.9%	88.2%	84.6%
Demonstration/proof of concept	50.0%	47.4%	44.1%	38.5%
Manufacturing scale-up	35.7%	42.1%	11.8%	15.4%
Develop an existing product	28.6%	15.8%	11.8%	7.7%
Access new markets (product based)	7.1%	31.6%	0.0%	3.8%
Access new markets (geographical)	0	0	0	0
Explore new R&D opportunities	35.7%	36.8%	38.2%	30.8%
Establish new collaboration	21.4%	21.1%	47.1%	30.8%

Source: Project survey

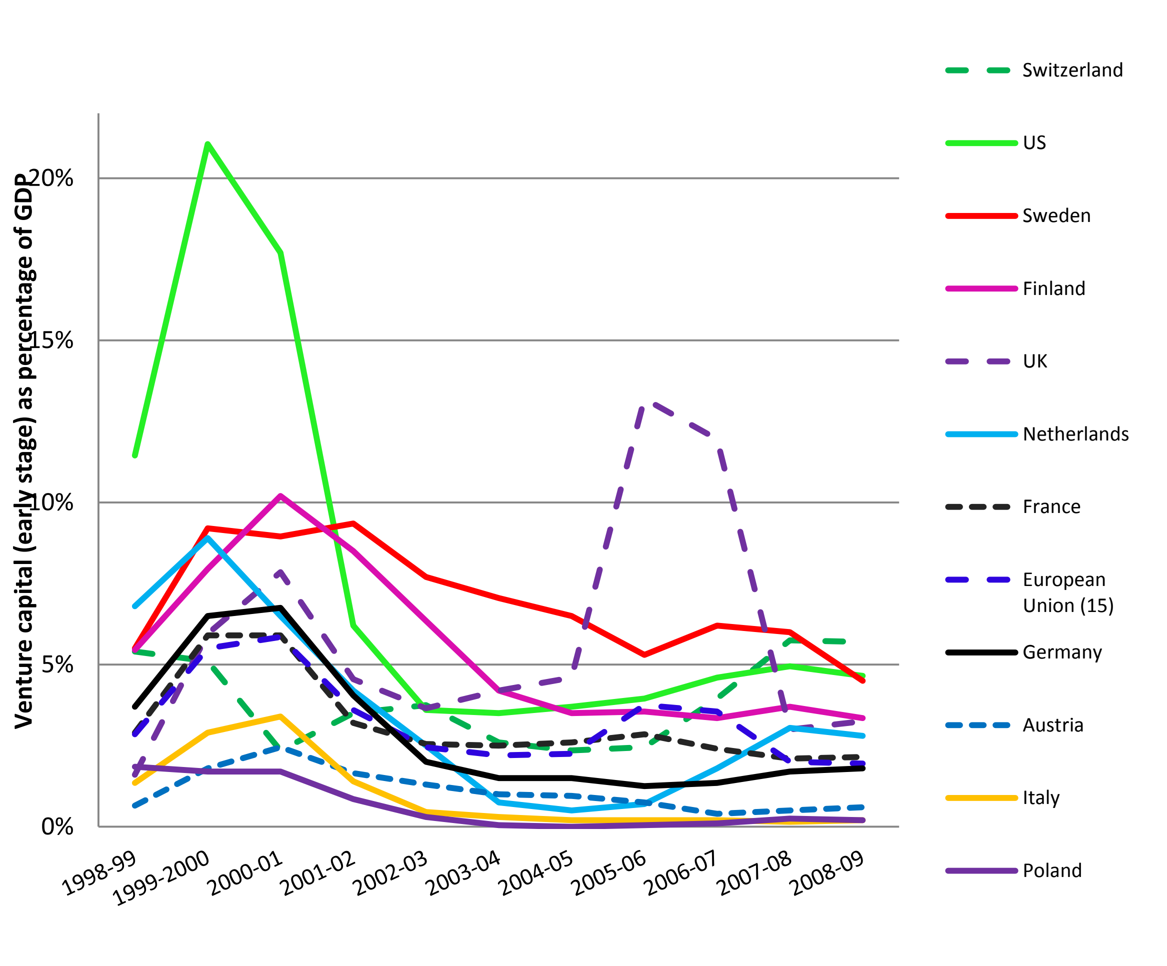
4.1.3 Venture capital

Venture capital is an important financial source. Venture capital funding worldwide in nanotechnology was estimated as 65M US$ in 1999 and nearly 500M US$ in 2005. (Lux Research, 2004; Anquetil, 2005; PriceWaterhouseCoopers, 2005; Hullmann, 2006). Few companies dominate the total venture capital investment, e.g. three US companies (Nanosolar, A123 Systems and Neophotonics) received around 75 B$. In Europe, the venture capital in nanotechnology received by four companies (Nanda Technologies, Crocus Technologies, Nanotech Semiconductor and Genomic Vision) accounted for 24 M€ (ObservatoryNano, 2010).

Venture capital investment often focuses on two different phases: a) early stage, and b) expansion and replacement. Given the fact that venture capital is a highly volatile indicator, as Hollanders and Van Cruysen (2008) have suggested, two-year averages are used to reduce the volatility rate.

The early stage venture capital information (Figure 7) shows material fluctuations, with large increases and decreases in particular in the US and UK. The US had a peak in 1999-2000, with a percentage of 21.1%, but this declined rapidly in the following two or three years, reaching 3.6% in 2002-2003. The UK shows a strong increase between 2005 and 2007. However it seems that the general trend is downward. A few countries, such as Switzerland and the Netherlands, appear to escape this trend to a certain extent. On average, during the whole period 1998-2008, the US has the highest percentage. From EU countries, the UK and Sweden are the highest, with an average 6.9% and 5.8% respectively.

Figure 7[12] – Venture capital as a percentage of GDP – early stage

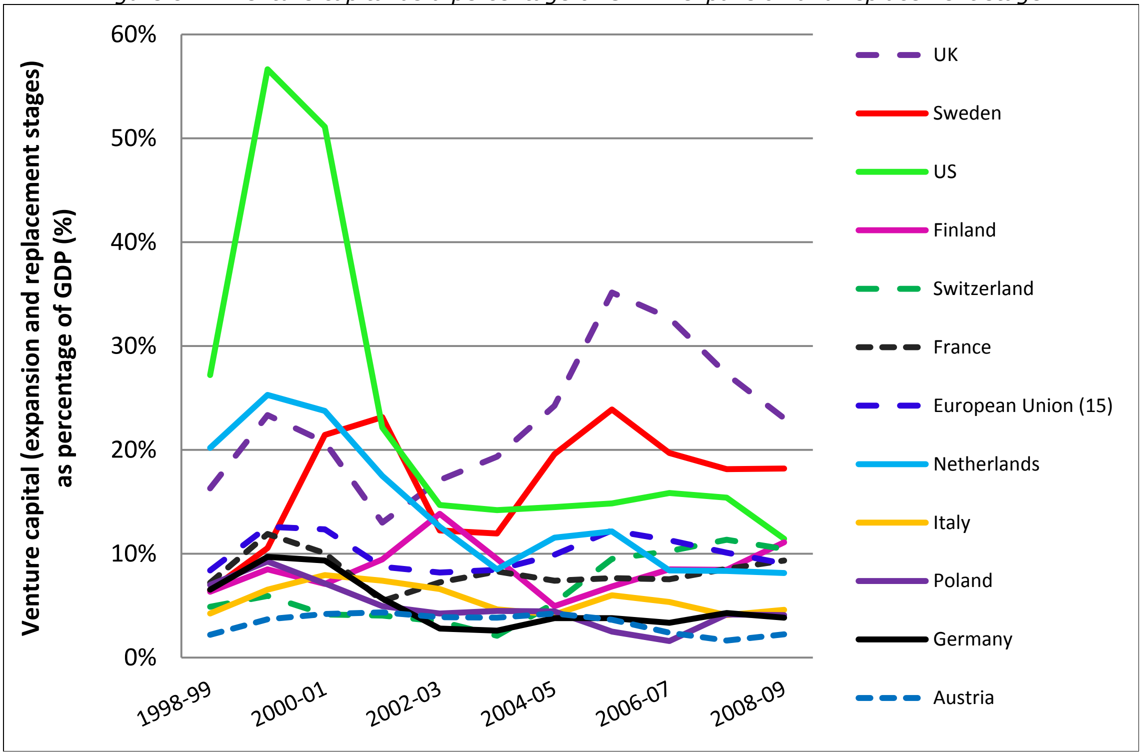


Source: EUROSTAT

In the expansion and replacement stage (Figure 8), venture capital in the US has also appeared to have a similar peak as early stage venture capital, immediately followed by sharp declines. In Europe, the UK has the highest level of such expansion and replacement venture capital, with a steady increasing trend between 2001 and 2006, although afterwards it shows also a declining trend. On average, during the period 1998-2008, the US has the highest level (23.5%), followed closely by the UK (22.9%). Sweden and the Netherlands have an average percentage of 16.9% and 14.2%, respectively.

[12] The percentage is a two-year average.

Figure 8[13] – Venture capital as a percentage of GDP – expansion and replacement stage



Source: EUROSTAT

Data referring to the EU15 , indicate that venture capital represents about 10% of total investment funds raised in both 2006 and 2007. The situation for each selected country in these two years is summarized as follows:

- Austria: Venture capital fund increased by 76.3%, mainly focused on expansion and development. High-tech sectors received more than non high-tech.
- Finland: The allocation to venture capital decreased slightly, with more drops in high-tech than non high-tech.
- France: The absolute value of venture capital allocations suffered most with a 66.3% drop, but high-tech later stage was the only sector with an increasing allocation.
- Germany: Early-stage benefited the most. High-tech share increased to more than half of the total in 2007.
- Italy: Venture capital is mainly located in non high- tech, though the share of high-tech increased mildly from 2006 to 2007.
- The Netherlands: Venture capital allocation changed substantially from 2006 to 2007. Non high-tech funding reduced to zero, while high-tech funding was sustained by early-stage with a drop in later stage high-tech allocation. In 2007, the venture capital allocation was 100% fully in high-tech in the Netherlands.
- Poland: In 2006, Poland was the only European country with 100% non high-tech venture capital, which changed to a 50-50% share in 2007.
- Sweden: Venture capital allocation increased more than four fold. The allocation to non high-tech venture capital increased considerably from

[13] The percentage is a two-year average.

27.2 M€ to 380 M€, while high-tech allocation increased slightly, from 142.4 M€ to 375.2 M€. Therefore the shares in high-tech and non high-tech reached almost the same level in 2007.

- Switzerland: Venture capital allocation tripled from 231.5 M€ in 2006 to 690.7 M€ in 2007. High-tech received the majority of this investment.
- The UK: Venture capital allocation to non high-tech dropped 92.3% from 2006 to 2007. Hence high-tech dominated the venture capital investment.

Looking at the constitution of venture capital recipients, for instance in 2007, it is of interest to see that two types of organizations are the major receivers of venture capital investments, namely, institutes with 20-99 employees and 1000-4999 employees, receiving 31.1% and 24.3% of the total amount, respectively [14].

4.1.4 Industrial R&D expenditure

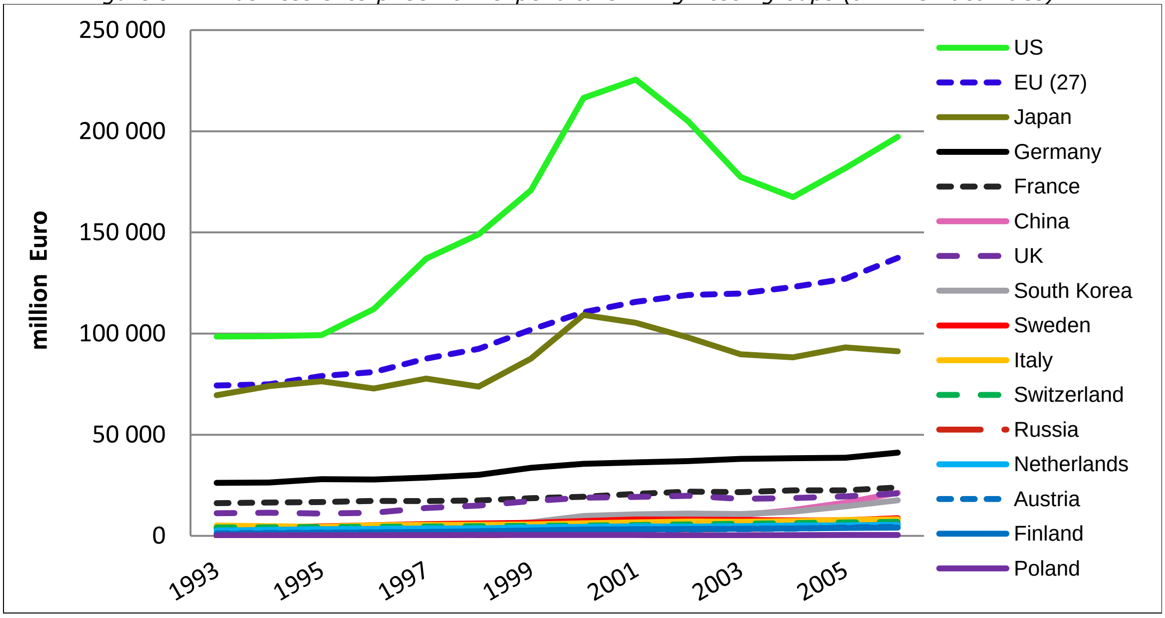
Figure 9 provides data gathered for BERD (Business Enterprise Expenditure on R&D) in the high-tech sectors. It can be seen that the EU countries as a whole have been able to maintain a steadily increasing level of business R&D expenditures, in contrast to the US and Japan.

When comparing the high-tech BERD information to the previous GERD information, it can be seen that although China has had increasing business spending on R&D, the level is still not as high as some other countries. Amongst the EU selected countries, Germany is the leading country regarding BERD in high-tech sectors, with France and the UK in second and third position.

Of interest here is that already in 2006 China was about to surpass the UK and claim, after the US, Japan, Germany and France, the fifth highest position with respect to high-tech business R&D expenditure. Poland trails these countries with a low amount of high-tech related business expenditure.

[14] EVCA Yearbook 2008, P.40

Figure 9[15] – Business enterprise R&D expenditure in high-tech groups (all NACE activities)



Source: EUROSTAT

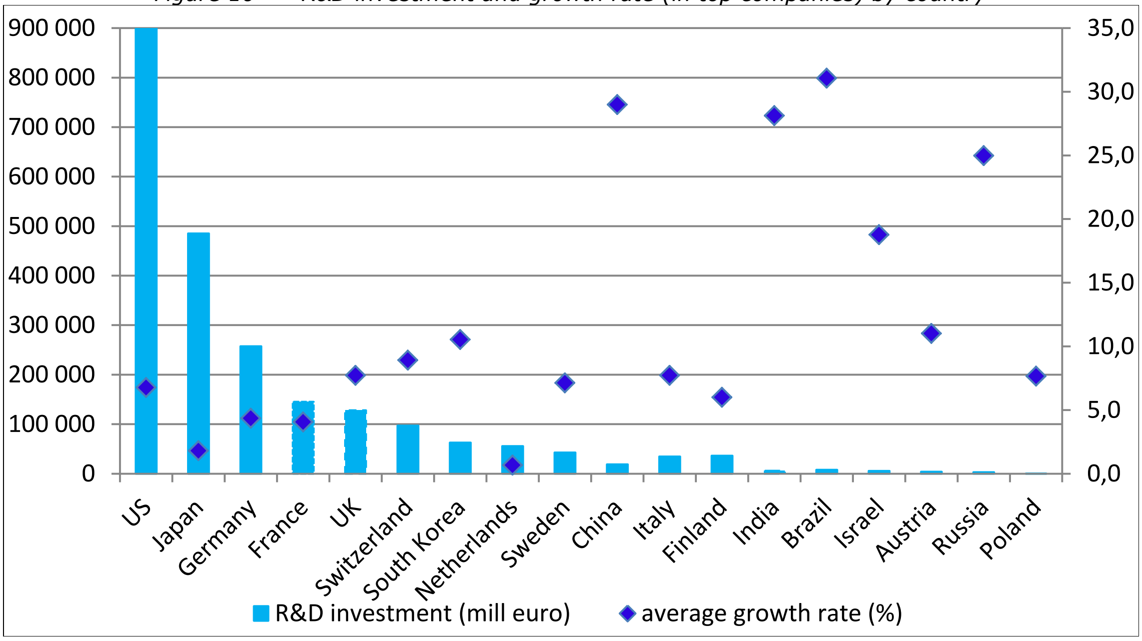
The following analysis focuses on the R&D investment, growth rate and intensity associated with net sales in top companies.

Based on the top 1,000 EU and top 1,000 non-EU companies,[16] all the top companies in each of the 18 selected countries have been identified. By summing the results for these companies in each country, an estimate of the total R&D value for each country is achieved. Given such top companies are often the world's largest high-technology corporations, this can be used as a value indicator representing the industrial level of investment for their countries.

Figure 10 compares the calculated total R&D investment (as the sum for years 2005-2010) and its growth rate. The US, Japan and Germany are the three countries with the highest R&D investments, constituting 70% of the worldwide R&D investment under this measure. Countries with low values of total R&D investment all showed strong R&D growth in the 5 years analysed. In particular, the annual growth rate in China, India and Brazil were all above 28%.

[15] data available for China and Russia during 1993-1988, and South Korea during 1993-1997.
[16]From the EU Industrial R&D Investment Scoreboards, various years.

Figure 10[17] – R&D investment and growth rate (in top companies) by country



Source: European Commission, JRC/DG RTD, the EU Industrial R&D Investment Scoreboards, 2006, 2007, 2008, 2009, 2010 and 2011

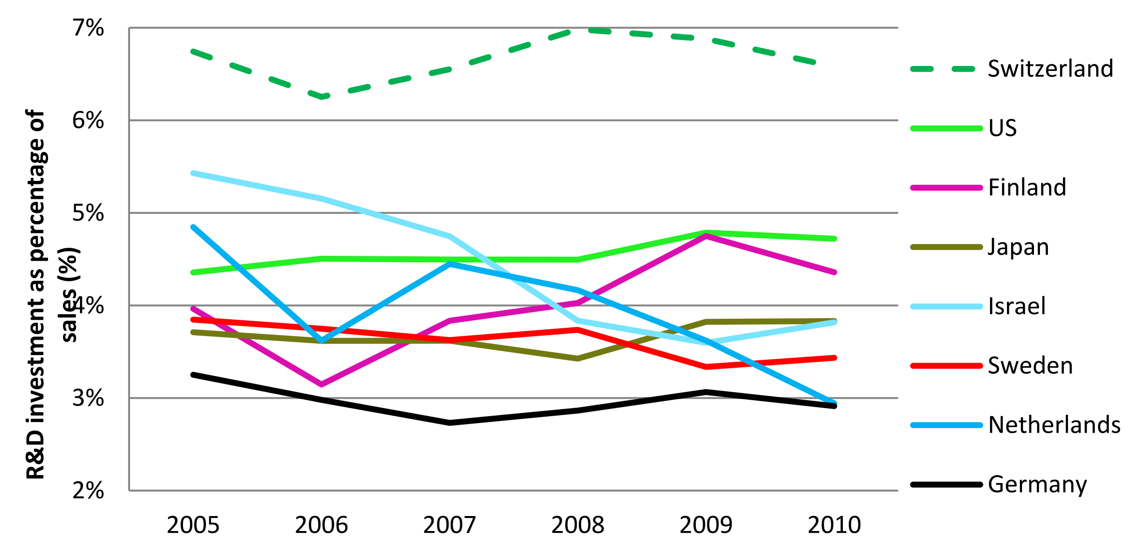
The share of global R&D in developing countries continues to increase gradually, albeit their total R&D value is still low. The high growth rates of R&D investment in developing countries projected a catch-up trend of those nations in S&T field, which indicates that transition or emerging economies are making efforts in moving in a more innovation-oriented direction.

R&D investment intensity, defined as the ratio between a company's investment in R&D and its sales, offers another perspective on R&D concentration in companies. Figure 11 shows the countries with highest R&D investment intensities. The main findings are as follows:

- Most countries seem to share a common decreasing trend in their industrial R&D intensities, which indicates a slower growth rate in R&D investment than that of net sales. Exceptions are Finland and Poland;
- The increase of R&D investment intensity in the US is also an exception, which can be said to be mainly caused by the decrease of its net sales.

[17]Note: 1) Data are summed from the top 1000 EU and top 1000 non-EU companies. 2) R&D investment is the total of five years (2005-2010) and growth rate is the average growth rate.

Figure 11 [18] – Industrial R&D investment intensities in selected countries (R&D investment as percentage of sales)



Source: European Commission, JRC/DG RTD, the EU Industrial R&D Investment Scoreboards, 2006, 2007, 2008, 2009, 2010 and 2011

In the survey, we analysed respondents' re-investment of turnover in R&D activities. Approximately 31% of all respondents invest more than 25% of turnover in internal RTD. These respondents came from all groups (universities, research institutes, micro enterprises, SMEs, and large enterprises). In contrast 14% invest nothing at all, and these all came from universities, research institutes, or micro enterprises. 11% invest more than 25% of turnover in new collaborations, with respondents coming from universities, micro enterprises and SMEs. In contrast 16% invest nothing at all, again these tend to be universities, research institutes, or micro enterprises - although not necessarily the same ones as above. 9% invest more than 25% of turnover in externally contracted RTD, with these coming from universities, research institutes and one large enterprise. In contrast 31% invest nothing at all, represented by all groups except large enterprises. 10% invest more than 25% of turnover in capital equipment and facilities – mainly universities and research institutes, while 18% invest nothing at all, represented by all groups except large enterprises. Finally, 5% invest more than 25% of turnover in training for R&D staff, and these are all universities or research institutes with the exception of one SME. In contrast, 20% invest nothing at all, represented by all groups except large enterprises.

4.1.5 Infrastructure

Infrastructure use is an enabling factor within R&D and innovation. This study aimed to construct a composite indicator for infrastructure, made up of three sub-indicators: Geo-distribution of institutions and firms in NMP; Laboratories and research facilities for NMP; Use of funding, capabilities and capacities in NMP. Although a large amount of data was obtained by desk-based research, as described in Section 2.6.1, much of this data was qualitative (see Annex 5) and, as such, a full indicator on infrastructure was not developed. Nonetheless, the

[18]Note: 1) Data are summed from the top 1000 EU and top 1000 non-EU companies. 2) R&D investment is the total of fiveyears (2005-2010) and growth rate is the average growth rate.

qualitative information gathered was drawn into the overall analysis (see Section 5.1.5).

4.2 Output indicators

When studying the output indicators we have considered the following sub-categories for NMP: Nanoscience and nanotechnology, Materials science, Chemical engineering, Construction and building, and Machine tools, Mechanical engineering, Production and processing, and Textile.

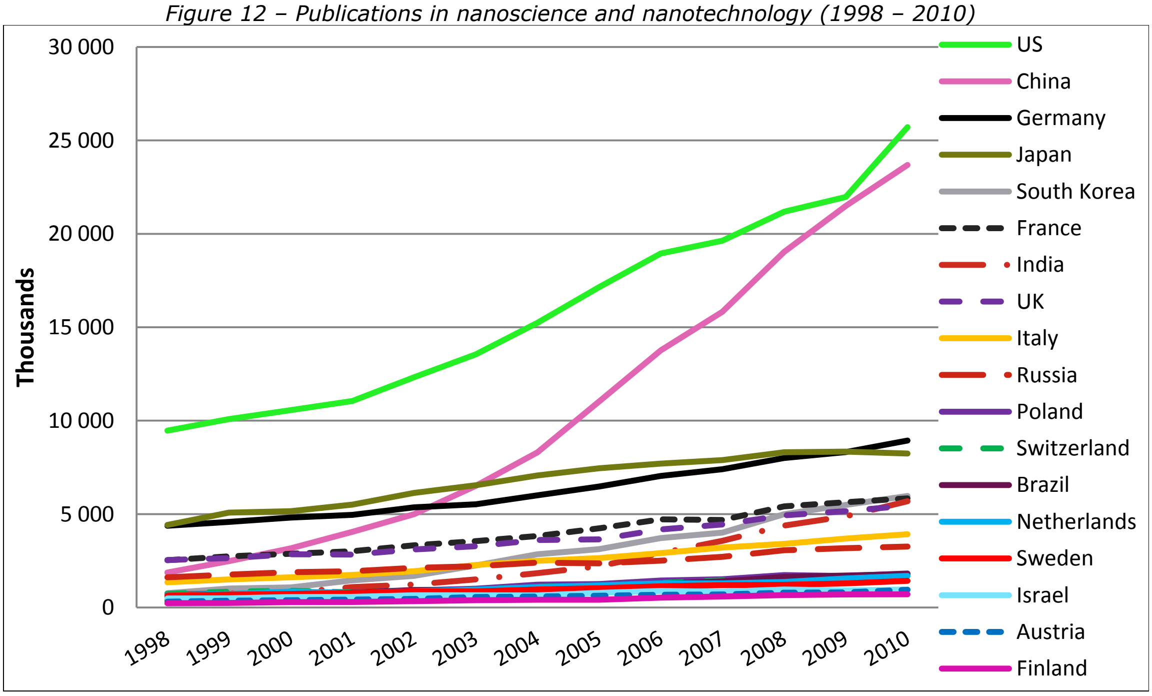
4.2.1 NMP scientific publications

Scientific publications are a direct output of basic research, which received 60% of the funding obtained by the respondents of the survey. Scientific publications have been analysed in both quantitative and qualitative terms. The former sub-indicator is illustrated by the publication numbers, the latter embodied by the journal impact factor.

4.2.1.1 Quantitative indicator - publication numbers

<u>Nanoscience and nanotechnology</u>
Figure 12 illustrates an interesting picture for nanoscience and technology. The US has had a leading position in basic research. However, possibly due to leap-frogging, China has been able to catch-up in an impressive way, leaving other countries behind. Japan and Germany still play a role, although the trend seems to be for a levelling off in these countries. France, South Korea, the UK and India are in the third stratification, with India in a similar rising trend as China. Russia and Italy follow these countries, while all others trail behind.

Figure 12 – Publications in nanoscience and nanotechnology (1998 – 2010)

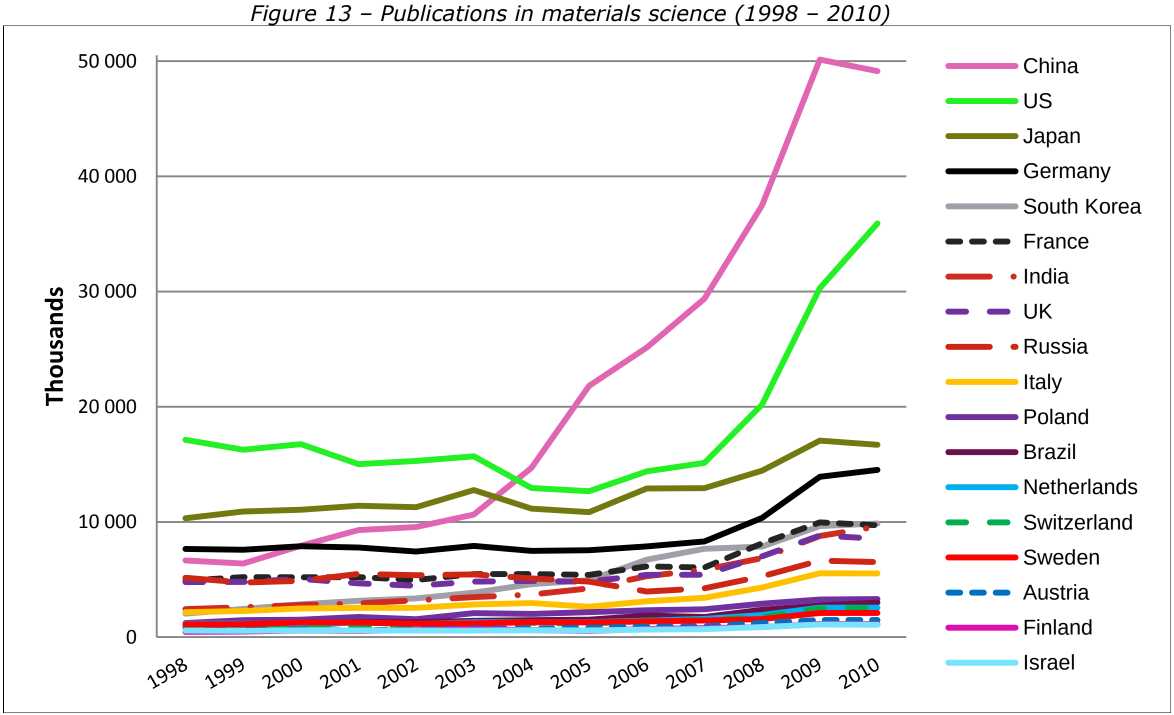


Source: MERIT nano publication database

Material science

Figure 13 on Material Science publications shows that many countries are in the same band, and that the field has two lead players - the US and China. There has been a large rise in Materials Science focused basic research in China, such that it has been the field leader since 2004. The reversal of this trend for China in 2010 is currently unexplained, and it will be interesting to see if this trend will be sustained. It is also clear that the US has been trying to catch up since 2007. Most other countries are fairly stable or slightly increasing.

Figure 13 – Publications in materials science (1998 – 2010)



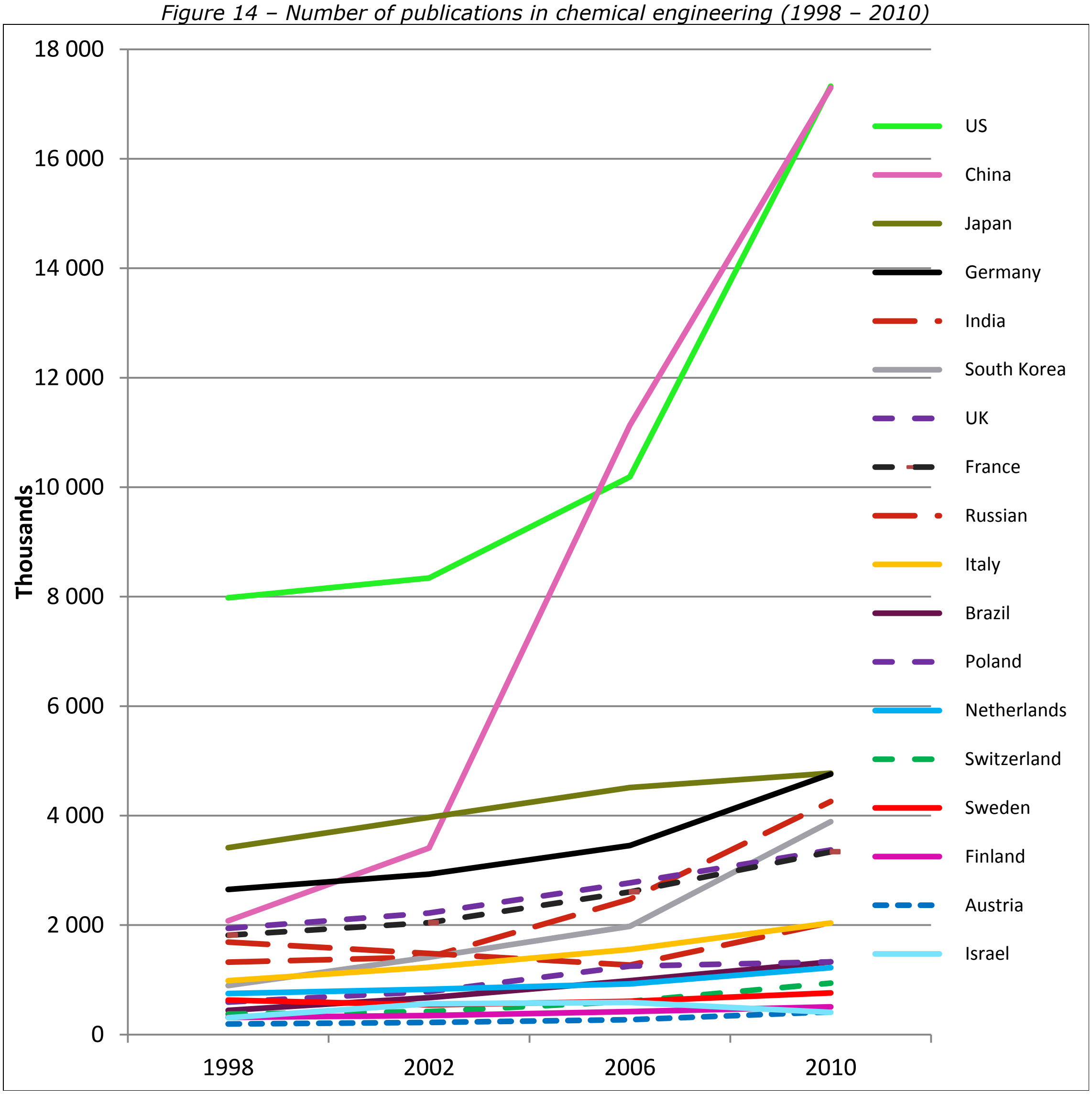
Source: Scopus - SciVerse Elsevier

The comparison with nanoscience and technology is informative. In a more traditional field, such as materials science, the countries with a strong tradition in these sciences also lead the field - giving a clear link between targeted investments and the desired outputs, such as publications and patents.

Chemical Engineering

Moving to the field of Chemical Engineering we find that a similar picture as the one that for Nanoscience and technology publications emerges. In Figure 14 we see that the US and China are vying for the top spot in terms of publication numbers, with an impressive gain in numbers by China starting in 2002. Japan is likewise levelling off against Germany which is showing respectable growth. India and South Korea are in 5th and 6th place respectively, while France and the UK share a 7th place, with near equal growth.

Figure 14 – Number of publications in chemical engineering (1998 – 2010)



Source: Scopus - SciVerse Elsevier

The publication numbers of the next five sectors, Construction and building, Machine tools, Mechanical engineering, Production and processing, and Textile, are much lower than those from Nanoscience and technology, and Materials science. Thus, the Figure for these five sectors (Figure 15) includes only the top 6 countries which have significant records in each field.

<u>Construction and building</u>
In the construction and building field, Austria has the leading position in the period, although Brazil catches up rapidly, from 32 records of publications in 1998 to 713 in 2010.

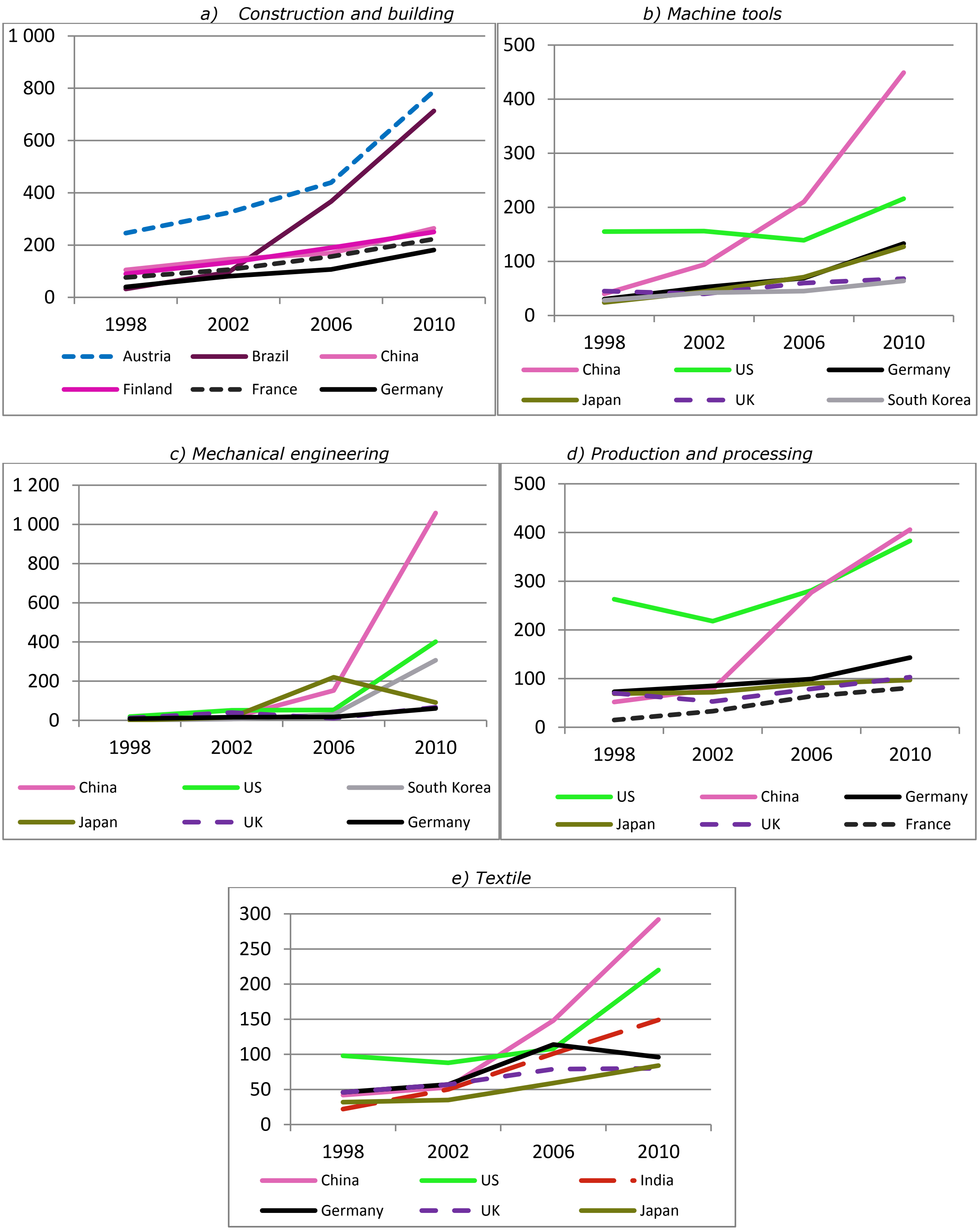
<u>Machine tools</u>
In the field of machine tools, the US headed the list in 1998 with 155 publications, but stagnated in the middle period and improved mildly in 2010. China started with a rather low number (40 publication records in 1998) but reached 449 publications in 2010.

Mechanical Engineering
In mechanical engineering, all countries started from almost the same level, but greatly diverged from 2006. China had over 1,000 publication records in 2010, very far ahead of the US (401 publications).

Production and processing
In the production and processing field, the US was the leader until 2006, when China overtook. Germany, Japan, the UK and France all experienced gradual and steady increases during the period, but none of them grew as fast as China.

Textiles
Textile is the field with the fewest publications, although there is a clear growing general trend in publication records.

Figure 15 – Publication numbers in construction and building, machine tools, mechanical engineering, production and processing, and textile (1998 – 2010) – top 6 countries



Source: Scopus - SciVerse Elsevier

4.2.1.2 Publication quality

The impact factor[19], an index based on the frequency with which a journal's articles are cited in other scientific publications, is a widely accepted approach in measuring journal quality. This section uses impact factors to evaluate publication quality by country.

The approach for the five sectors with relatively fewer publications (Construction and building, Machine tools, Mechanical engineering, Production and processing, and Textile), was as follows:

- Publication records by journal were extracted for each field in four studied years (1998, 2002, 2006 and 2010);
- Based on the publication numbers (from high to low), approximately 50 journals were selected that appeared in all four years. In order to have a comparable framework, journals were not included if they appeared in the list less than four times. Thus the selected 50 journals must have existed during 1998-2010;
- For each journal the average SJR score in 1998, 2002, 2006 and 2010 [20] was calculated;
- Based on the ranking of the average impact factor score, the top 10 journals were selected;
- Finally, for each of these 10 top journals, publication records were retrieved by country, and then the total number aggregated for each country. This represents the total paper numbers published in these top 10 journals by country.

For two of the larger sectors – Materials science and Chemical engineering – a different strategy was used. The same steps (i) to (iii) were used. However once the average ranking was done, the top 50 journals were selected. This higher number of core journals was used due to the larger set of publications in these sectors, enabling a better spread of publication output over a larger core journal set. The final step involved retrieving publication records by country and by year, while finally aggregating these numbers for each country.

This strategy was also used for Nanotechnology. However the normalization was done using the citation scores collected in the years 1998, 2002 and 2006. This excluded 2010 due to the low amount of citations acquired by the publications from this year. Citation lag, which is on average three years, leads to a skewed distribution when compared to the citation scores for publications from later years. This can be noticed in the table for nanotechnology.

This phenomenon is also a reason for the use of the (average) Impact Factor X Publication Score based model as opposed to the Impact Factor X Citation Score based model when calculating a quality related indicator, at least when including recent years.

Table 5 illustrates the publication shares in the top 10 journals by sector and by country. In general, the top 6 countries, the US, China, Germany, the UK, Japan and France, account for 62.5% of total publications in the top 10 journals.

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[19] Also known as SCImago Journal Ranking indicator in Scopus.
[20] SJR score is not available for 1998, therefore the 1999 score was used.

Table 5 – Publication shares in the top 10 journals, by sector

	Average percentage of four years (1998, 2002, 2006, 2010)					
	Construction	**Machine tools**	**Mechanical engineering**	**Production and processing**	**Textile**	**Average of 5 sectors**
US	37.1%	18.4%	18.8%	34.3%	12.7%	**24.2%**
China	16.9%	14.6%	3.9%	7.9%	9.1%	**10.5%**
Germany	9.4%	12.7%	6.3%	12.3%	4.2%	**9.0%**
UK	7.5%	8.2%	8.9%	4.7%	9.7%	**7.8%**
Japan	10.2%	12.7%	1.8%	7.9%	2.3%	**7.0%**
France	6.7%	0.0%	1.6%	6.5%	5.3%	**4.0%**
India	1.8%	2.5%	1.6%	0.7%	10.9%	**3.5%**
Italy	3.0%	4.4%	2.6%	2.9%	2.6%	**3.1%**
Poland	1.0%	3.2%	1.3%	0.4%	9.5%	**3.1%**
South Korea	3.6%	2.5%	1.0%	2.2%	2.4%	**2.4%**
Netherlands	2.6%	0.0%	1.3%	3.2%	0.7%	**1.6%**
Brazil	0.7%	3.2%	1.0%	0.4%	1.2%	**1.3%**
Austria	1.0%	1.9%	0.5%	2.2%	0.5%	**1.2%**
Switzerland	1.2%	2.5%	0.0%	1.1%	1.2%	**1.2%**
Sweden	1.1%	0.6%	1.3%	0.4%	1.0%	**0.9%**
Israel	1.3%	0.6%	0.5%	1.1%	0.1%	**0.7%**
Russia	0.6%	0.6%	0.3%	0.4%	1.0%	**0.6%**
Finland	0.4%	0.0%	0.3%	0.0%	0.7%	**0.3%**

Source: Scopus – SciVerse Elsevier with authors' own calculation

The US is leading in all sectors, in particular in the sectors 'Construction' and 'Production and Processing', both of which contribute a very large share in the total number of publications in top journals, of more than 30% in each sector. China is the second highest in terms of publication shares in top journals, followed by Germany, the UK, Japan and France. When looking at the trend over the past 12 years (Figure 16), we see the decreasing shares from the US in most sectors. In particular, the (top journal) publication shares in the Production and Processing sector experienced a sharp decline in the US, from 60% in 1998 to 18.6% in 2010. On the contrary, China increased its share steadily in almost all the sectors. In the Textile sector, there is no country which is constantly leading. The shares of the top six countries vary considerably over the years.

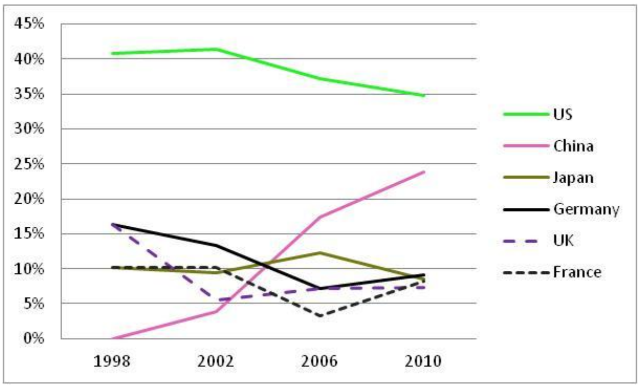
<u>Material science</u>
Table 6 shows the proportional division of publications in the top 50 peer reviewed journals in the field of Material Science, accumulated during the years, 1998, 2002, 2006 and 2010. The division per country shows a clear lead by the US, followed at a distance by China, Germany and the UK. Japan, France and India are in 5th, 6th and 7th places, all with a percentage above 6%".

<u>Chemical Engineering</u>
Table 7 shows the proportional division of publications in the top 15 peer reviewed journals in the field of Chemical Engineering, accumulated during the years, 1998, 2002, 2006 and 2010. The division per country shows a clear lead by Switzerland in terms of the quality of publications, followed by four other European countries; Germany, Sweden, France and the Netherlands. These four deviate only 0.5% from one another, and could be seen to share a 2nd place after Switzerland. In third

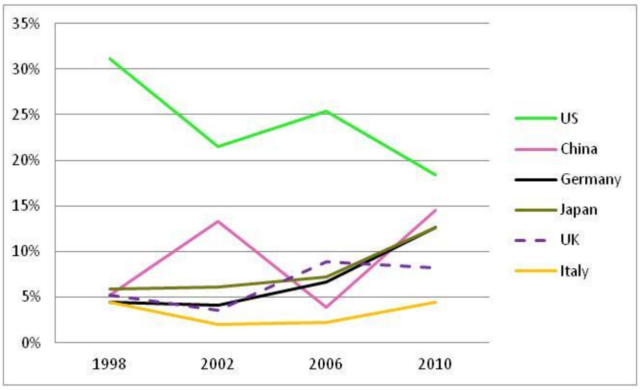
place is then the UK, followed by the first non-European country; South Korea. The US claims a surprising 8th place in the quality ranking of our sample.

Figure 16 – Publication shares (in the top 10 journals) of the top 6 countries over the period 1998 - 2010

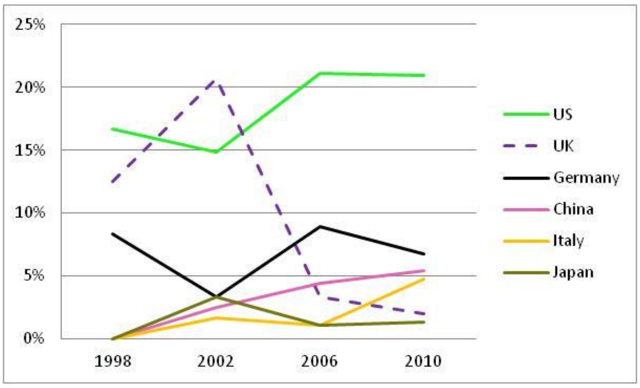
a) Construction and building



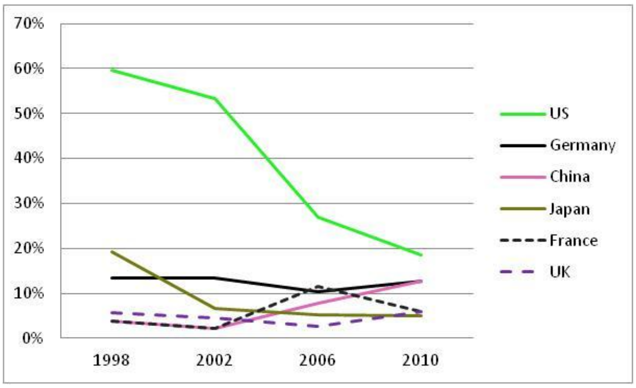
b) Machine tools



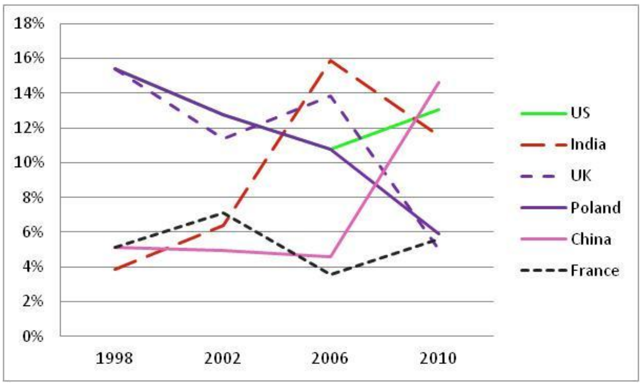
c) Mechanical engineering



d) Production and processing



e) Textile



Source: Scopus - SciVerse Elsevier with authors' own calculation

Table 6 – Publication scores in top 50 peer reviewed journals in materials science

	Publication scores					
	1998	**2002**	**2006**	**2010**	**Average**	**Percentage of publications**
US	1067.68	1205.01	1029.80	3345.94	**1662.11**	**21.6%**
China	344.83	527.17	1236.06	1936.67	**1011.18**	**13.6%**
Japan	660.90	654.05	702.10	1053.91	**767.74**	**11.6%**
Germany	420.86	421.57	549.99	1244.19	**659.15**	**9.4%**
India	242.21	205.74	375.53	1159.63	**495.78**	**6.3%**
South Korea	235.21	441.25	407.04	725.60	**452.27**	**6.2%**
France	344.12	377.62	433.56	589.89	**436.29**	**6.6%**
United Kingdom	346.60	282.74	342.61	681.45	**413.35**	**5.8%**
Russia	173.62	105.74	98.61	925.34	**325.83**	**4.7%**
Italy	126.18	167.18	212.27	419.61	**231.31**	**3.4%**
Netherlands	71.94	93.46	134.35	253.50	**138.31**	**1.8%**
Sweden	131.30	77.18	109.98	222.74	**135.30**	**1.8%**
Switzerland	127.62	60.28	104.09	190.92	**120.73**	**1.6%**
Brazil	124.78	85.52	101.02	164.8	**119.03**	**1.6%**
Poland	132.10	85.06	94.28	139.21	**112.66**	**1.7%**
Israel	114.77	55.44	62.47	124.72	**89.35**	**1.2%**
Austria	23.12	27.51	49.66	118.28	**54.64**	**0.8%**
Finland	24.34	31.99	38.64	87.01	**45.50**	**0.6%**

Source: Scopus – SciVerse Elsevier with authors' own calculation.

Table 7 – Publication shares in top 15 peer reviewed journals in chemical engineering (1998 – 2010)

Country	Percentage
Switzerland	28.6
Germany	19.2
Sweden	19.2
France	19.1
Netherlands	18.8
UK	17.2
South Korea	16.9
US	16.5
Japan	16.1
Italy	15.6
Israel	14.5
Austria	13.4
Finland	11.4
China	10.7
Brazil	9.2
Poland	7.9
India	6.5
Russia	4.0

Source: Scopus - SciVerse Elsevier with authors' own calculation

Nanoscience

Due to the fact that the articles or journals publishing the outcomes of basic science research would be cited more than those focusing on applied science, an effort has been taken to correct the bias of measurement of citations, which has arisen due to the nature of the research conducted in different organizations. We use the aggregate impact factors of subject categories in the Journal Citation Reports of Web of Science to discount the advantage associated with basic science research.

The results of citation analysis in Nano sector (Table 8) show that the US and Europe lead in the quality of publications. The institutions in US, Europe, Israel and Australia have higher scores than their counterparts in Asia. Taking 2006 as an example, in the top 75 institutions among the world's most prolific measured by citation score, there are only 7 institutions located in Asia. None of these top 75 organizations is from China or India.

Compared with the publication results by country, it shows that improvement of the quality of the publications from the Asian countries in the past ten years is not as dramatic as the increase in the amount of publications produced there. Though Asian countries increase their ranking gradually, it takes much longer for them to improve citation scores than increasing publication numbers.

Table 8[21] – Nano publication citation score

1998		2002		2006	
Country	**Citation score**	**Country**	**Citation score**	**Country**	**Citation score**
Switzerland	14.24	US	9.74	Netherlands	2.59
US	14.04	Switzerland	8.49	Switzerland	2.37
Netherlands	13.86	Netherlands	8.03	US	2.27
Israel	11.57	Israel	8.00	UK	2.02
Sweden	11.23	Austria	7.78	Germany	1.95
Finland	11.08	UK	7.72	Israel	1.86
UK	11.07	Finland	7.63	Austria	1.82
Germany	10.14	Germany	7.52	Sweden	1.77
France	9.37	France	6.92	France	1.72
Austria	8.88	South Korea	6.85	Finland	1.67
Japan	7.91	Sweden	6.78	Italy	1.57
Italy	7.91	Italy	6.62	Japan	1.53
Brazil	6.55	Japan	5.90	South Korea	1.43
South Korea	6.08	China	5.42	China	1.33
India	5.93	India	4.67	India	1.15
China	5.29	Brazil	4.25	Poland	1.14
Poland	5.21	Poland	4.01	Brazil	1.08
Russia	4.63	Russia	3.34	Russia	0.98

Source: MERIT Nano database with authors' own calculation

[21] This is aggregated from top institutions for each country.

4.2.2 NMP patents

Patent application data was extracted from EPO-PATSTAT. Considering that 2010 patent data is incomplete yet in the 2011 version PATSTAT database, we choose 2009 as the most recent year. (As a matter of fact, due to the time lag between the priority date and the availability of patent information, patent numbers in 2009 are still not completely included in the database.)

For the following sectors, the patent numbers are patent applications, and the country total is based on the distinct patent ID’s in the country of inventors. The IPC codes from WIPO are adopted for the sectoral classifications[22]. For Nanoscience and technology, Construction, Mechanical engineering and Textile sectors, we used the four-digit IPC code. However, for the rest of the sectors (Material science, Machine tools, Manufacturing, and Chemical engineering) which are not covered directly by the hierarchical categories, we had to use both 4- and 8- digit codes.

It is worthy of mention that the coverage of IPC codes in different sectors varies greatly. The sector of Nanoscience and nanotechnology has a clear IPC code, thus corresponding patent applications can be regarded as “accurate” nanotechnology patents. However, for sectors like materials, Chemical engineering, machine tools and manufacturing, IPC codes are widely spread across almost all fields, therefore the patent applications extracted by those codes include not only “accurate” but also some “related” patents. Considering the fact that less accurate sectors (like Material science and Chemical engineering) cover a large amount of patent applications, the impact from accurate sector (e.g. Nanotechnology) is less pronounced in the patent density analysis.

<u>Nanoscience and nanotechnology</u>
When the patent applications in nanoscience and nanotechnology are investigated (see Figure 17), it can be seen that in terms of applied research and commercialization the US was leading until early 2000. Numbers of nano patent in South Korea have been increasing rapidly since 2002. As shown in Figure 17, South Korea outperformed the US and reached first position after 2006. In Europe, most of the patent applications have been from Germany, France and the UK.

<u>Material science</u>
Figure 18 presents the patent applications in materials science. Material science is incorporated into almost all areas, hence the 8 digit IPC codes were applied in extracting patent applications.

<u>Chemical Engineering</u>
From Figure 19 on patent applications in Chemical Engineering, patenting behaviour follows a path which is similar to the Materials science patent distribution. Figure 19 shows that the US has a significant leading position in all years, though with a decreasing trend after 2002. China has increased rapidly during 1998-2006 and reached almost the same level as Germany and Japan in 2006.

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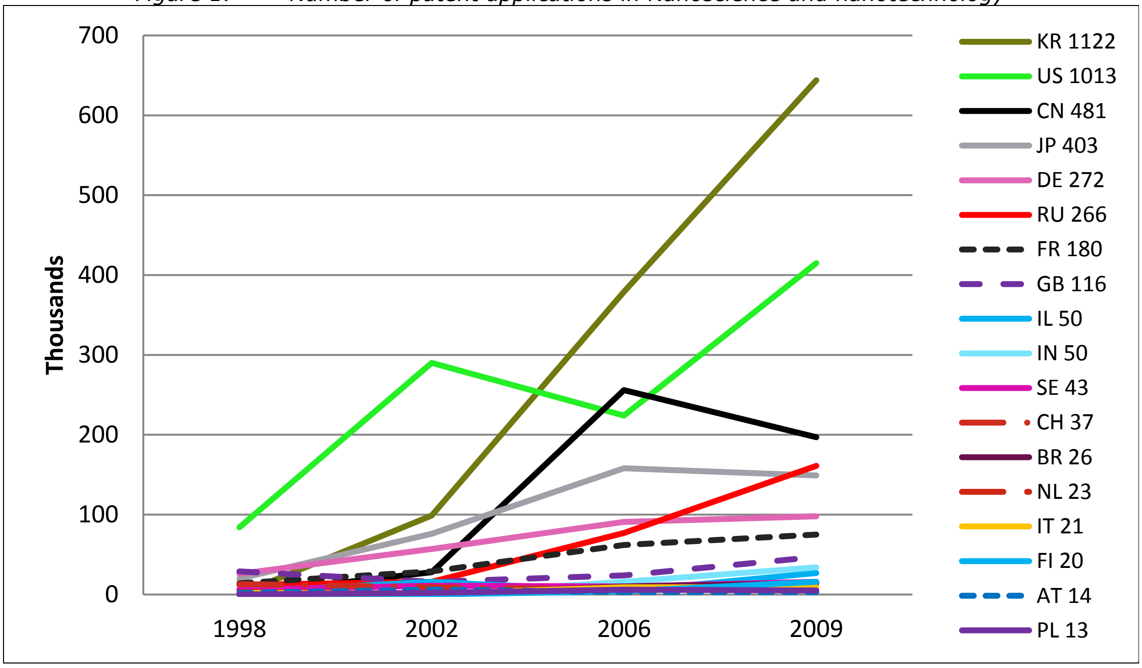
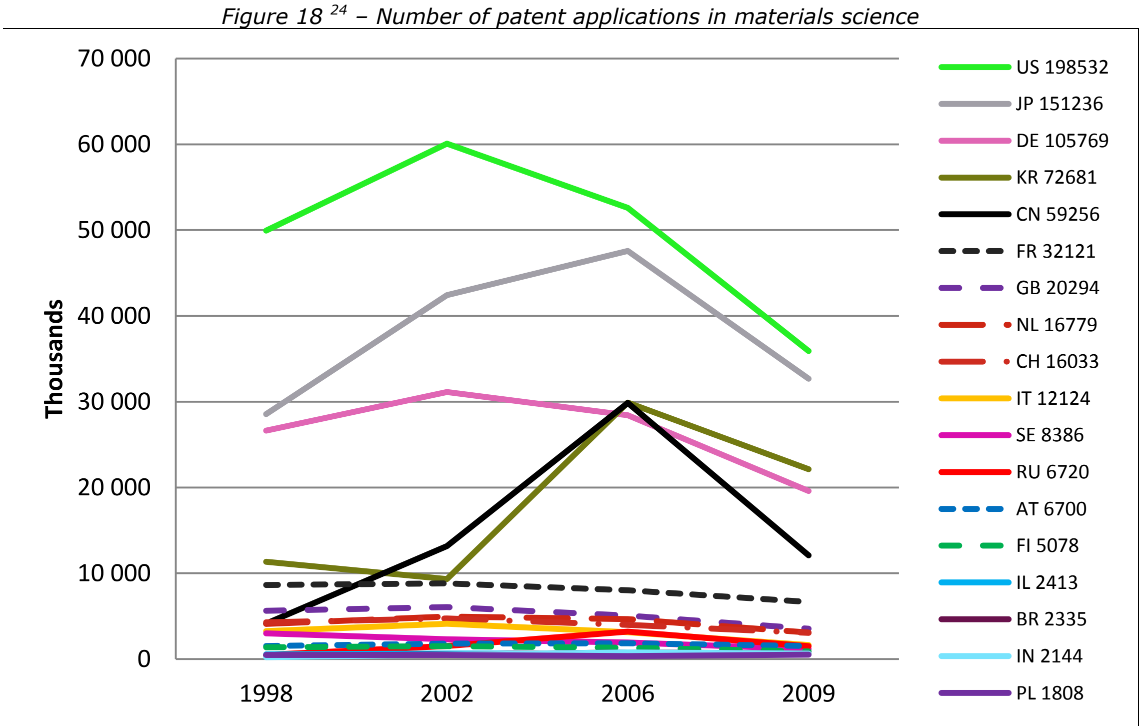
[22] More details at http://www.wipo.int/classifications/ipc/en/

Figure 17 [23] – Number of patent applications in Nanoscience and nanotechnology



Source: EPO-Patstat

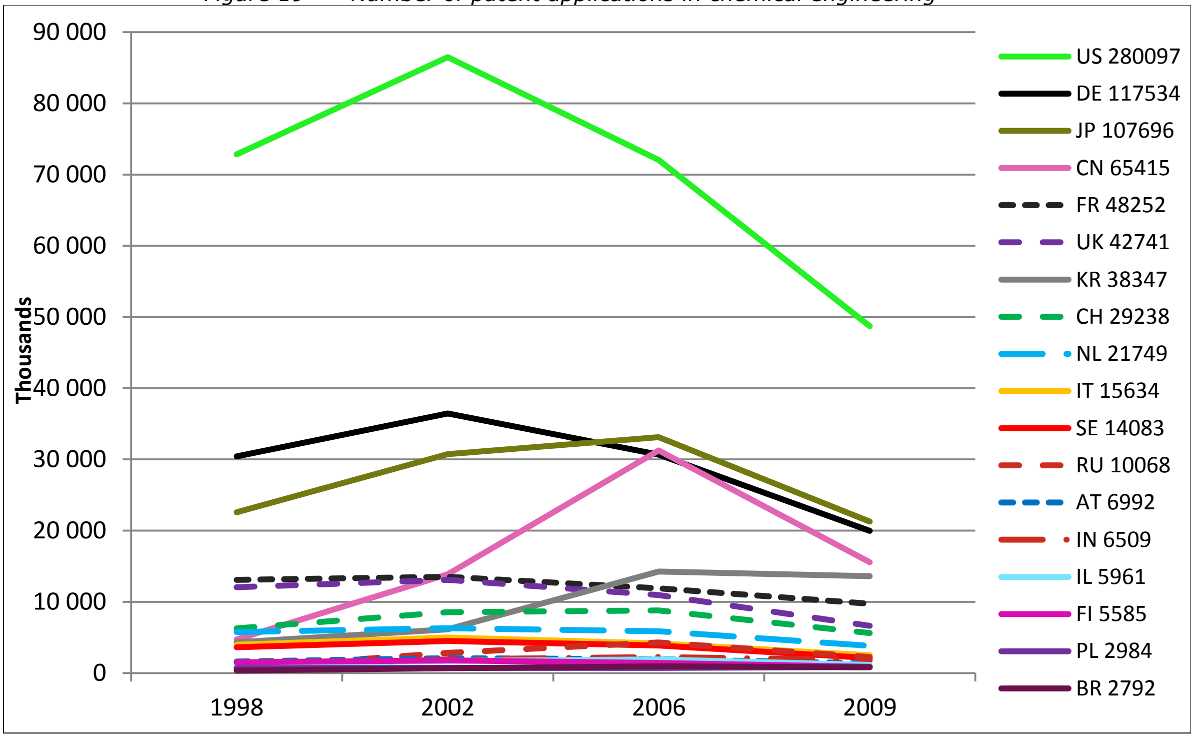
Figure 18 [24] – Number of patent applications in materials science



Source: EPO-Patstat

[23] The number behind each country is the total patents summed in the four years.
[24] The number behind each country is the total patents summed in the four years.

Figure 19 [25]– Number of patent applications in chemical engineering



Source: EPO- Patstat

Construction and building

In the field of Construction and building (Figure 20), patent applications in China increased dramatically and reached a peak in 2006. The US remains relatively stable, being in the leading position in most of the years except 2006. At a relatively slower speed, patent applications in Germany decreased mildly, from 10615 in 1998 to 6401 in 2009, while South Korea increased from 1316 in 1998 to 7965 in 2009.

Machine tools and Mechanical engineering

Similar to Construction and building, China experienced a sharp growth until 2006 in terms of patent applications in the field of Machine tools and Mechanical engineering. Germany has kept the leading position throughout, with the US and Japan occupying second and third places respectively (except in 2006). This is shown in Figure 21.

Manufacturing

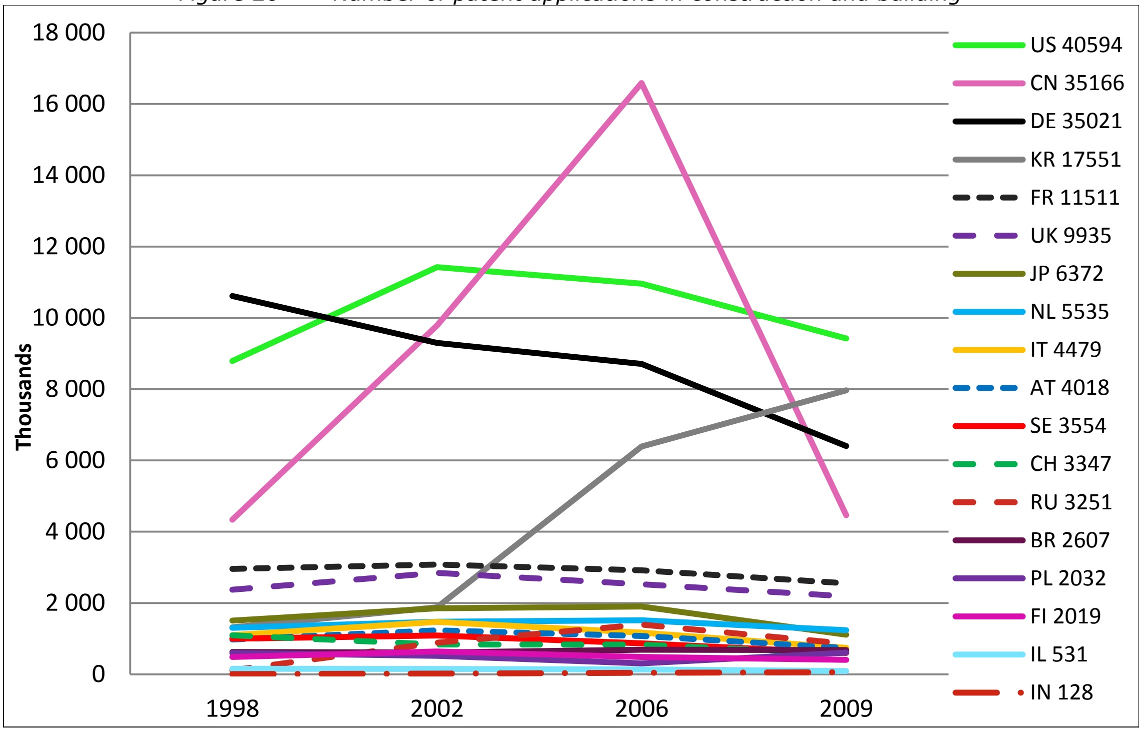
In the manufacturing field (Figure 22), the US keeps an obvious leading position in patent applications. Japan is in second place and Germany is the main contributor in Europe. China shows again a fast growing trend during 1998-2006. The three leading countries (the US, Japan and Germany) share a similar declining trend after 2002.

[25] The number behind each country is the total patents summed in the four years.

Textiles

In the Textiles field (Figure 23), China makes a leap again between 1998 and 2006, while the US, Germany and Japan have seen a mild decrease after 2002. Similar to China, South Korea also shows a clear increase in textile patent applications between 2002 and 2006.

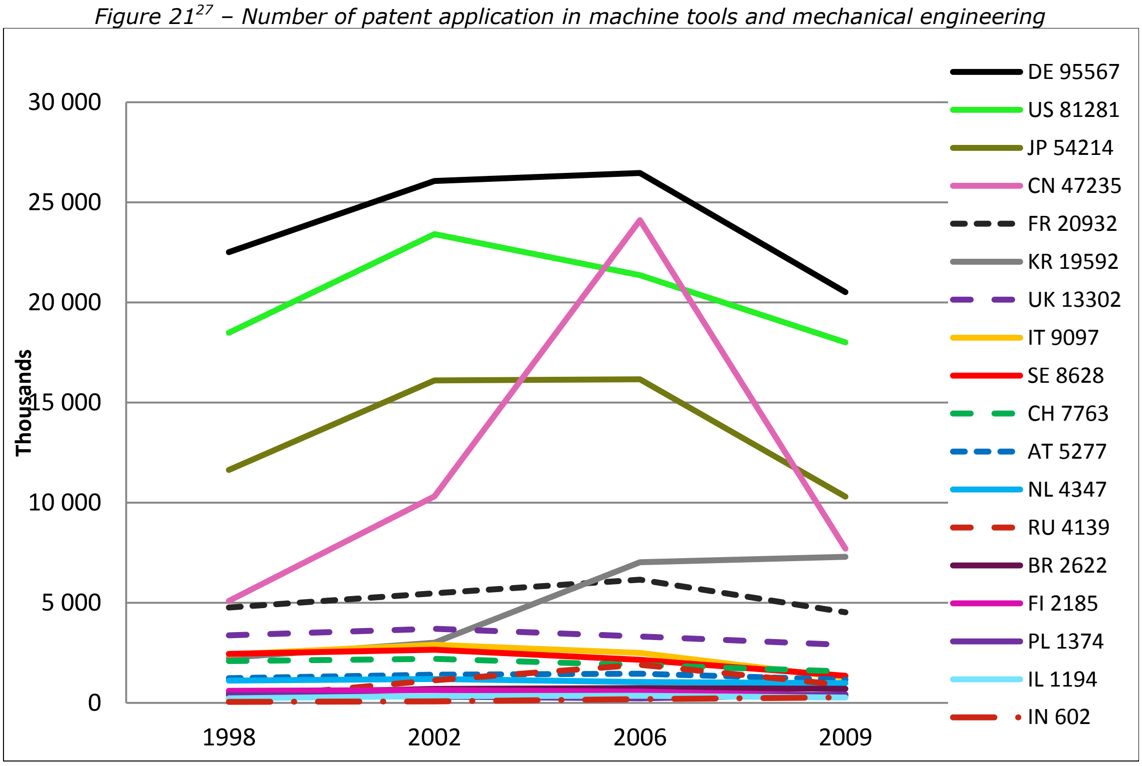
Figure 20 [26] *– Number of patent applications in construction and building*



Source: EPO-Patstat

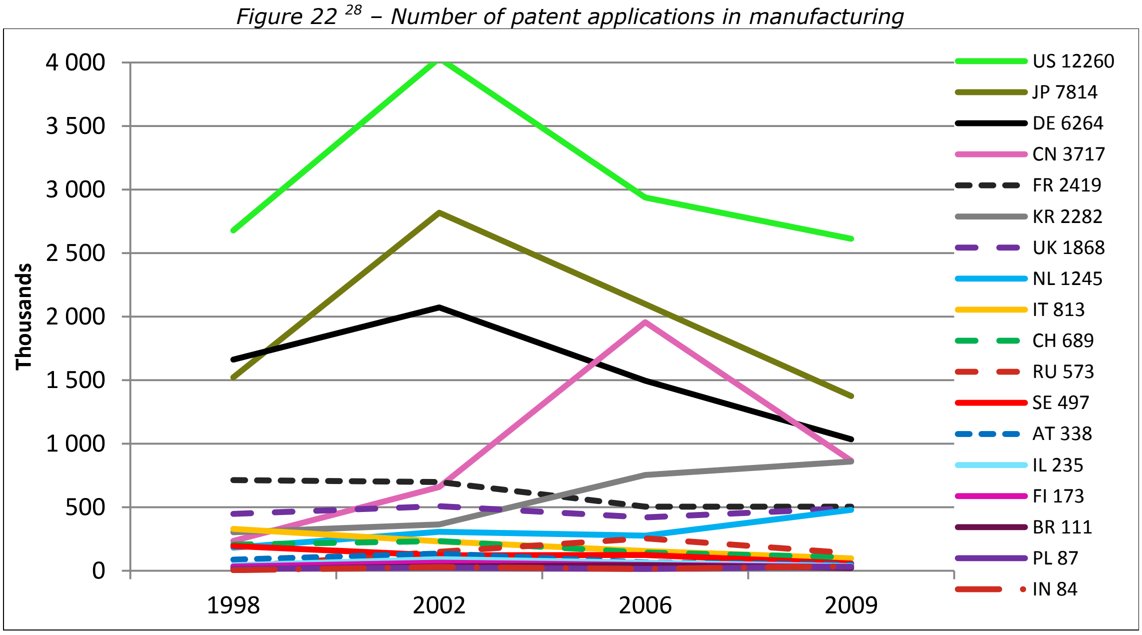
[26] The number behind each country is the total patents summed in the four years.

Figure 21[27] – Number of patent application in machine tools and mechanical engineering



Source: EPO-Patstat

Figure 22 [28] – Number of patent applications in manufacturing

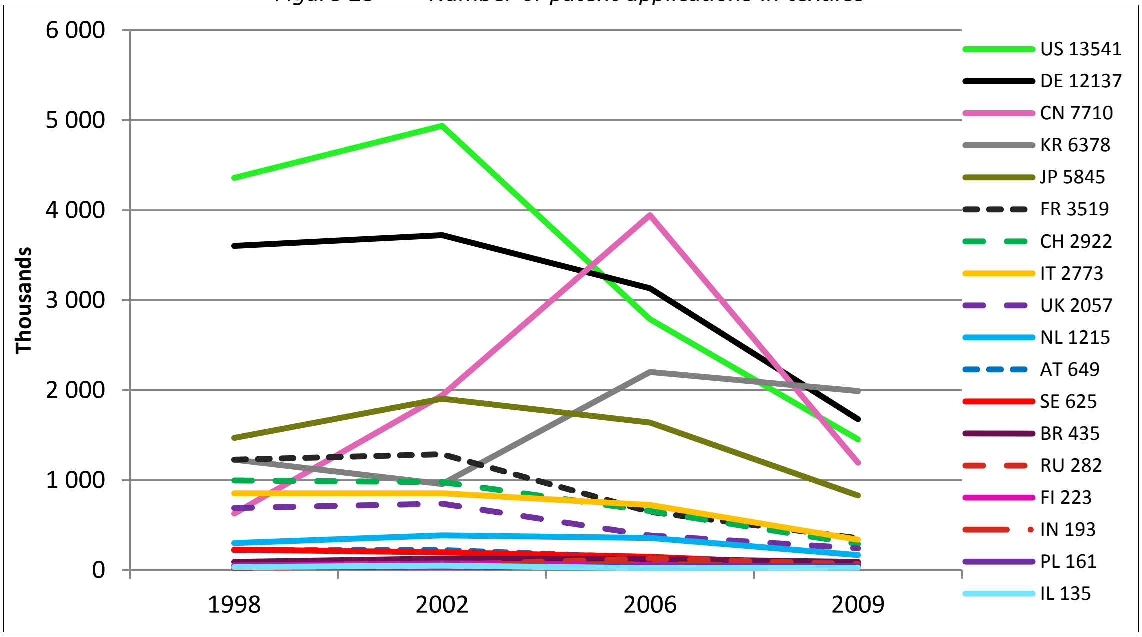


Source: EPO-Patstat

[27] The number behind each country is the total patents summed in the four years.

[28] The number behind each country is the total patents summed in the four years.

Figure 23 [29] *– Number of patent applications in textiles*



Source: EPO-Patstat

4.2.3 Research intensity in NMP

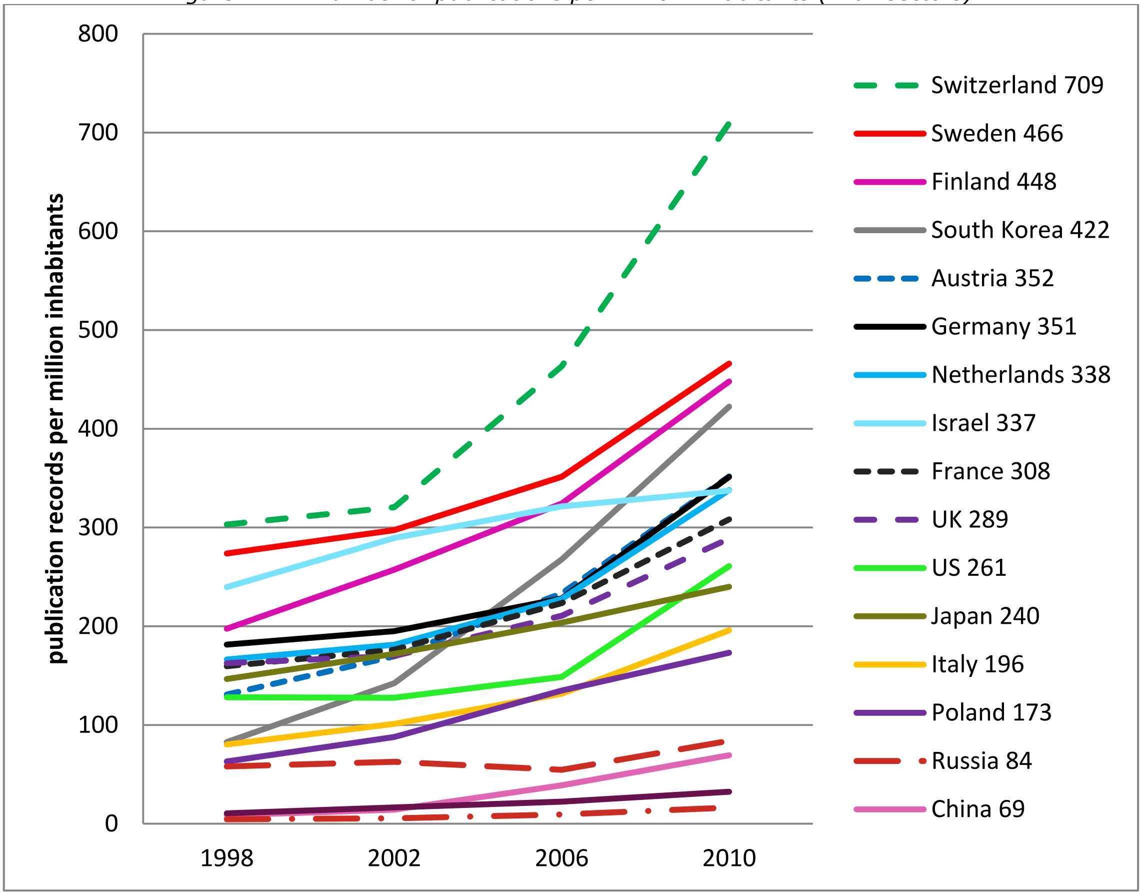
Taking the country/population size into account, we present in this section research intensity values, *i.e.* the number of publications *per* million inhabitants (Figure 24), and number of patent applications *per* million inhabitants (Figure 25). All aforementioned NMP sectors were considered when calculating the total numbers of publications and patents (see sections 4.2.1 and 4.2.2).

In terms of publication intensity, European countries, such as Switzerland, Sweden, Finland and the Netherlands were, in 2010, the top four countries with the highest publication recorded *per* capita. Big countries like the UK, Germany, France and the US are located in the middle position of the 18 countries studied. China, Brazil and India have the lowest publication numbers *per* capita.

The ranking of patent application intensity shows a different picture. Switzerland keeps its first place in all years, but South Korea catches up dramatically. Germany is the biggest contributor from Europe, with a relatively constant number over years, while the patent intensity in Sweden slightly goes down after 2002.

[29] The number behind each country is the total patents summed in the four years.

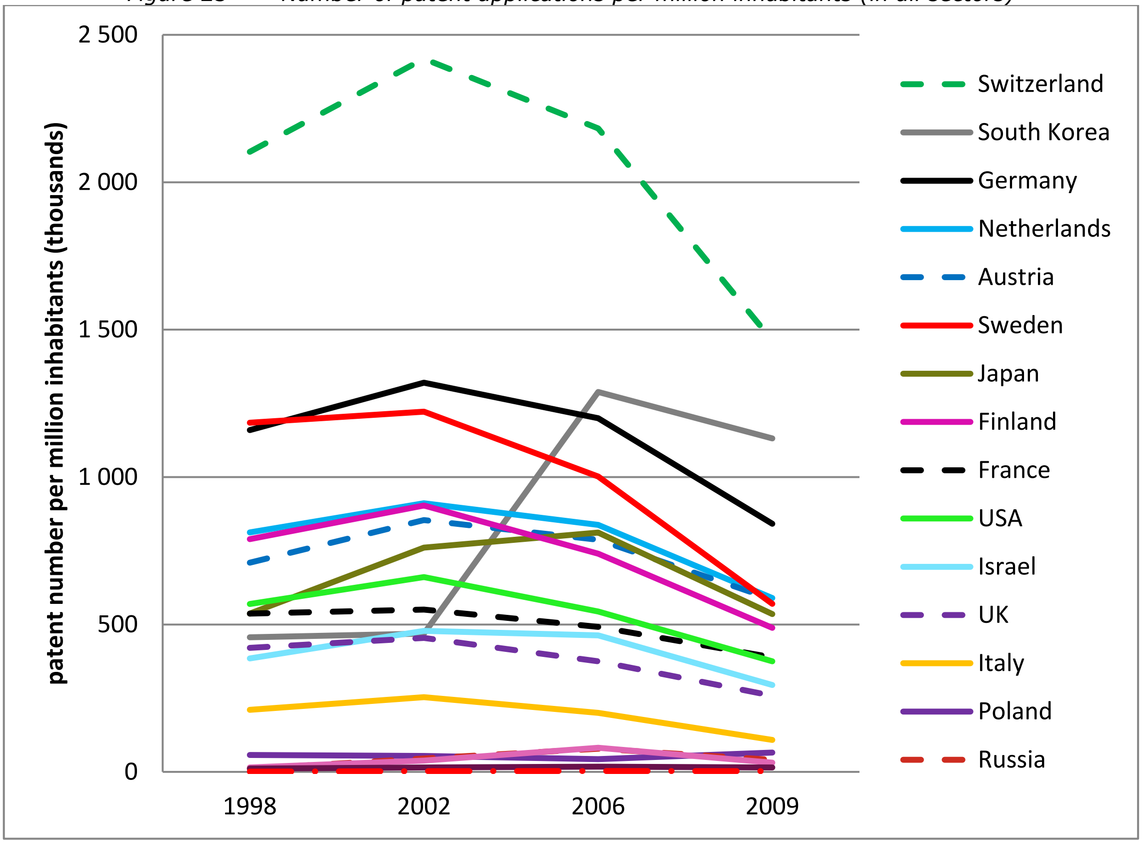
Figure 24[30] – Number of publications per million inhabitants (in all sectors)



Source: Scopus - SciVerse Elsevier and MERIT nano publication database

[30]Note: 1) It includes all the previously mentioned sectors. 2) The numbers are four year (1998-2002-2006-2010) total. 3) The number behind each country is the last year (2010)'s number.

Figure 25 [31] *– Number of patent applications per million inhabitants (in all sectors)*



Source: EPO-Patstat

4.2.4 Open innovation schemes, linkages and R&D collaborations

Innovative activities and R&D in general depend on the transfer of knowledge. This knowledge can be basic, in the form of theoretical research, or it can be applied. The latter takes the form of inventions, usually as patent applications. This technology transfer can be a directly measurable indicator of returns on government R&D investment.

The aim is to measure and visualise collaborative behaviour between academic and government R&D organizations on one side and industrial organizations on the other. For this, bibliometric data gathered for this project is used to provide geographical data and the necessary linkages as harvested from the address data. Of interest is the mapping of collaborations on the institutional or organizational level and between profit and non-profit organizations. Analysis of publication data has shown that basic, theoretical research is the premise of academic and government organizations with marginal corporate involvement. Therefore, the assignee data from the patent applications is used to construct the patent cooperation networks. Nevertheless we make some illustrative use of publication networks, in nanoscience and technology, and for this we use the affiliation data of the authors in order to specify the geographic location.

[31]Note: 1) It includes all the previously mentioned sectors. 2) The numbers are four year (1998-2002-2006-2010) total. 3) The number behind each country is the last year (2010)'s number.

The results presented use PATSTAT and a PATSTAT derived dataset. The Derwent Innovation Index (DII) was also tested. However, it was not used because the DII contains only basic inventions and, although there are 16 million basic inventions classified within the DII, this is not comparable with the amount of patent applications that are submitted world-wide since 1963 (which is the year DII has started collecting basic inventions). Nevertheless, it is important to identify basic inventions as "being distinct from mere additional accumulations of scientific knowledge" (Mueller, 1962). We should note then that "real" innovations are significantly lower in number than patents that denote an incremental change in technology. However the latter ones might be a more realistic representation of R&D activity as such.

VantagePoint bibliometric software was employed to clean and organize the data according to the two main groups mapped: academic/public research institutions and industry. In order to calculate network measures and visualize the data, UCINET and NetDraw network analysis software was used, enabling the mapping of cooperative relationships.

4.2.4.1 Network Analysis

A deeper understanding of the applied R&D collaboration patterns within a specific country can be achieved by analysing the linkages within a network of patent application assignees. For this network analysis we mainly used the above mentioned patent applications data. The relevant data was extracted from PATSTAT and the PATSTAT derived IISC dataset[32]. VantagePoint bibliometric software was employed to clean and organize the data. UCINET network analysis software was used to enable the mapping of cooperative relationships and to calculate the Degree Centrality and Betweenness Centrality measures. Furthermore Netdraw software is used to visualize these networks.

We chose to analyse the three main areas of the study: Nano-science and technology, Materials Science, and Manufacturing and Processing technology. In order to achieve a reliable and relevant picture of the collaborations a minimal data-set size was required. In order to achieve this minimal "critical mass" we had differing time series for each area. For Nano S&T we had, due its emerging nature, a set incorporating all Nano S&T classified patent applications from 1975 to 2009. For Materials Science we used a set containing patent applications filed in 2008 and 2009. This, as Materials Science is a huge field, supplies an overwhelming amount of data for a network presentation. Manufacturing and Processing is a field which finds itself in the middle of the aforementioned extremes. Here we used a data set with a time-series running from 1998 to 2009.

The graphs shown focus on two specific measures called Degree Centrality and Betweenness Centrality (Knoke and Yang, 2008). These measures seek to quantify:

1. the prominence of an actor, or in this case assignee, in a network by increasing the measure in relation to the increase in links, or relation, to or from that actor. This measure is called Degree Centrality. The higher the Degree Centrality the more connected the assignee is. In practice this

[32] Intelligent Information Services Corporation (IISC) provides a high quality dataset derived from the EPO's PATSTAT.

means that the more prominent an actor is in a network, the more attractive collaboration with this actor is.

2. the control of access to knowledge that each organization in a network, or cluster, has. If organizations have to go through another organization in order to have access to knowledge of other cluster members then this "gatekeeper" organization has an important role in enabling knowledge transfer. Without this organization the knowledge, or access to this knowledge, would be lost to these other cluster members. The higher the Betweenness Centrality, the more control an organization has over the access to knowledge within the network or cluster.

To expand a bit on the Betweenness Centrality measure, we see that this concept gives an indication of the extent to which an actor, or organization in this case, controls the flow of information and knowledge between two other actors which are not directly connected but can be connected via a geodesic path leading through the aforementioned organization. To give a practical example: If we state that organization A has to communicate "through" organization B in order to reach the information or knowledge owned by organization C, we can see that organization B has the power to influence and control various attributes of the information or knowledge owned by organization C and desired by organization A. Changes to the timing of the interaction, changes to the access to the desired content, and even changes to the context of the information or knowledge exchanged can be envisaged. As such organization B has a powerful position in this network. However this position will only remain powerful if there are no alternative geodesic paths of similar distance for organization A to choose from in order to reach organization C. As such this measure is, to a certain degree, open to policy influence.

Applied R&D collaborations as signified by patent applications can provide us with a subjective visualization of a country's R&D policy or National Innovations System (Nelson, 1993). We can see whether the policy focus is on encouraging government R&D or industrial R&D, or a combination of both. We can also see which organizations are the main collaborative partners, by increasing the node size according to their degree centrality measure and betweenness centrality measure.

Publication data was used to illustrate the differences in collaborative behaviour. This we did for Nano-science and technology, for the year 2009, due to the size of the collaboration network. For the network construction we used the author affiliation data from Web of Science which was comparable to the assignee data in PATSTAT. Also size related was the subsequent use of Ego-networks instead of whole country networks. Egocentric networks are the basic level of analysis, consisting of one focal node, or organization in this case, and all other organizations with which the focal node has direct relations as well as the links between these alters.

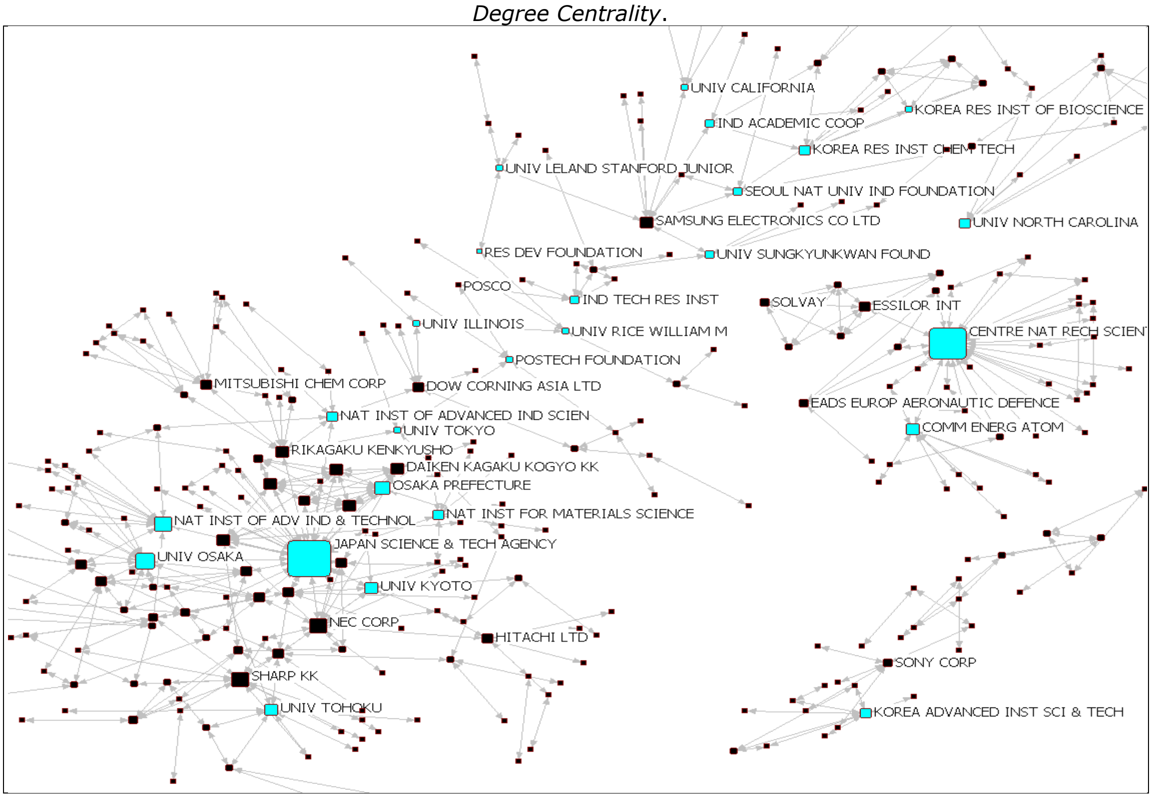
The differences in roles for the organizations are indicated by the colours of the active nodes, with magenta denoting academic and government sponsored organizations and the black nodes denoting corporate organizations. This is so for the large active nodes while the small nodes are, by default, black in color.

This main report provides the key results, tables and figures. Given the large number of tables and figures created by the analysis, some of the other tables and figures are provided in Annex 6.

<u>NanoScience and Technology Collaboration Networks</u>

The first field we mapped was nano-science and technology (Nano S&T) for which see below in Figure 26 the Degree Centrality representation for the largest clusters in the world network. The US, Japan, South Korea, Germany and France are visible as the main players and we thus focused our mapping and analysis on these countries. In Figure 26 we see that two large and thus well connected nodes dominate the map. These are both government sponsored; the Japanese Science and Technology Agency (JST) and the Centre National de la Recherche Scientifique (CNRS) in France.

Figure 26 – World patent application collaborative network for Nano S&T, node size established using Degree Centrality.

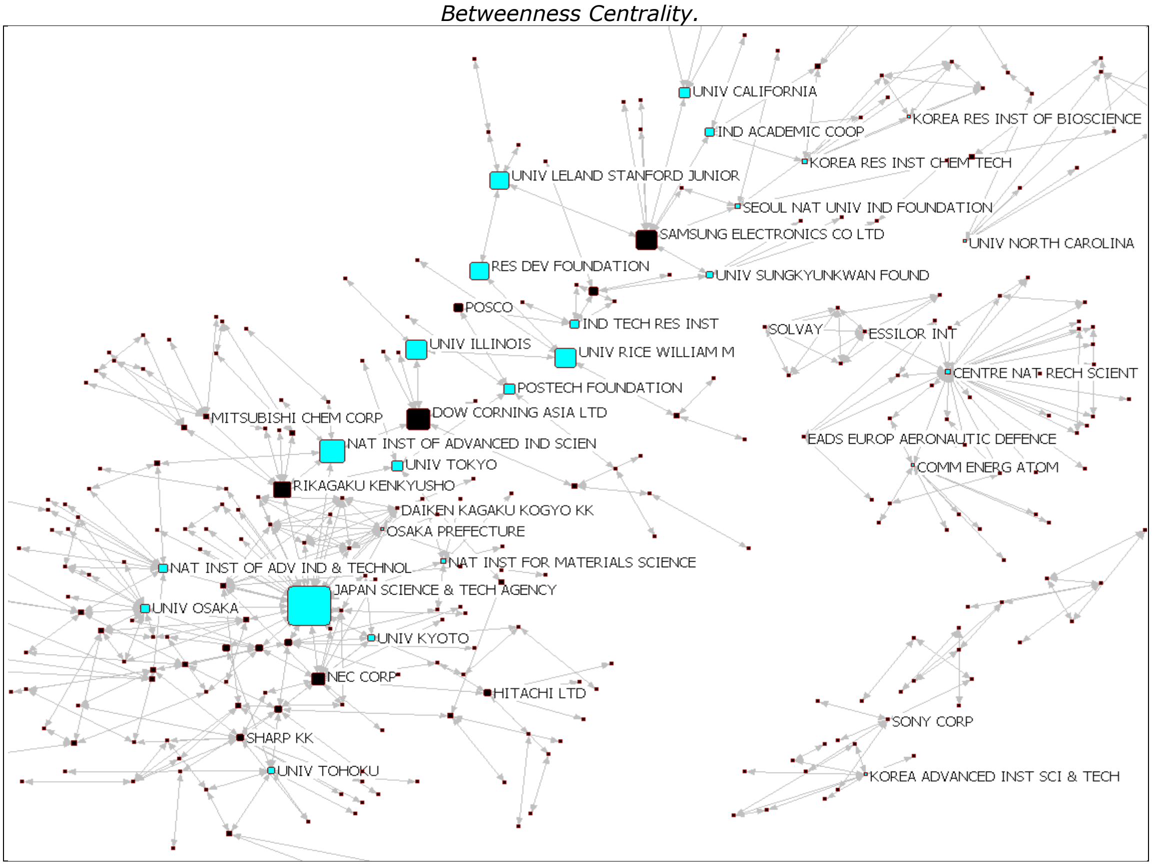


Source: Authors' own analysis

If we now look below at Figure 27 at the Betweenness Centrality calculation of this same network we see that CNRS losses its position, meaning that it is not that connected to other sub-networks/sub-clusters, in this world Nano S&T network. JST remains dominant together with a raft of South Korean and US universities and government organizations and a few companies. What is also striking, from both Figures 26 and 27, is the amount of collaborative academic and government involvement in Nano S&T patenting. The control on access to knowledge in Figure 27 is indicative of this.

The reduction in control of knowledge, as proven above in the Betweenness Centrality calculation, of such a well connected organization as CNRS is intriguing. We already see that the French cluster is quite isolated and it will be interesting to see how it is constructed.

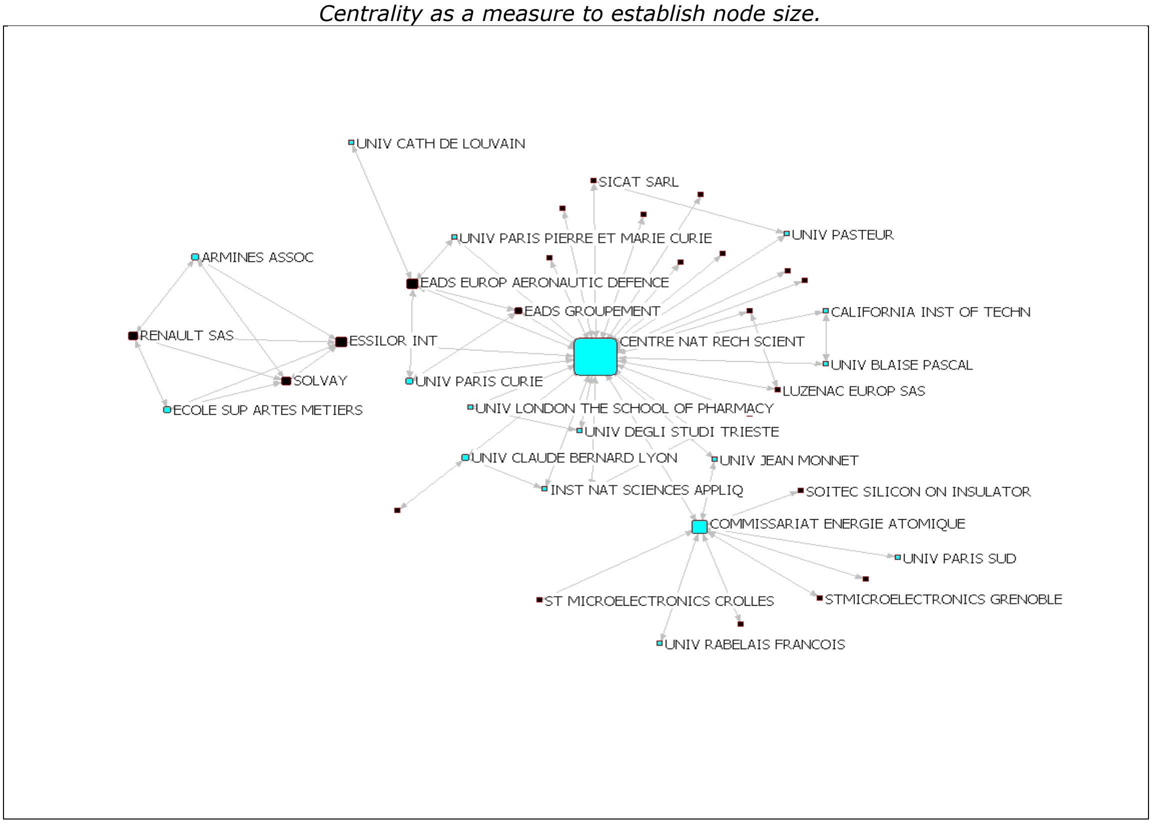
Figure 27 – World patent application collaborative network for Nano S&, node size established using Betweenness Centrality.



Source: Authors' own analysis

Below, in Figure 28 we show the main collaborative network cluster in Nano S&T patent applications for France. CNRS has the highest centrality measure in this network as also earlier shown in Figures 26 and 27, followed in the second tier by CEA. These are both large academic organizations, while Essilor International, EADS, and Solvay are the largest commercial organizations in the network. The considerable size difference between CNRS and the other nodes seems to point to a highly centralized system depending for a large part on government R&D funding to finance nanoscience and technology innovation. We should note that all commercial organizations in this network have a very strong link to France.

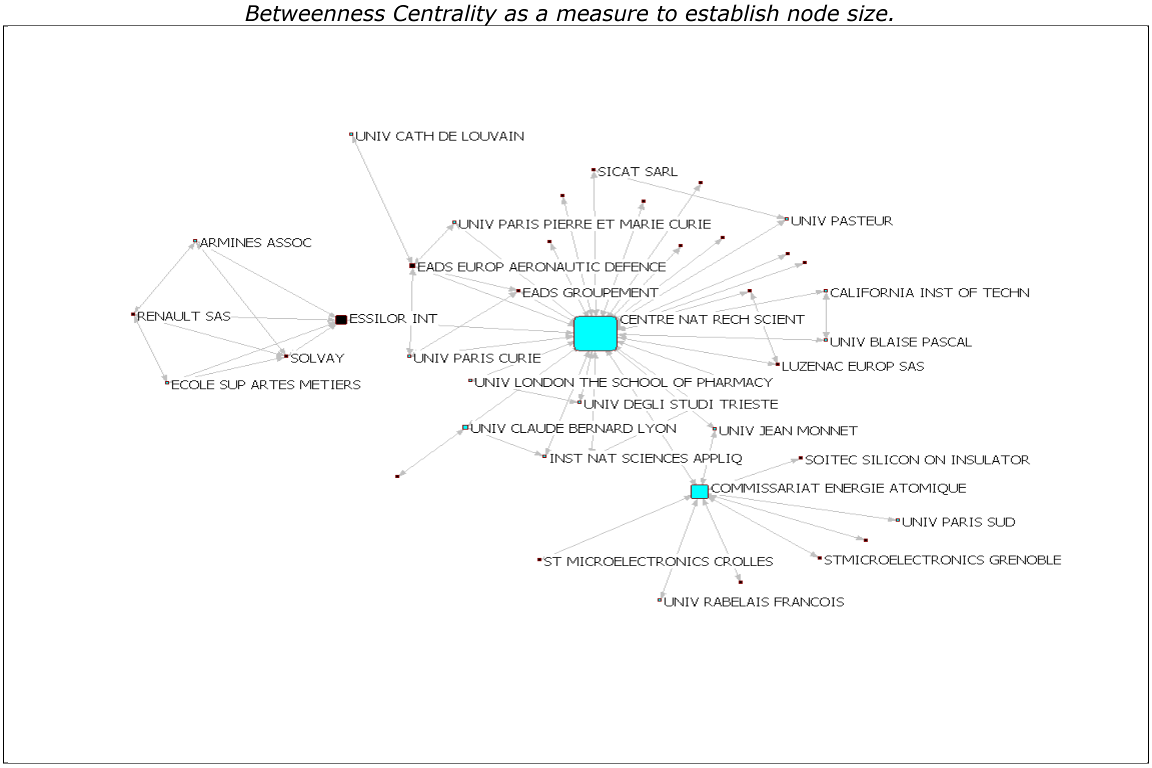
Figure 28 – Patent application collaboration network in France: Core Nano S&T network using Degree Centrality as a measure to establish node size.



Source: Authors' own analysis

If we now look at the Betweenness Centrality in Figure 29 we see that CNRS strengthens its position as the controlling entity in terms of knowledge diffusion in the visualized cluster. The Commissariat Energie Atomique (CEA) follows, while Essilor remains as the sole commercial organization with a relatively high Betweenness Centrality measure.

Figure 29 – Patent application collaboration network in France: Core Nano S&T network using Betweenness Centrality as a measure to establish node size.



Source: Authors' own analysis

If we compare the node sizes with the actual patent applications we see that CEA has the largest knowledge pool in terms of patent applications but lags in the diffusion of this knowledge. CNRS, on the contrary, is highly efficient in diffusing and controlling the knowledge generated within the organization. For commercial organizations the same is true for EADS and Essilor, while large assignees such as Arkema, Merial and Thales are absent from this core network.

As a comparison, the egocentric (egonet) co-publication network for the CNRS in the field of Nano S&T. We see an overwhelming amount of academic relations with a wide variety in terms of geographic position. Although the largest partners are mainly French as well as the Italian and Spanish equivalents of the CNRS: the CNR and CSIC respectively, also the Russian and Chinese academies of science are included as well as several large US and UK universities. Corporations are not among the main partners in basic, theoretical Nano S&T.

In Figure 30 a part of the network for the German patent applicants is represented. We see that there is a lot of activity, in various clusters, but only the Fraunhofer and Max Planck clusters are of meaningful size. What is very interesting to note is that each of the clusters has an academic partner. This might be a sign that Nano S&T is still a frontline technology. Nevertheless the smaller networks are also interesting to note, as they do include some large industrial partners

Figure 30 – Patent application collaboration network in Germany: Core Nano S&T network using Degree Centrality as a measure to establish node size.

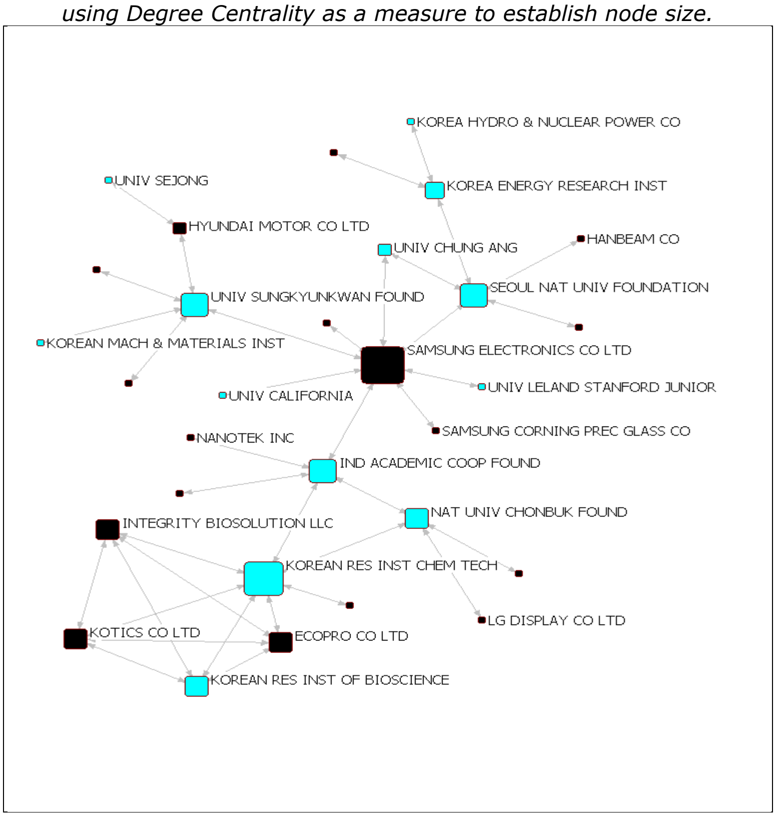
Source: Authors' own analysis

We also see that the division of patent applications is distributed over all of the clusters. However as the clusters are all rather isolated there is no opportunity for knowledge diffusion at this level. A more unifying policy would help Germany maintain and even accelerate its position in Nano S&T R&D. Due to the distributed nature of the German network it is not that interesting to measure knowledge control. It is quite clear that none of the organizations in the network will have a large Betweenness Centrality measure.

In the egonet shown in Annex 6 for the Forschungzentrum Karlsruhe we see that the German government sponsored institutes populate a large part of the network, with research institutes from the Helmholtz-Gemeinschaft, and the Max Planck centers responsible for a significant amount of connections.

If we move on to the Asian countries we find in Figure 31 the core Nano S&T network for South Korea. In the main South Korean cluster, the central position is taken by a commercial organization, Samsung, while the second tier is almost completely filled by academic organizations. As with the French network, we can see a higher degree of collaboration, with a notable difference; a higher amount of industrial partners.

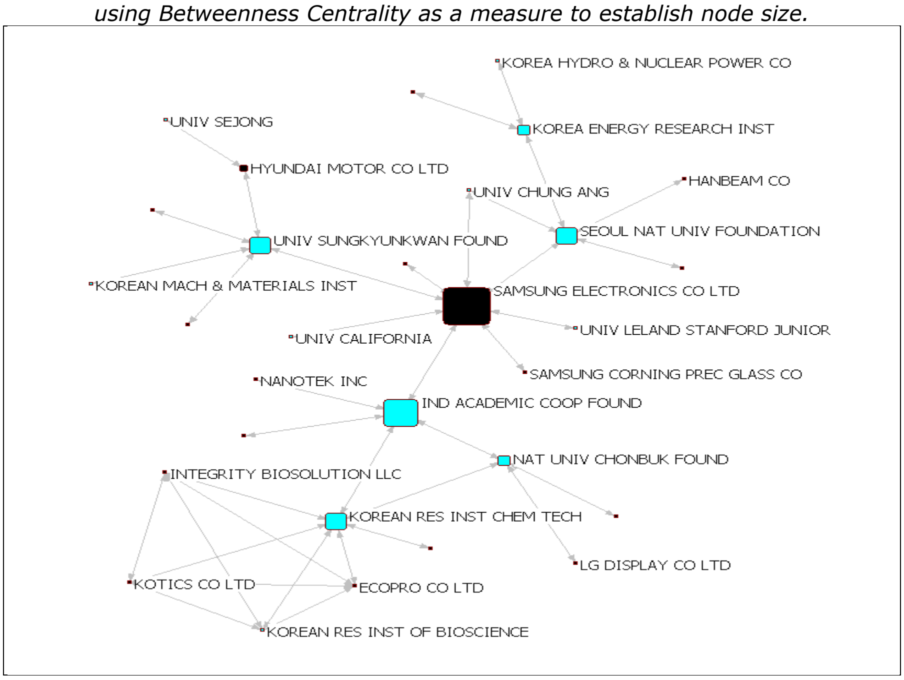
Figure 31 – Patent application collaboration network in South Korea: Core Nano S&T network cluster using Degree Centrality as a measure to establish node size.



Source: Authors' own analysis

In Figure 32 we show the same cluster but focus on Betweenness Centrality. Here we see that, apart from the central node; Samsung, the control on knowledge diffusion rests with the main academic organizations and as such is in government control. This is something not directly visible from Figure 31. What is also interesting to see is that in the core cluster shown there are few non-native organizations. This is also mirrored in Annex 6 where Samsung leads all others with a wide margin.

Figure 32 – Patent application collaboration network in South Korea: Core Nano S&T network cluster using Betweenness Centrality as a measure to establish node size.

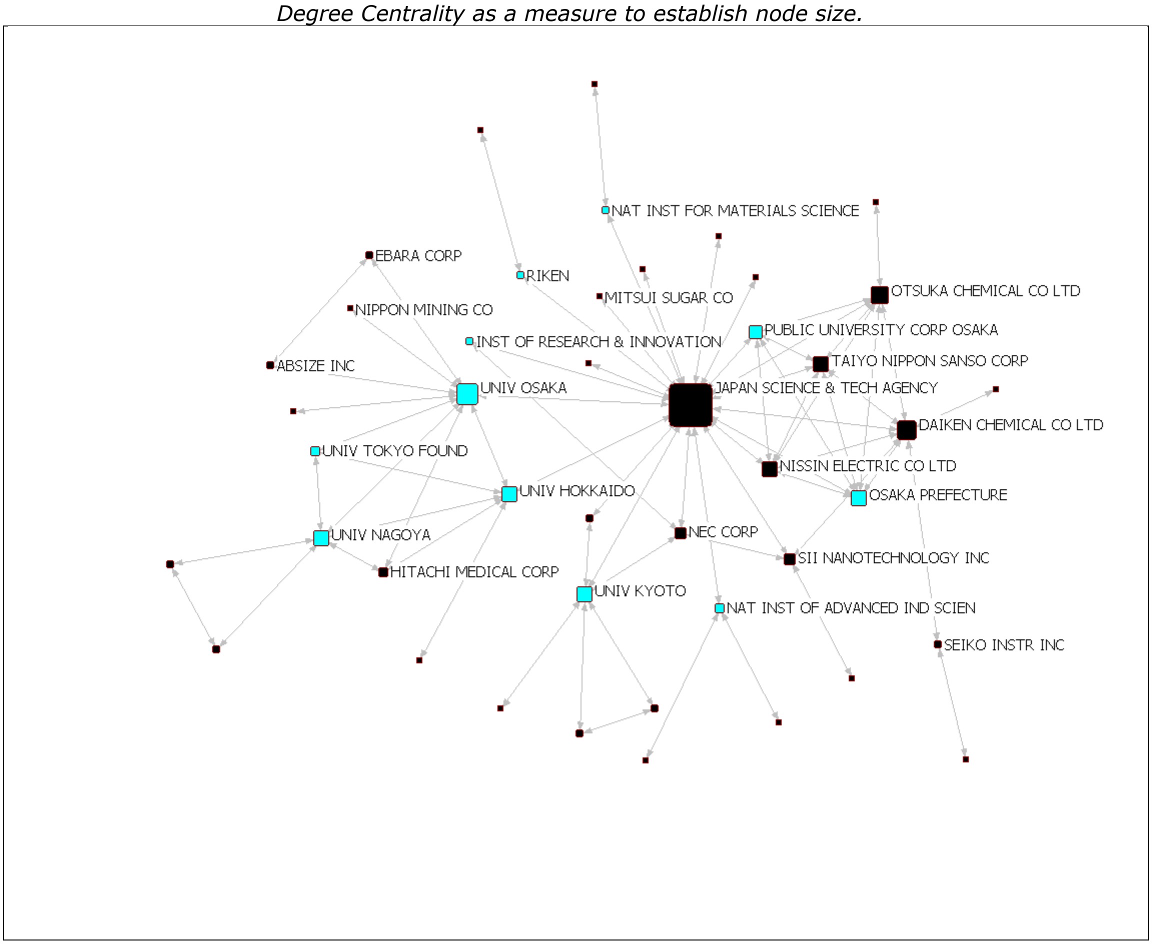


Source: Authors' own analysis

The egocentric network for the best performing South Korean government organization in terms of patent applications; Korean Advanced Institute of Science and Technology (KAIST). Although the main co-authors originate from other South Korean academic organizations there is also quite some cross-border activity, even with the European Union. What is again missing in this network is evidence of partnerships with commercial organizations. This underlines the seemingly absence of interest in basic, theoretical, science from corporate R&D.

Figure 33 shows the Japanese core Nano S&T network. Contrary to South Korea, and somewhat similar to France, the main node in this cluster is the Japanese Science and Technology Agency (JST). From the Degree Centrality measurement we see that the academic and government organizations are the most well connected nodes in the network cluster. A sizeable amount of industrial partners are also present as well as some regional government organizations.

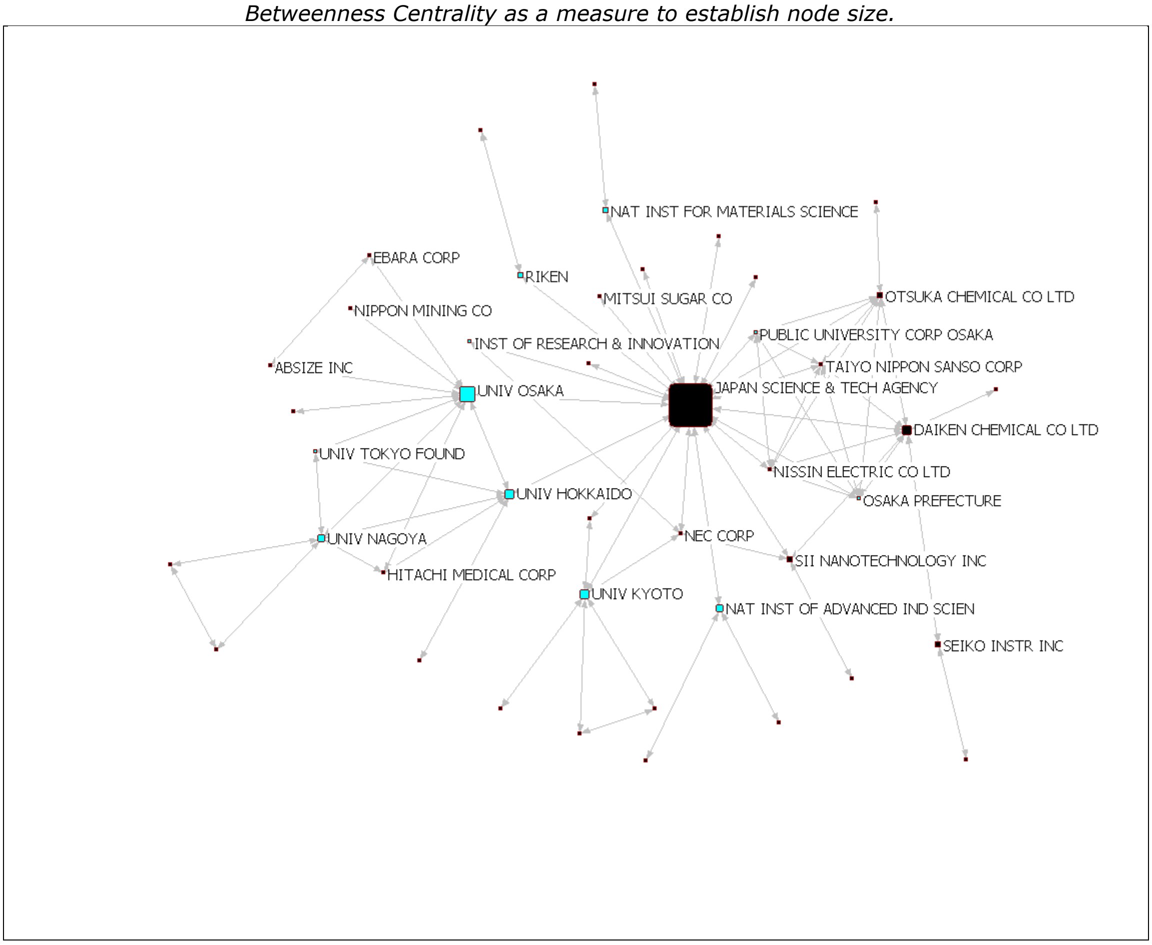
Figure 33 – Patent application collaboration network in Japan: Core Nano S&T network cluster using Degree Centrality as a measure to establish node size.



Source: Authors' own analysis

From Figure 34 it is also clear that academic and government organizations control the access to knowledge within the network, with a very prominent place for the JST and to a lesser extent the University of Osaka. Contrary to South Korea, Japan does not seem to rely that strongly on industrial partners for Nano S&T knowledge generation and diffusion.

Figure 34 – Patent application collaboration network in Japan: Core Nano S&T network cluster using Betweenness Centrality as a measure to establish node size.



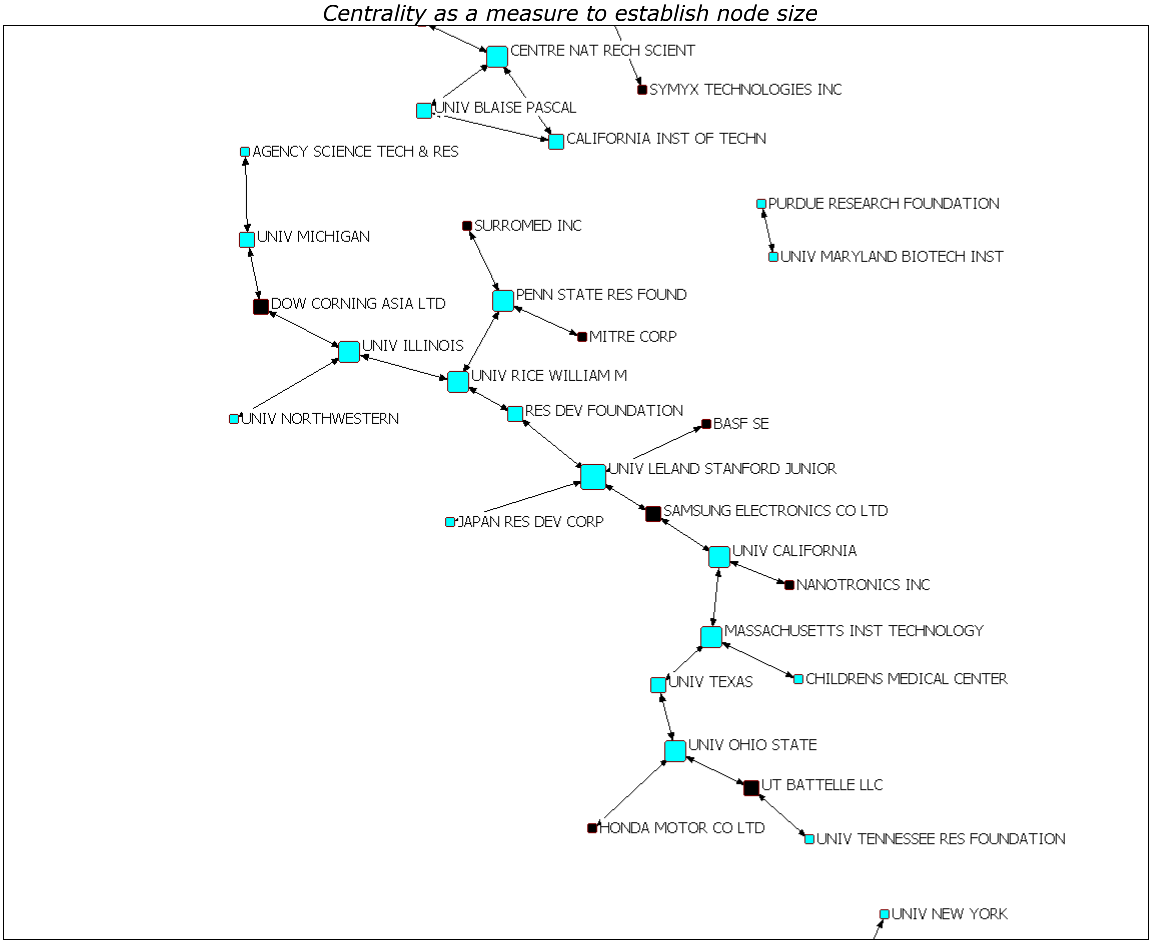
Source: Authors' own analysis

This is also reflected in Annex 6 where, although we do see sizeable amounts of patent applications from commercial organizations in the Japanese Nano S&T network, 3 of the top 5 organizations are government organizations.

The ego-networks for the JST and for Osaka University are also provided in Annex 6. These two organization are the main nodes in the previous patent collaboration networks with many connections with commerical organizations and high control over the knowledge flows within Japanese Nano S&T. We see, as with the previous publication networks that co-authoring with corporate R&D centres is non-existent. Apart from the now obvious national patnerships we do see a lot of cross-border co-operations.

If we now move to the US (Figure 35) we see a hybrid of the German and Japanese networks. A large amount of disparate clusters with only few larger clusters are observed with most clusters including an academic or government partner. Interestingly a high occurrence of non-native organizations is visible in the Nano S&T network for the US.

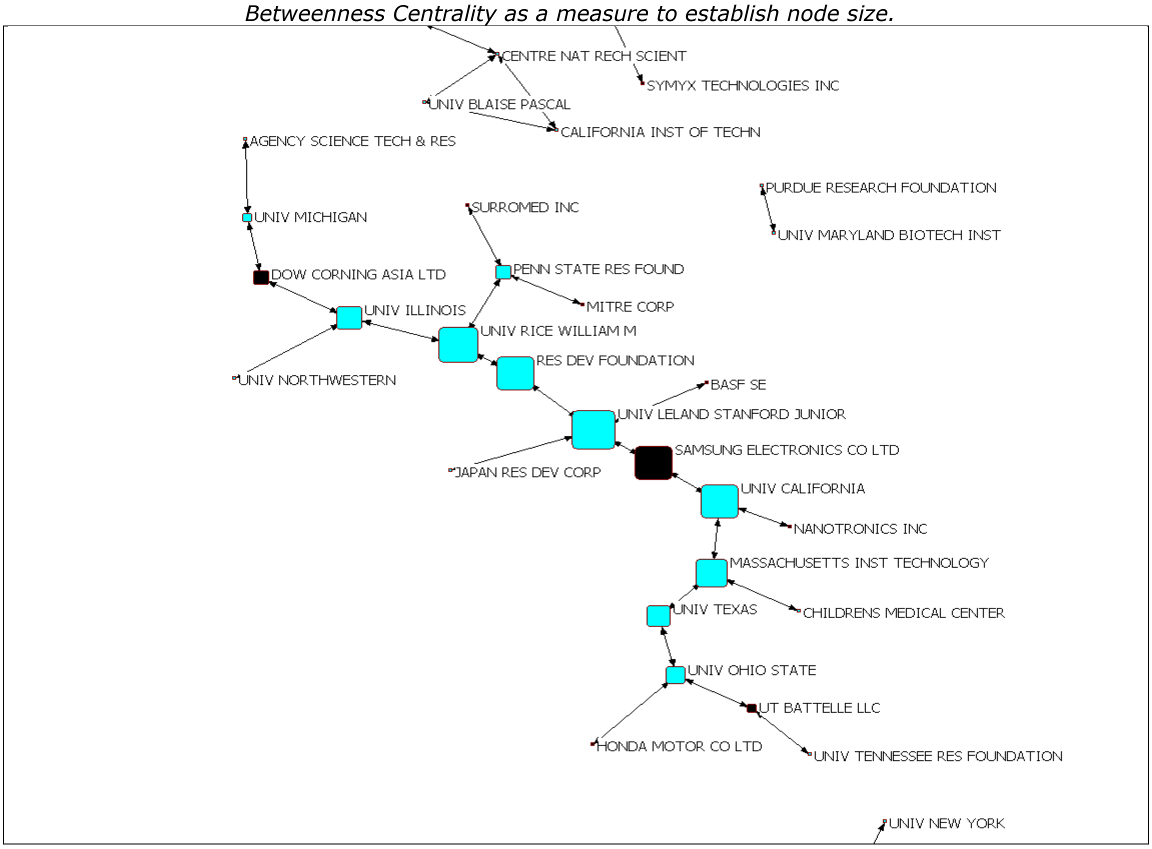
Figure 35 – Patent application collaboration network in US: Core Nano S&T network cluster using Degree Centrality as a measure to establish node size



Source: Authors' own analysis

Although, as with Germany, a Betweenness Centrality measurement is not really necessary for this field as we can see from Figure 35 that probably many organizations in this core cluster will have a large Betweenness Centrality measure. This speculation is corroborated by Figure 36, although interestingly one commercial organization has a large Betweenness Centrality; Samsung, which is not only commercial but also foreign owned. However, the majority of organizations that control knowledge diffusion in US Nano S&T are primarily academic and government organizations.

Figure 36 – Patent application collaboration network in US: Core Nano S&T network cluster using Betweenness Centrality as a measure to establish node size.



Source: Authors' own analysis

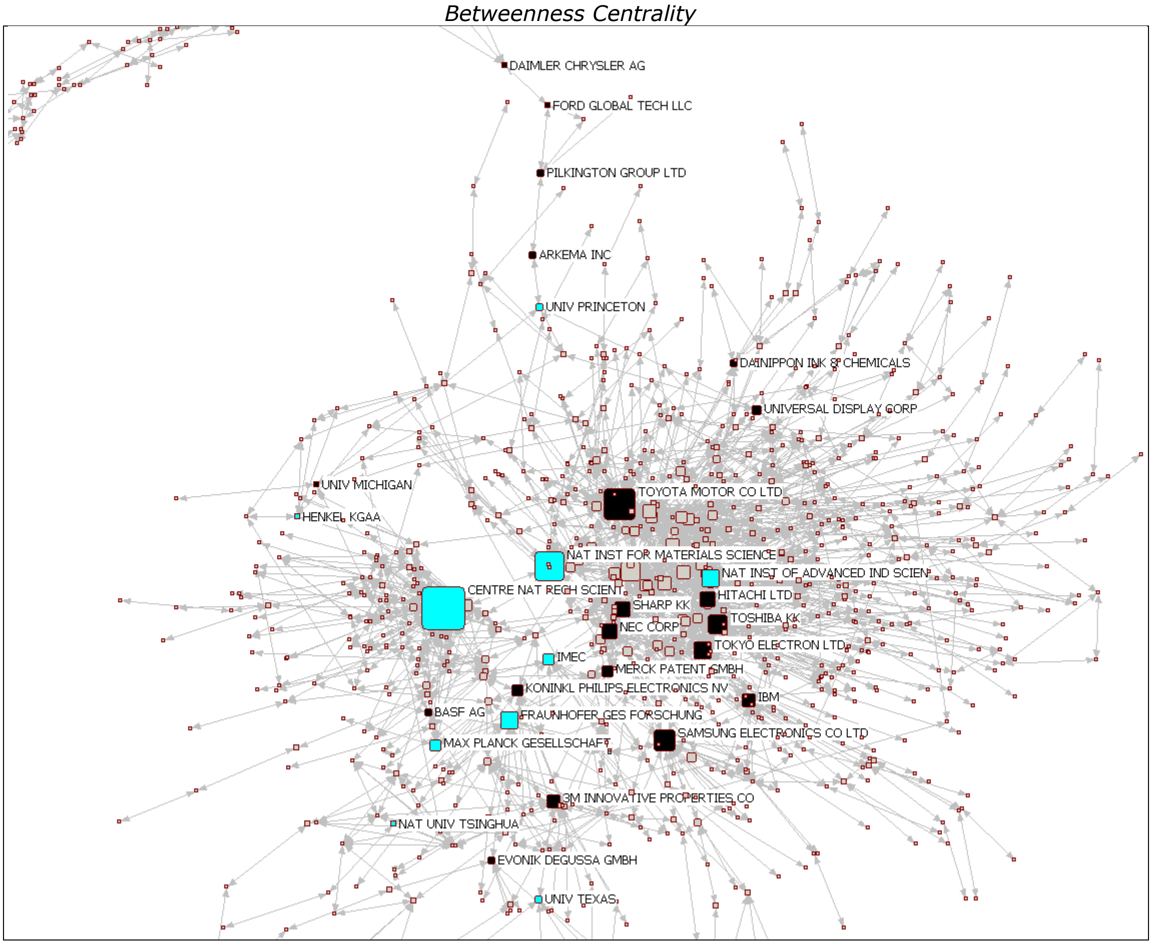
Like Japan, the large commercial organizations are not in the core cluster but are part of a smaller cluster, although they have the largest knowledge pool in terms of patent applications.

In the co-publication ego-centric network for Massachusetts Institute of Technology (MIT) (Annex 6) we see the same pattern of nearly non-existent cooperation with private companies. Links with Samsung, Intel and GlaxoSmithKline are present but barely noticeable.

Collaborative Patent Networks for Materials Science

In Figure 37 we see the densest part of the world network for Materials Science co-patenting (as represented by more than 5 collaborative patent applications). Control of world knowledge in Materials Science seems to rest with a small club of mainly government and government sponsored organizations and a few research intensive multinationals, with the French CNRS in an obvious lead-position.

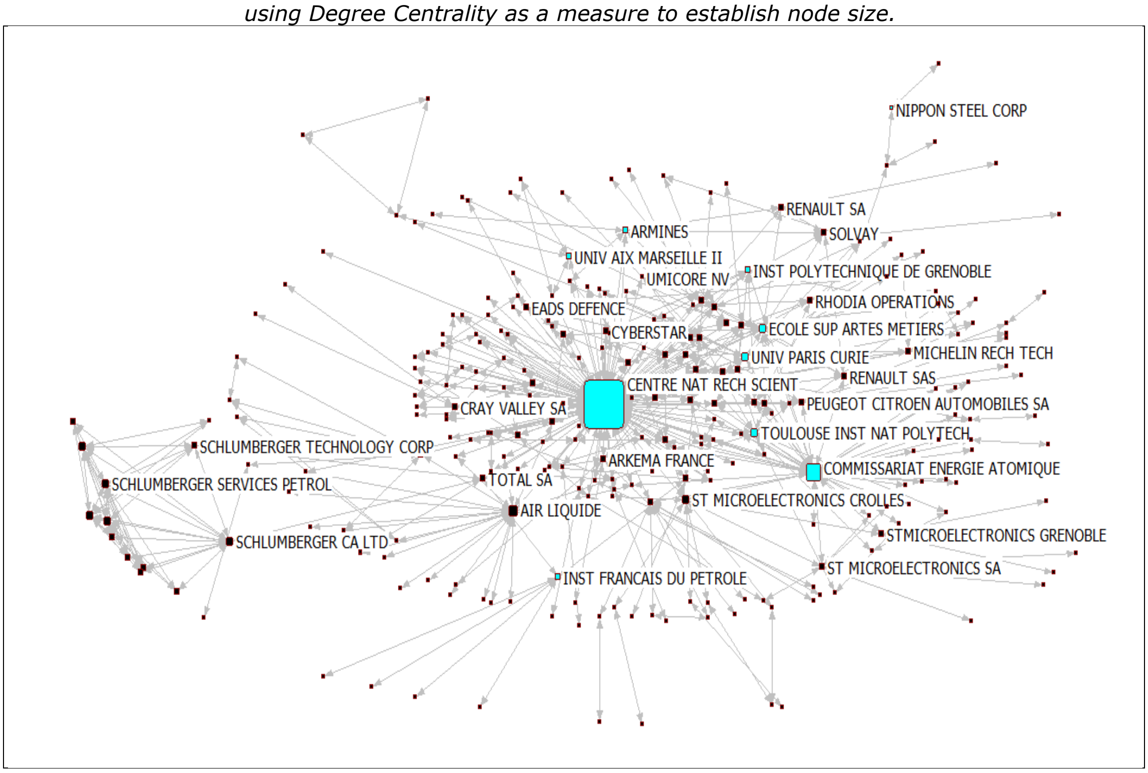
Figure 37 – Materials Science World (5+) patent applications network with node size determined using Betweenness Centrality



Source: Authors' own analysis

In Figure 38 we explore the core cluster in the network of patent application collaborations for Materials Science in France further. We see that some of the characteristics of the Nano S&T network return, with CNRS and CEA taking prime spots.

Figure 38 – Patent application collaboration network in France: Core Materials Science network cluster using Degree Centrality as a measure to establish node size.

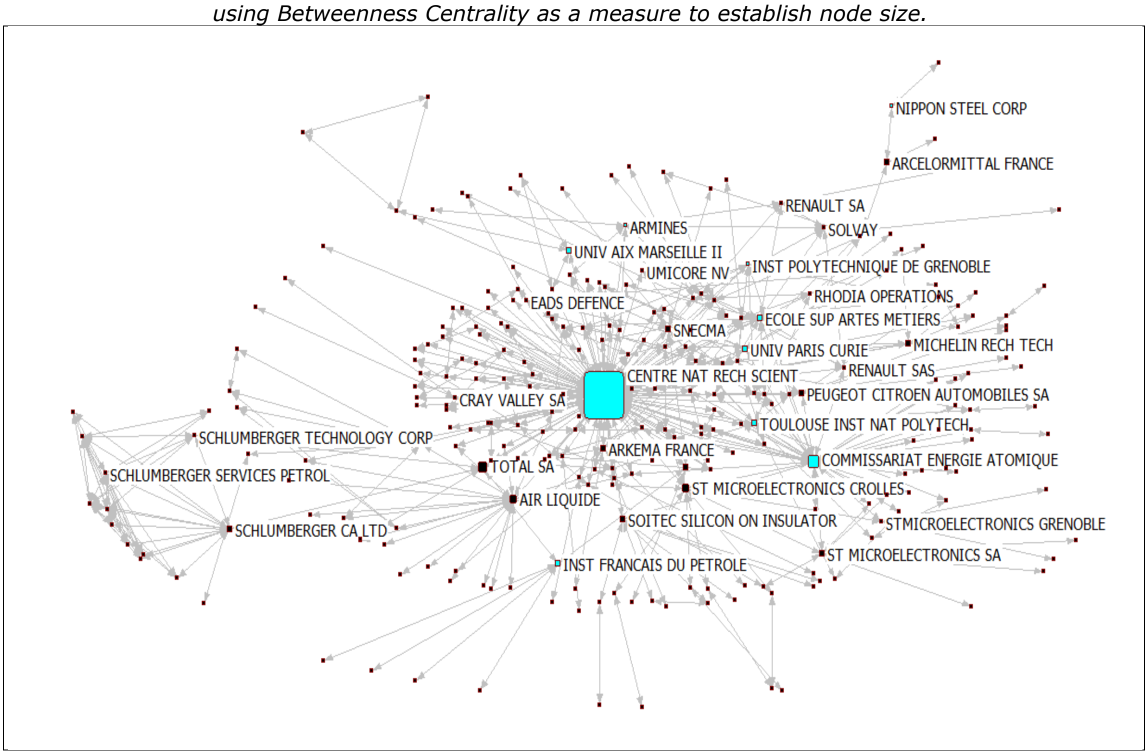


Source: Authors' own analysis

We notice as well that the second tier is mostly made up of academic and government organizations such Ecoles Superieure (Artes Metiers), Institutes Nationale (Grenoble, Toulouse) and various universities. STMicroelectonics and Air Liquide seem to be the leading industrial partners in this highly connected network.

If we now look at knowledge control in this network cluster we see in Figure 39 that CNRS and CEA are the nodes with the highest Betweenness Centrality. Following with a large lag in the second tier are a mix of industrial (Arkema, Air Liquide, SNECMA, Total, PSA, Michelin, STM, and ArcelorMittal) and academic/government (Inst Nat Grenoble, Ecole Sup Artes Metiers) partners, although there are more commercial organizations in this second tier.

Figure 39 – Patent application collaboration network in France: Core Materials Science network cluster using Betweenness Centrality as a measure to establish node size.

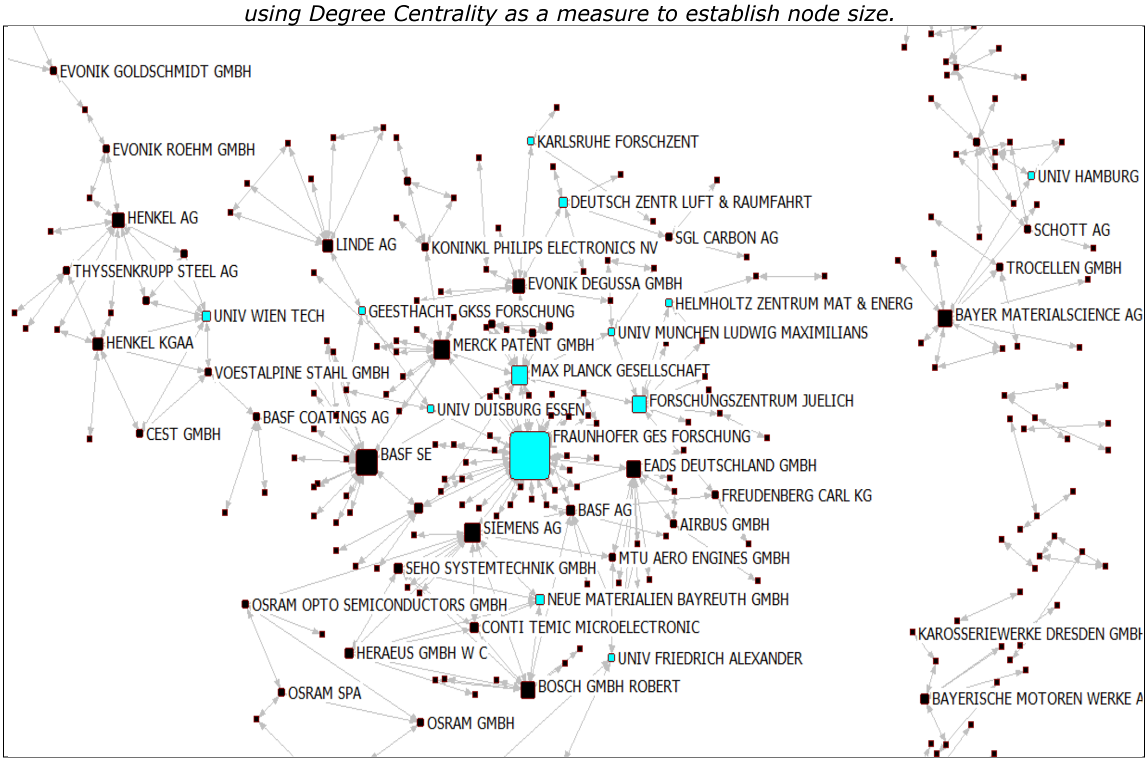


Source: Authors' own analysis

This observation is confirmed in Annex 6 where we see that CEA has the largest knowledge pool combining it then with a less efficient diffusion as shown previously in Figure 39. A number of big industrial partners take 3rd place onwards, with a noticeable petroleum cluster that is not represented in the core of the network as shown in Figures 38 and 39.

If we now move to Germany, in Figure 40, we find a dramatically different picture for Materials Science to the one presented for Nano S&T in Figure 30.

Figure 40 – Patent application collaboration network in Germany: Core Materials Science network cluster using Degree Centrality as a measure to establish node size.

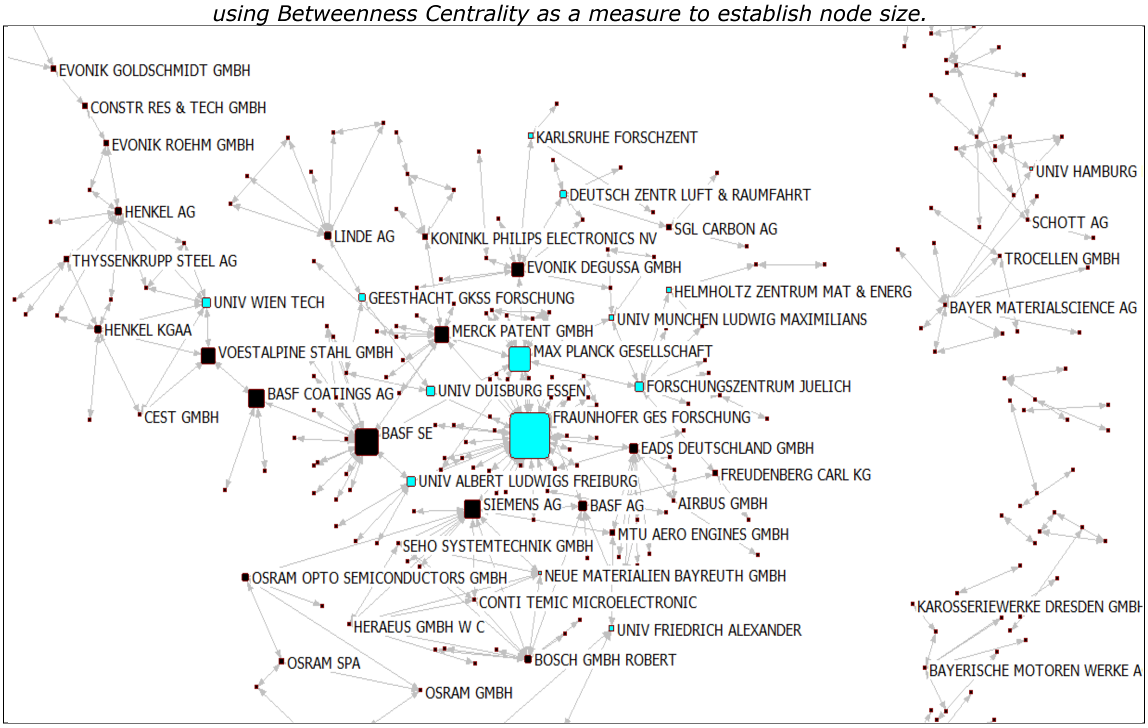


Source: Authors' own analysis

Similar to in France, there is one large government sponsored organization with a large Degree Centrality measure: Fraunhofer. However this organization seems to link more directly to commercial collaborators, which contrary to France mostly make up the second tier of large degree centrality nodes; Siemens, Bosch, Merck, BASF, Evonik Degussa, and EADS. We can infer that although also centrally organized (through academic/government institutions such as Fraunhofer and Max Planck), more government funding seems to flow directly to commercial organizations, thus relying less on government organizations to drive Materials Science innovation.

This statement is further reinforced if we observe the Betweenness Centrality measurent in Figure 41 where Fraunhofer leads over a second tier made up again of mostly industrial partners. An interesting sub-cluster incorporating Austrian firms and academic organizations can be observed in the top left corner.

Figure 41 – Patent application collaboration network in Germany: Core Materials Science network cluster using Betweenness Centrality as a measure to establish node size.



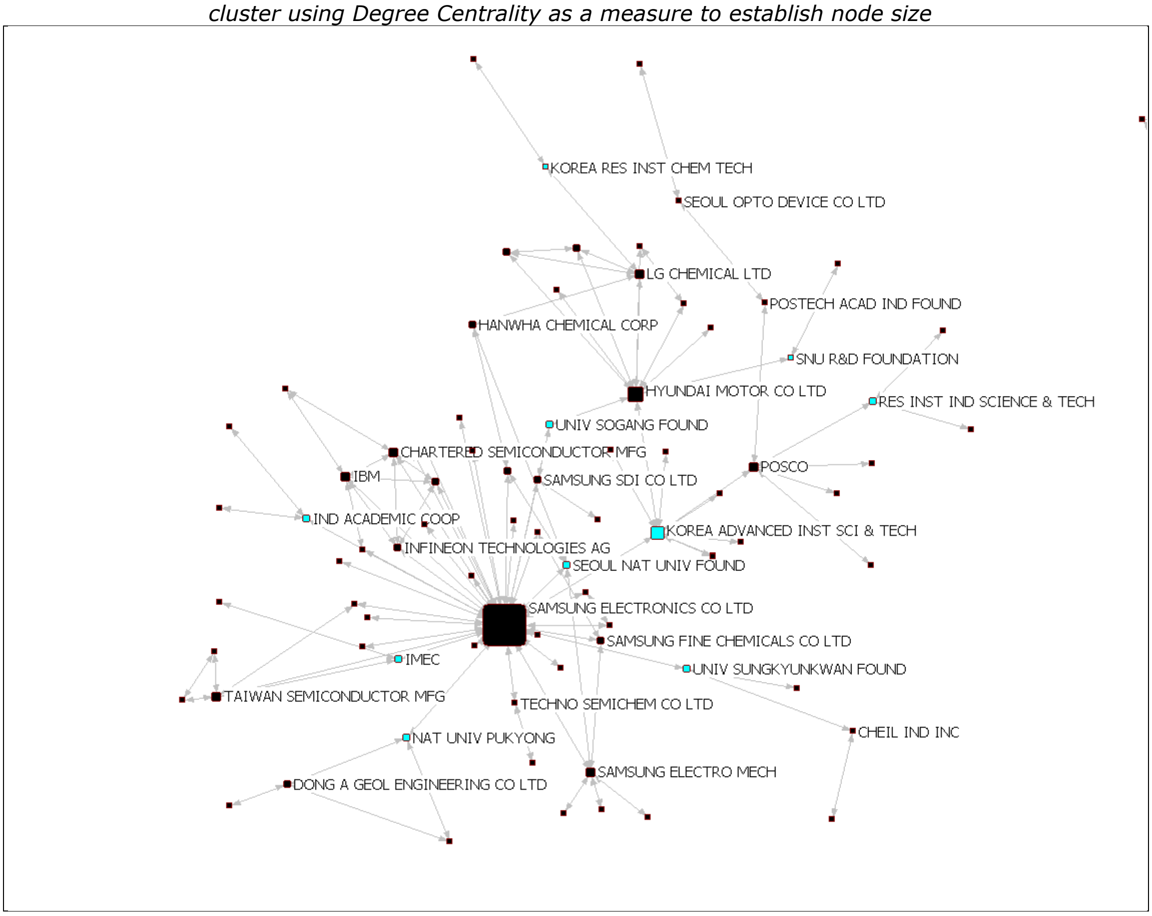
Source: Authors' own analysis

Even more interesting is that, contrary to France, the academic and government organizations are not leading in terms of patent applications. Fraunhofer is the only academic/government organization in the top 15, where commercial companies seem to own the largest part of the knowledge pool.

Moving the focus out of Europe towards East Asia we see in Figures 42, 43, and 44 that the picture has changed from government organizations to commercial organizations leading the collaborative efforts.

In Figure 42 we show the Degree Centrality measurement for the core collaborative cluster in South Korean Materials Science which is similar to the South Korean Nano S&T core cluster. Samsung leads with a number of industrial partners in the second tier. The Korean Advanced Institute for Science and Technology (KAIST) seems to be the only government organization in the second tier, although some universities can be found in a third tier which is less connected. Interesting also is the inclusion of a foreign private-public organization in this third tier: IMEC.

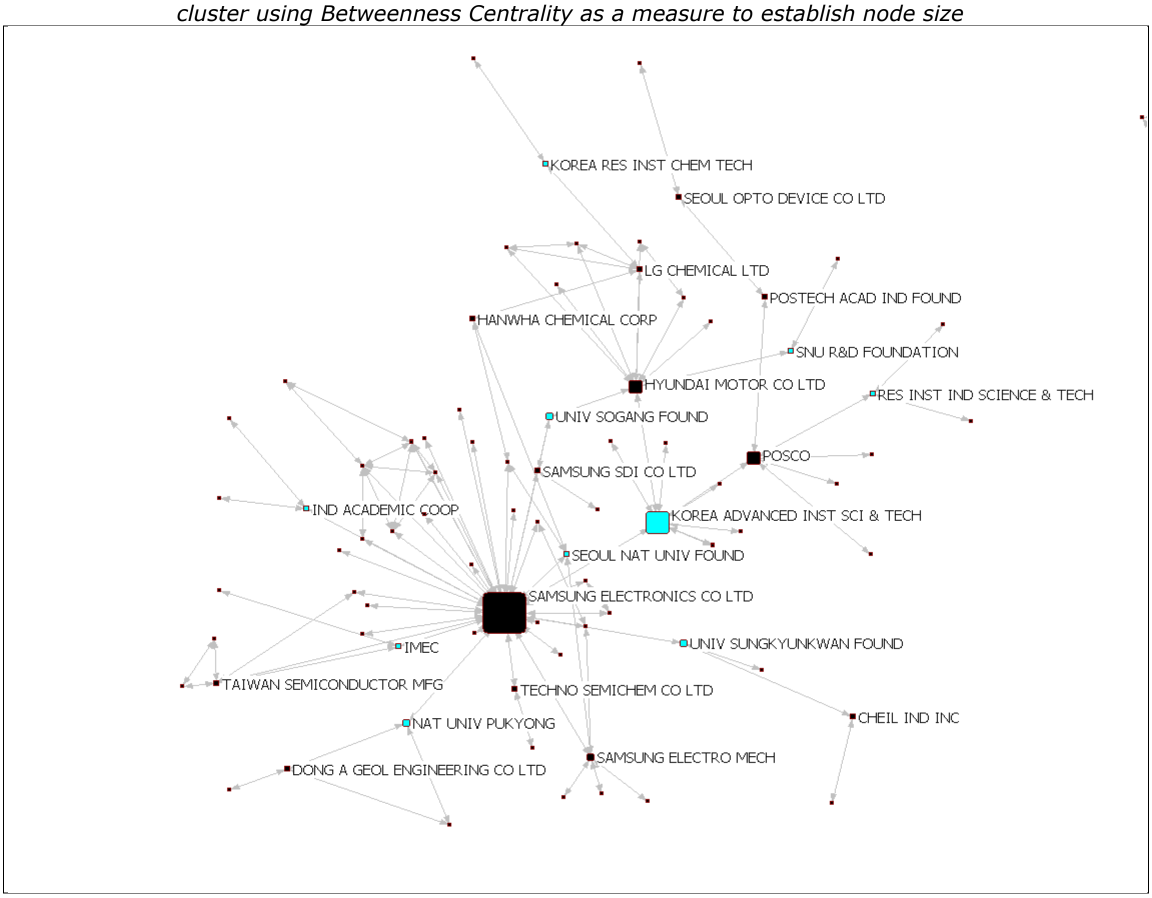
Figure 42 - Patent application collaboration network in South Korea: Core Materials Science network cluster using Degree Centrality as a measure to establish node size



Source: Authors' own analysis

We also see that the large Chaebols (Chang, 2006) like Samsung, Hyundai and the steel giant POSCO control access to knowledge as seen in Figure 43, although KAIST and Sogang University seem well positioned to control diffusion of knowledge between these large conglomerates.

Figure 43 – Patent application collaboration network in South Korea: Core Materials Science network cluster using Betweenness Centrality as a measure to establish node size

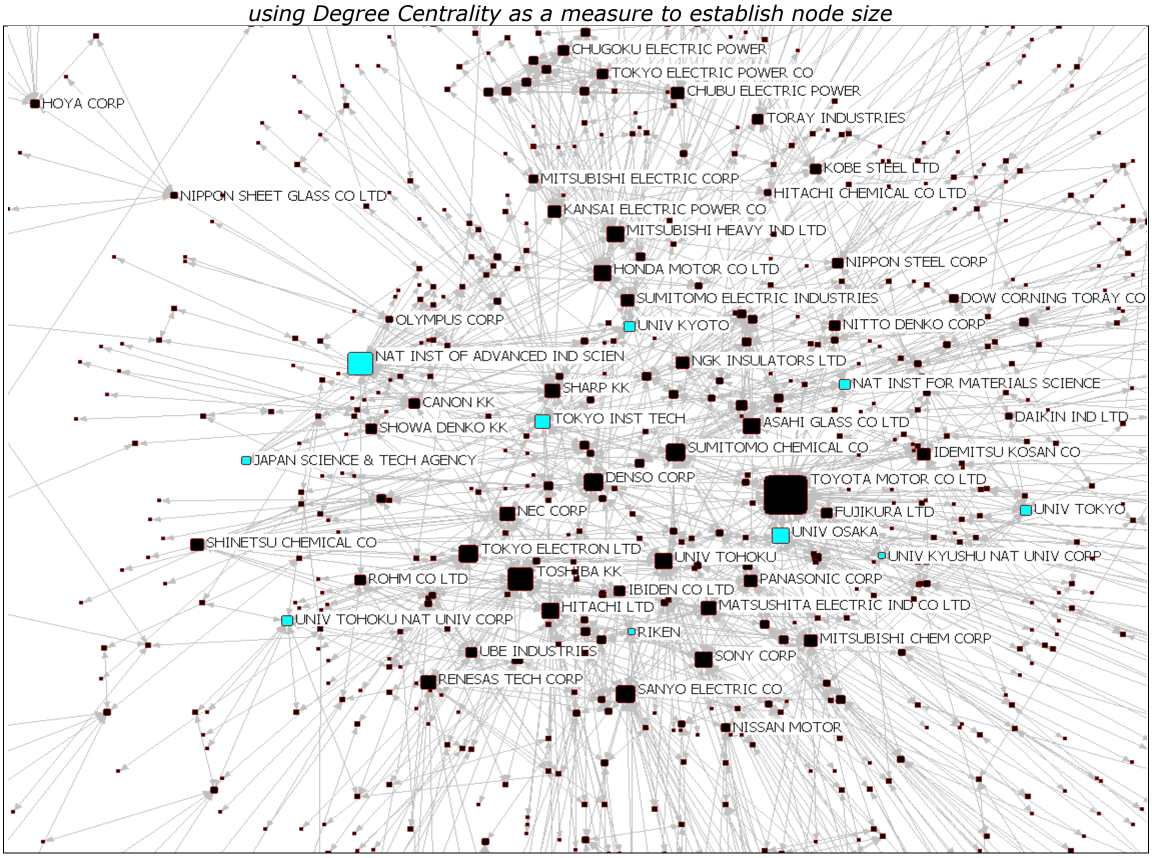


Source: Authors' own analysis

Samsung's leading position is further confirmed in Annex 6 where interestingly KAIST does not feature (it has 34 patents). We could infer that, like Germany, the South Korean government efficiently uses their institutes to enable the cooperation between industrial and academic partners as well as the distribution of funding.

In Figure 44 we focus on Japan, which as one of the largest economies in the world, has a very dense core network. Due to the density a Degree Centrality calculation, as shown in Figure 44 is not that conclusive although we can see that Toyota, Toshiba and the National Institute of Advanced Industrial Science and Technology (AIST) are the most connected organizations.

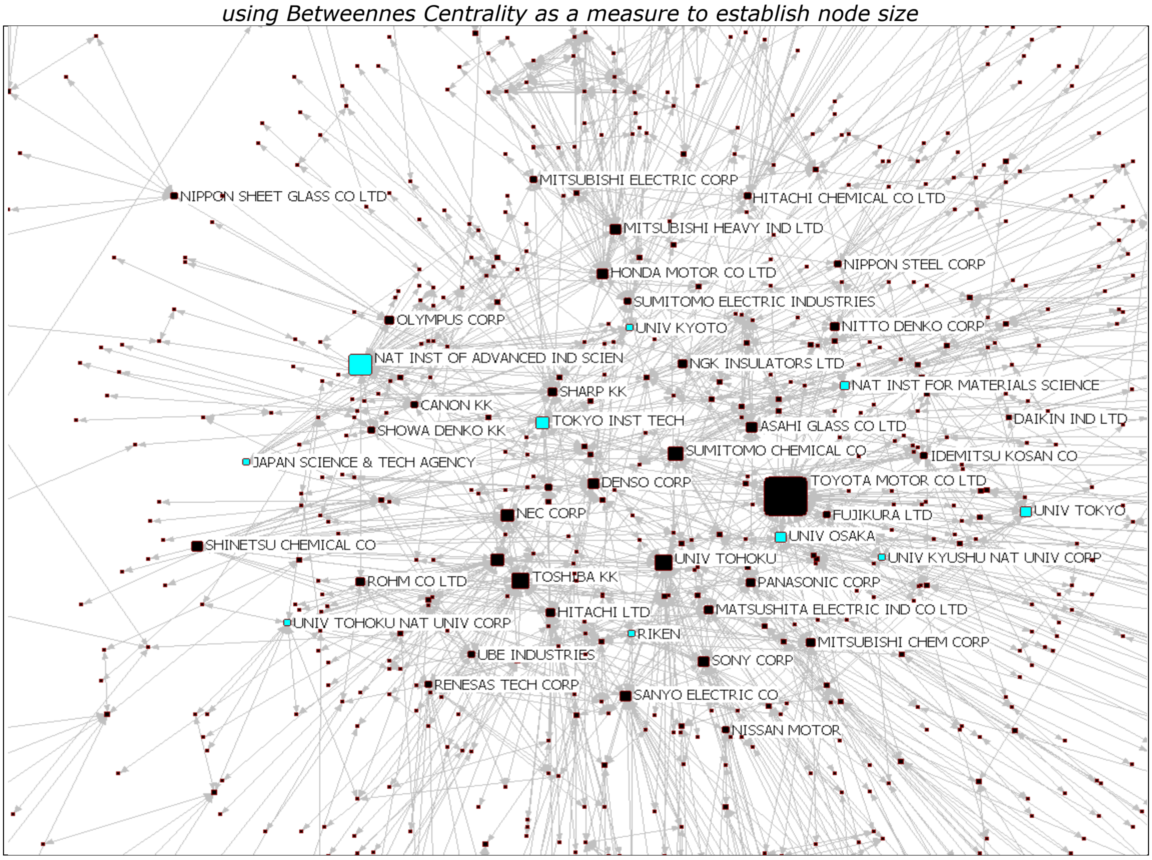
Figure 44 – Patent application collaboration network in Japan: Core Materials Science network cluster using Degree Centrality as a measure to establish node size



Source: Authors' own analysis

If we focus on the key organizations controlling knowledge diffusion in Figure 45 we see a slightly different picture.

Figure 45 – Patent application collaboration network in Japan: Core Materials Science network cluster using Betweennes Centrality as a measure to establish node size



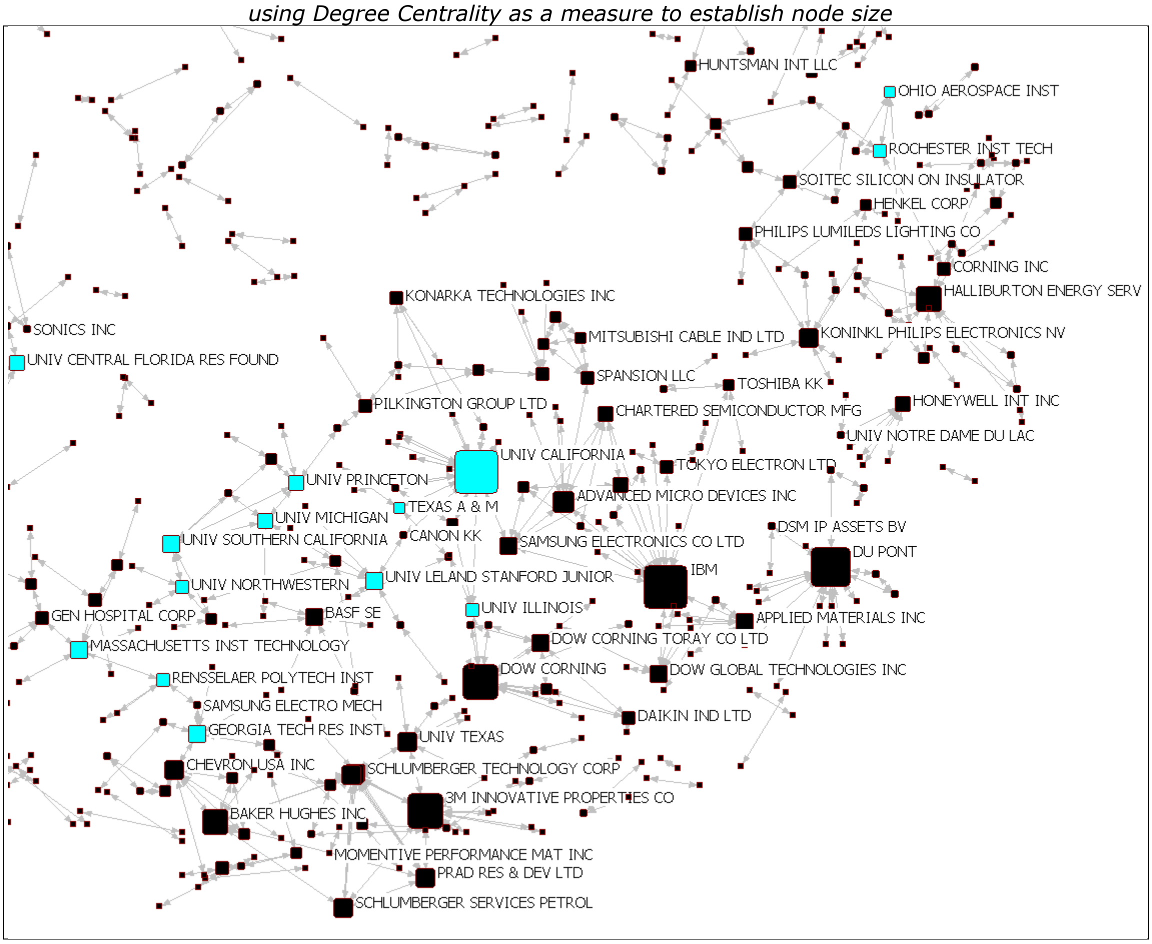
Source: Authors' analysis

Toyota is by far the most important node controlling access to knowledge, followed by Toshiba, Sumitomo and Denso. However the National Institute of Advanced Industrial Science and Technology (AIST), the Tokyo Institute of Technology and the Universities of Osaka and Tohoku are larger or equal to the latter industrial organizations. So although industrial partners represent the largest part of the organizations in the core cluster, academic and government organizations remain near the top, especially when looking at the control of access to knowledge and knowledge diffusion.

When we look at the top 15 applicants we see that none of the academic and government organizations are present. The first non-profit organization is AIST with 104 patent applications and as such is far down the list.

For the US we find that a similar network appears as for Nano S&T in that it also consists of a high number of disparate clusters, although for Materials Science these clusters are more connected. In Figure 46 we show the largest cluster revolving around the University of California. This cluster has two significant sub-clusters. One revolves around IBM and the other one around Dow Corning. Also two less significant sub-clusters are present: one surrounding Konarka and one around Stanford University.

Figure 46 – Patent application collaboration network in the US: Core Materials Science network cluster using Degree Centrality as a measure to establish node size

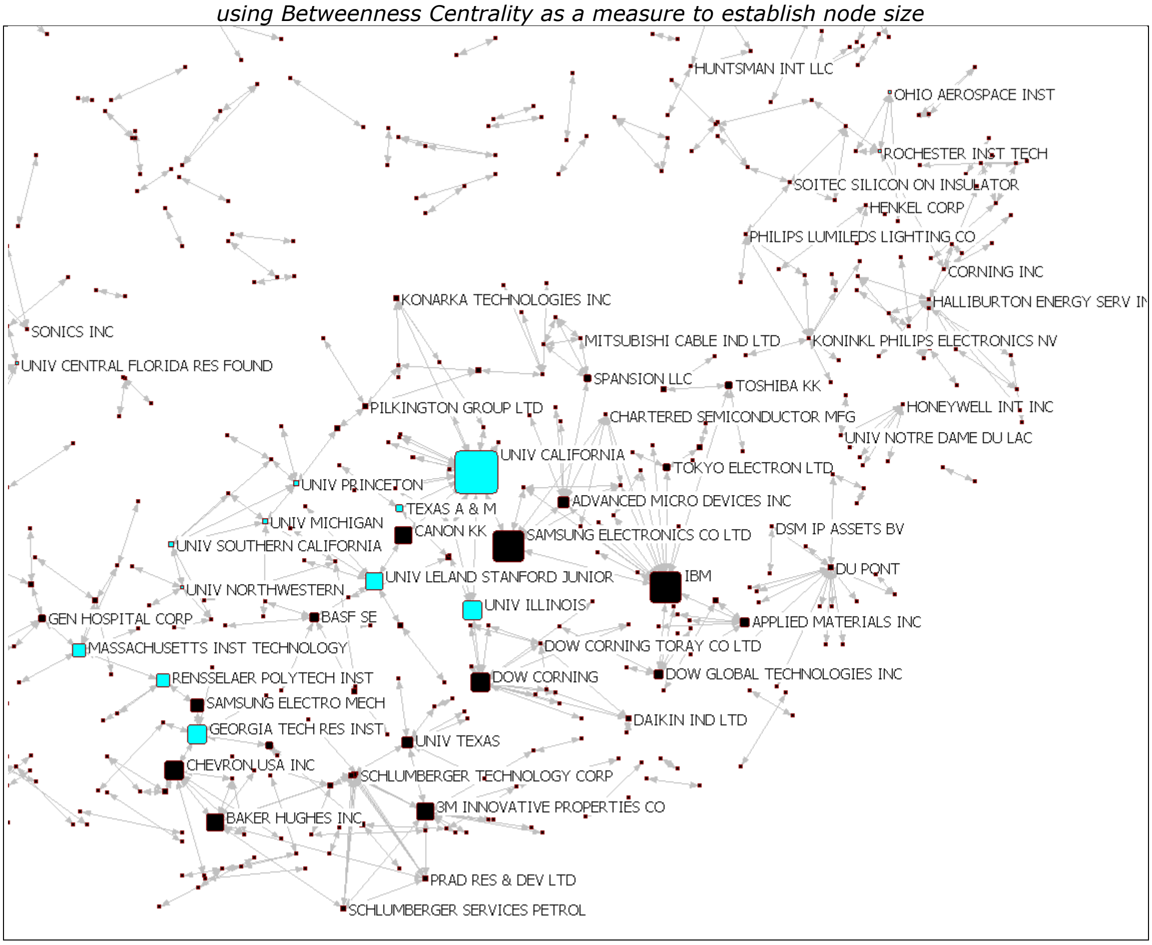


Source: Authors' own analysis

What is quite interesting in this cluster is that two foreign owned companies actually serve as bridges between the main and sub-clusters; Canon and Samsung.

This is visible in Figure 47, where we use Betweenness Centrality as a measure of control of access to knowledge. Here we see that Canon and Samsung, as well as the University of Illinois act as gatekeepers, with increasing importance relative to the other nodes, within the larger cluster. Nevertheless the US based companies and academic organizations ultimately remain in overall control of the knowledge diffused.

Figure 47 – Patent application collaboration network in the US: Core Materials Science network cluster using Betweenness Centrality as a measure to establish node size



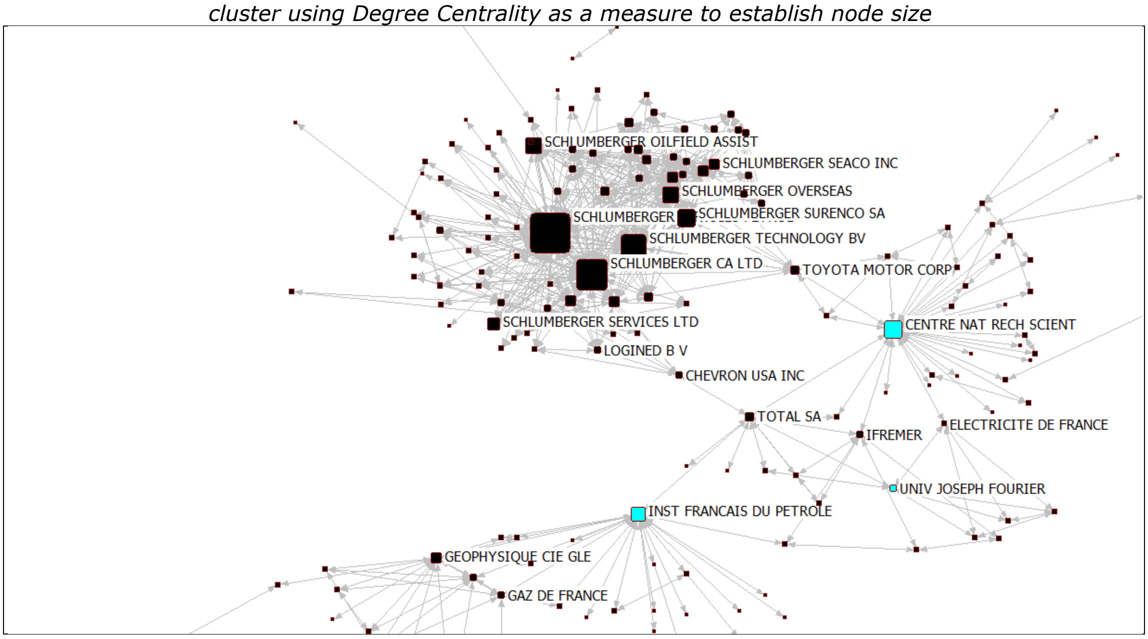
Source: Authors' own analysis

In Annex 6, it is shown that these foreign companies are not included in the top 15 however if it comes to patent application activity. This is still dominated by US based firms.

<u>Manufacturing and Processing Collaborative Patent Networks</u>

In Figure 48 we show the core cluster in the Manufacturing technology network for France.

Figure 48 – Patent application collaboration network in France: Core Manufacturing technology network cluster using Degree Centrality as a measure to establish node size



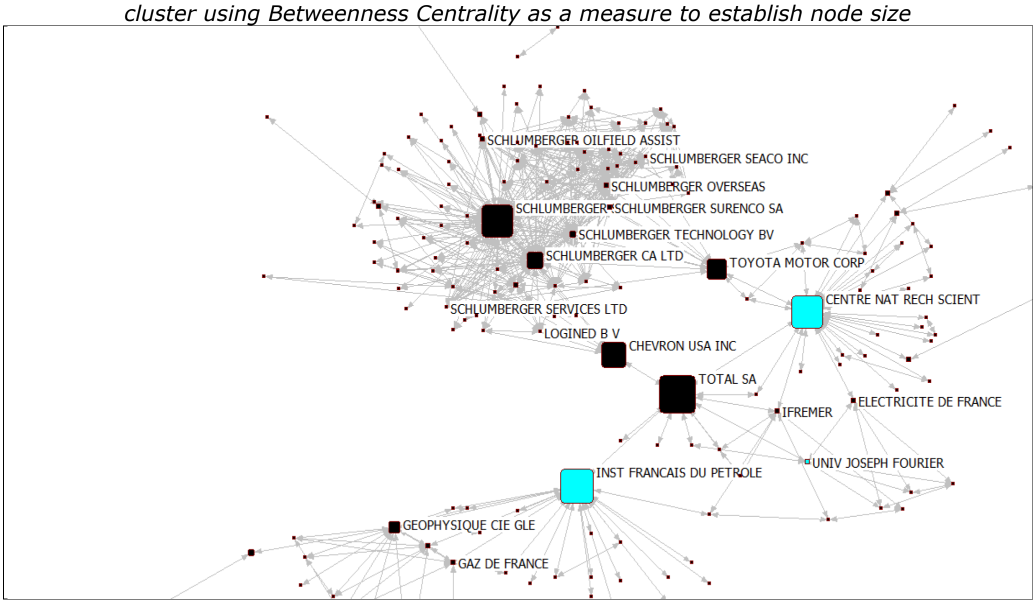
Source: Authors' own analysis

The centre of the above main cluster is again CNRS. And although several semi-foreign firms from the same conglomerate, Schlumberger [33], distort the visualization a bit, the other organizations in this network cluster are mainly French and rather well connected.

If we now look at the Betweenness Centrality measures for this same cluster we see in Figure 49 that the three largest organizations in terms of knowledge control are CNRS, Total, and the Institute Francais du Petrole.

[33] Although Schlumberger has its headquarters in Houston Texas, it has several large research centers in Europe where it originated. Schlumberger was originally a French company which moved headquarters at the outbreak of WWII.

Figure 49 – Patent application collaboration network in France: Core Manufacturing technology network cluster using Betweenness Centrality as a measure to establish node size



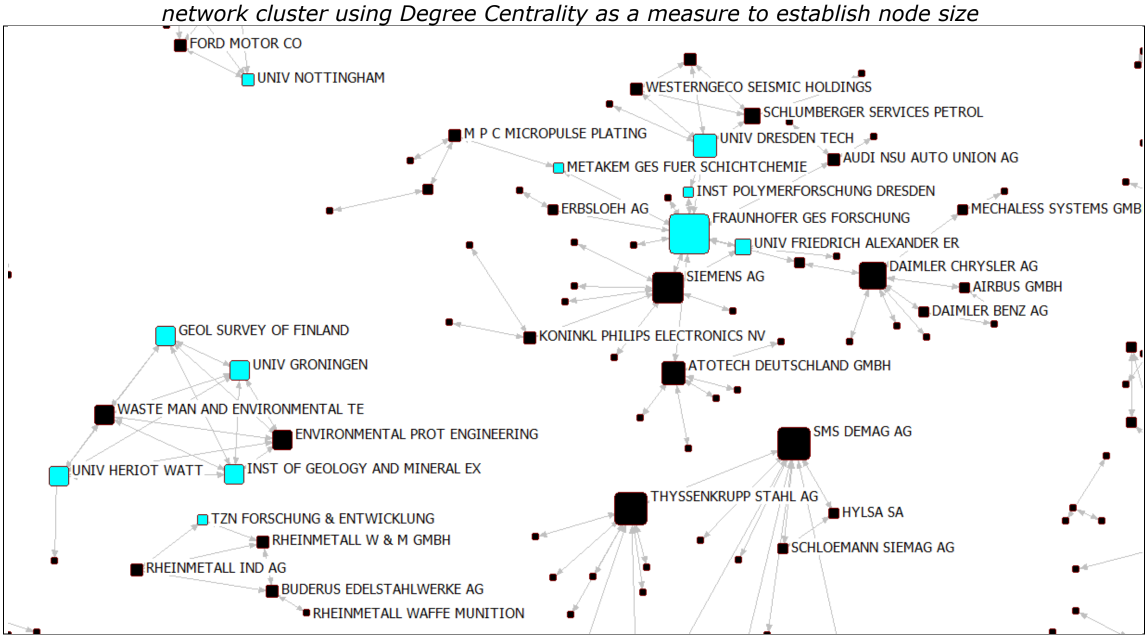
Source: Authors' own analysis

As with the previous networks for France, we see that academic and government organizations claim the highest amount of patents. If we discount the Schlumberger/Prad sub-cluster, we see that the Institute Francais du Petrole has a respectable amount of manufacturing technology patent applications.

We also notice that CEA and CNRS are in the top 15. We can infer that also in this field public R&D is very important for France.

If we now turn to Germany, in Figure 50, we see that the main cluster surrounds the Fraunhofer Forschungs Gesellschaft, and that the second tier consists of large German corporations such as Siemens, Daimler and Atotech. In a third tier we do find foreign firms such as Philips and Schlumberger.

Figure 50 – Patent application collaboration network in Germany: Core Manufacturing technology network cluster using Degree Centrality as a measure to establish node size

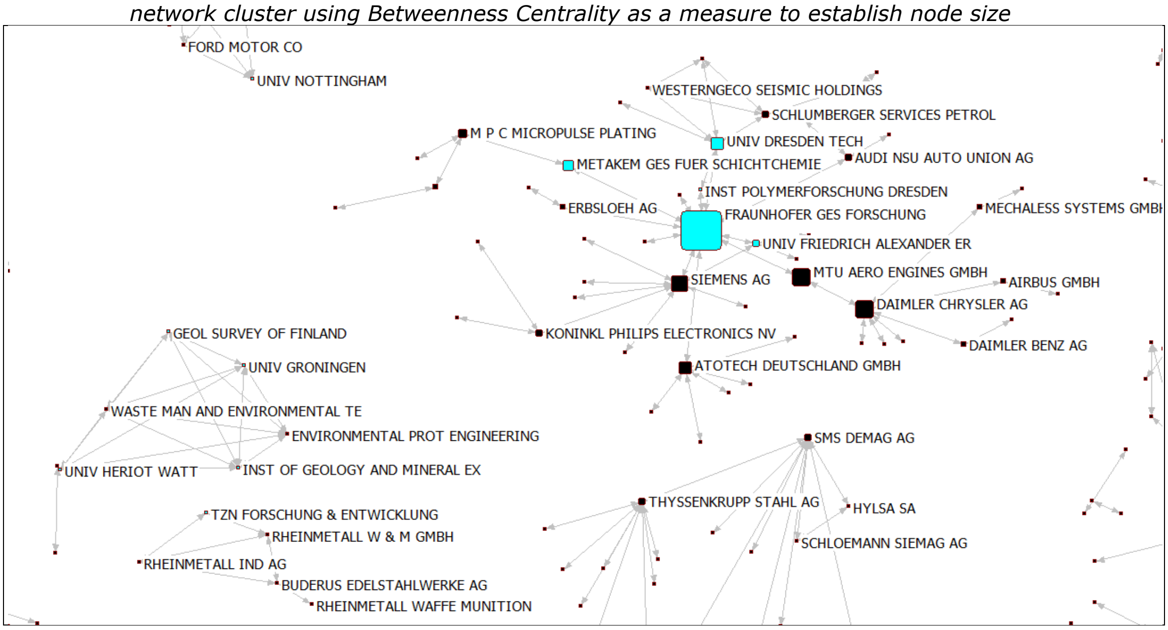


Source: Authors' own analysis

There is also a technology focus visible in this cluster, to the extent that knowledge on automotive, petroleum and electronics technologies is coming together possibly for car manufacturing.

In Figure 51 we show a representation of Figure 50 while focussing on the access to knowledge and we see that Fraunhofer is in overall control of the knowledge that is diffused through this network

Figure 51 – Patent application collaboration network in Germany: Core Manufacturing technology network cluster using Betweenness Centrality as a measure to establish node size

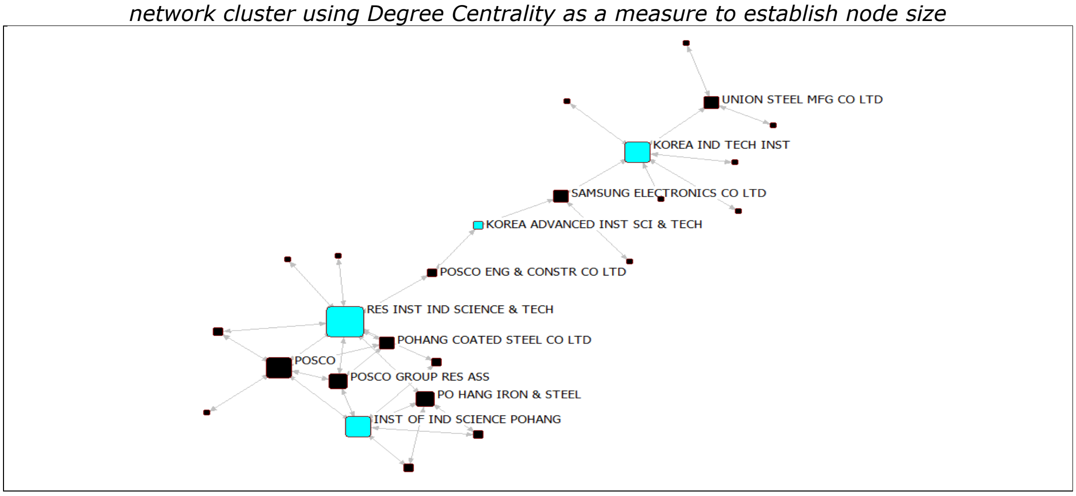


Source: Authors' own analysis

Unlike France, Germany does not exploit its public R&D as much, but possibly sees the public R&D organizations such as Fraunhofer and Max Planck more as accelerators of industrial R&D.

Turning to the Asian countries we explored we find in Figure 52 the main cluster in the manufacturing technology network of South Korea. We see a drastic difference with the previous networks for South Korea. Apparently the attention afforded to applied nano S&T and materials science is not replicated for manufacturing technologies. Also the previous lead role of commercial organizations is drastically reduced with only POSCO as the main commercial actor in this cluster.

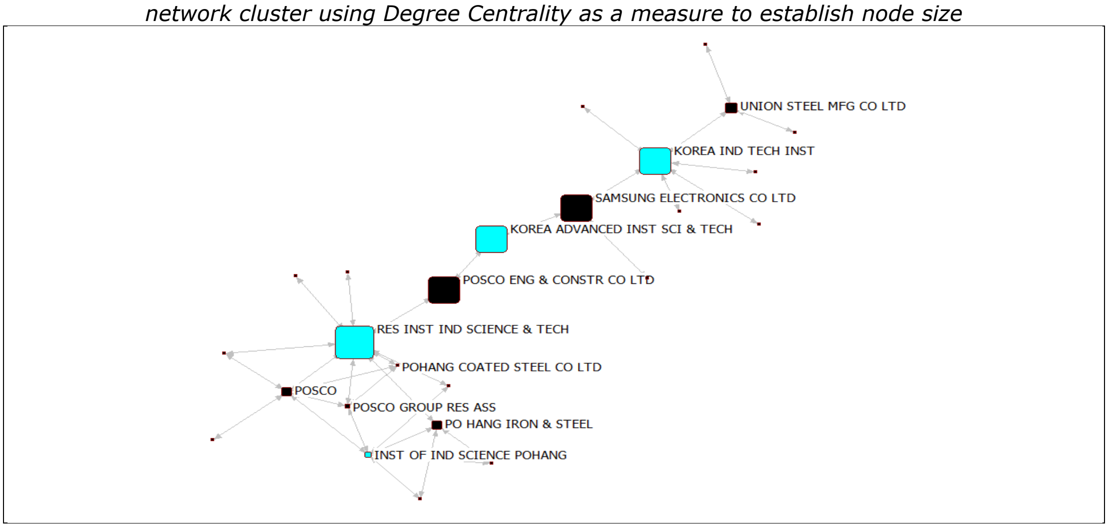
Figure 52 – Patent application collaboration network in South Korea: Core Manufacturing technology network cluster using Degree Centrality as a measure to establish node size



Source: Authors' own analysis

When we look at the Betweenness Centrality measures for this cluster (Figure 53) we see that organizations which did not appear important in the Degree Centrality view reclaim the central position that they had in the Nano S&T and Materials Science networks. This is certainly so for Samsung which regains an important position in the control of access to knowledge.

Figure 53 – Patent application collaboration network in South Korea: Core Manufacturing technology network cluster using Degree Centrality as a measure to establish node size

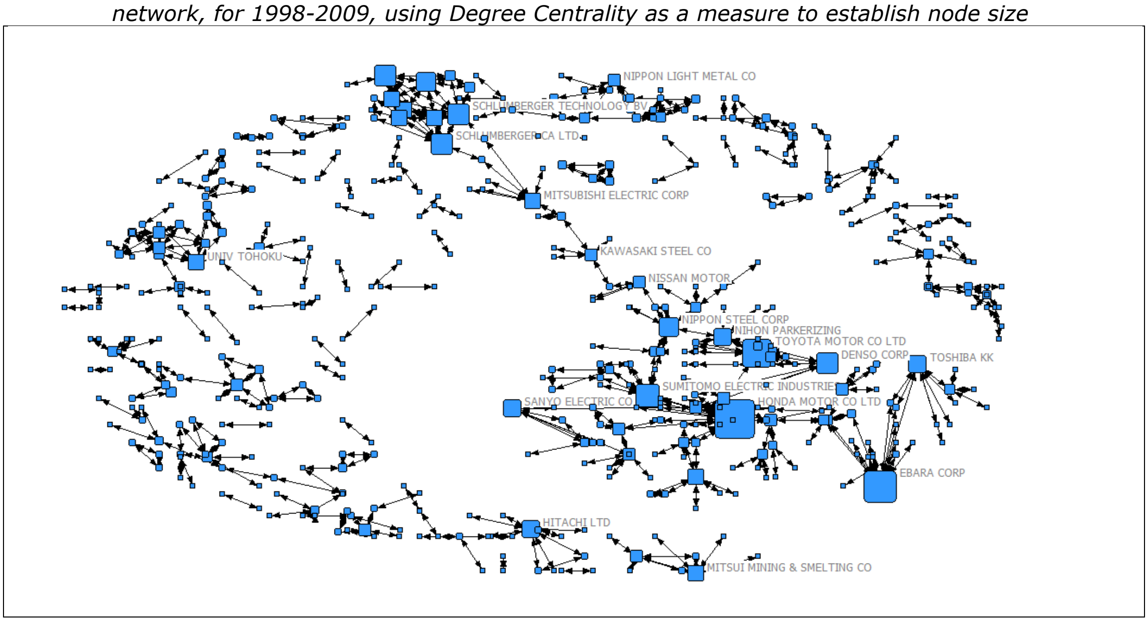


Source: Authors' own analysis

Annex 6 finally shows that besides the big steel conglomerates, Samsung indeed also has an important presence in the manufacturing technology network.

If we now look at Japan's Manufacturing and process technology network we see a striking similarity to Germany's network for this area, as can be seen in Figure 54.

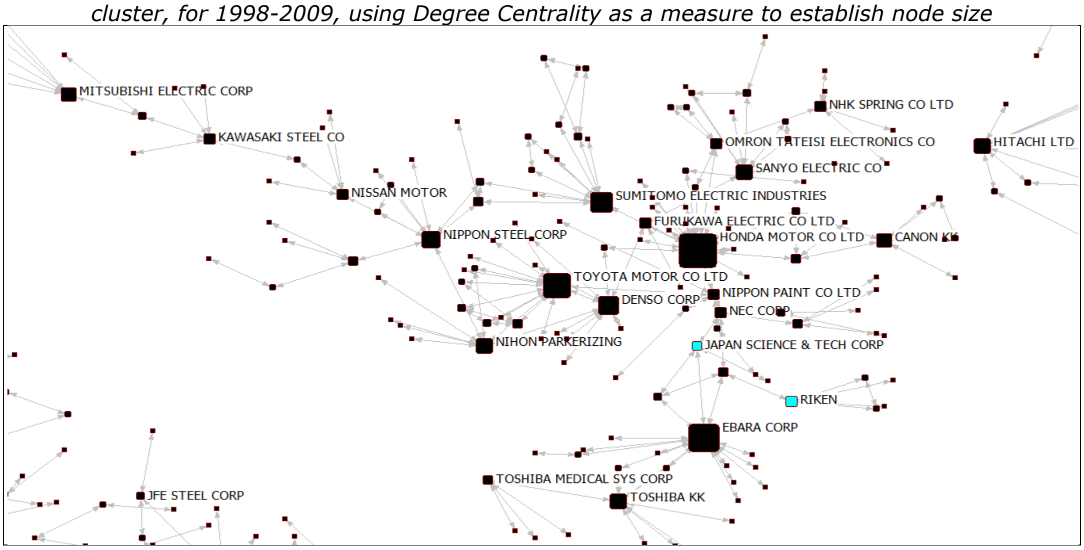
Figure 54 – Patent application collaboration network in Japan: Complete Manufacturing & Processing network, for 1998-2009, using Degree Centrality as a measure to establish node size



Source: Authors' own analysis

In this network we can see that there is a balance between government and industry collaborators in terms of degree centrality. Although the largest nodes are commercial companies; Honda, Toyota, Ebara, Sumitomo, Nippon Steel, Denso, Toshiba and Sanyo, the second tier follows closely with mostly universities and government institutes. The third tier is however again made up of industry partners such as Nissan, Hitachi, Mitsui and others. This network is highly dense showing lots of opportunities for collaboration in Materials Science which are most probably actively stimulated by both government and industry funding as can be seen in below Figure 55 zooming in on the main cluster

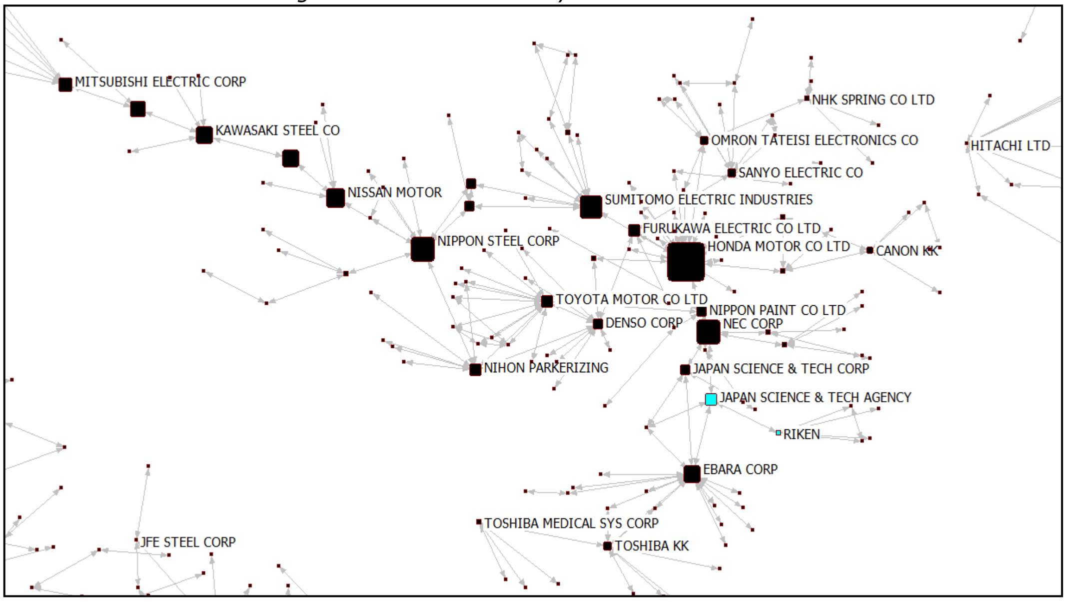
Figure 55 – Patent application collaboration network in Japan: Main Manufacturing & Processing network cluster, for 1998-2009, using Degree Centrality as a measure to establish node size



Source: Authors' own analysis

Focussing on this main cluster within the network we find (as shown by Figure 56 below) that contrary to the Materials Science network in this network Honda is the leading industrial organization, while Toyota does not play such a prominent role. Also the JST and the AIST do not play an important role here. Apart from Honda, the main organizations controlling access to knowledge are Nippon Steel, Sumitomo, NEC and Nissan.

Figure 56 – Patent application collaboration network in Japan: Main Manufacturing & Processing network cluster using Betweenness Centrality as a measure to establish node size

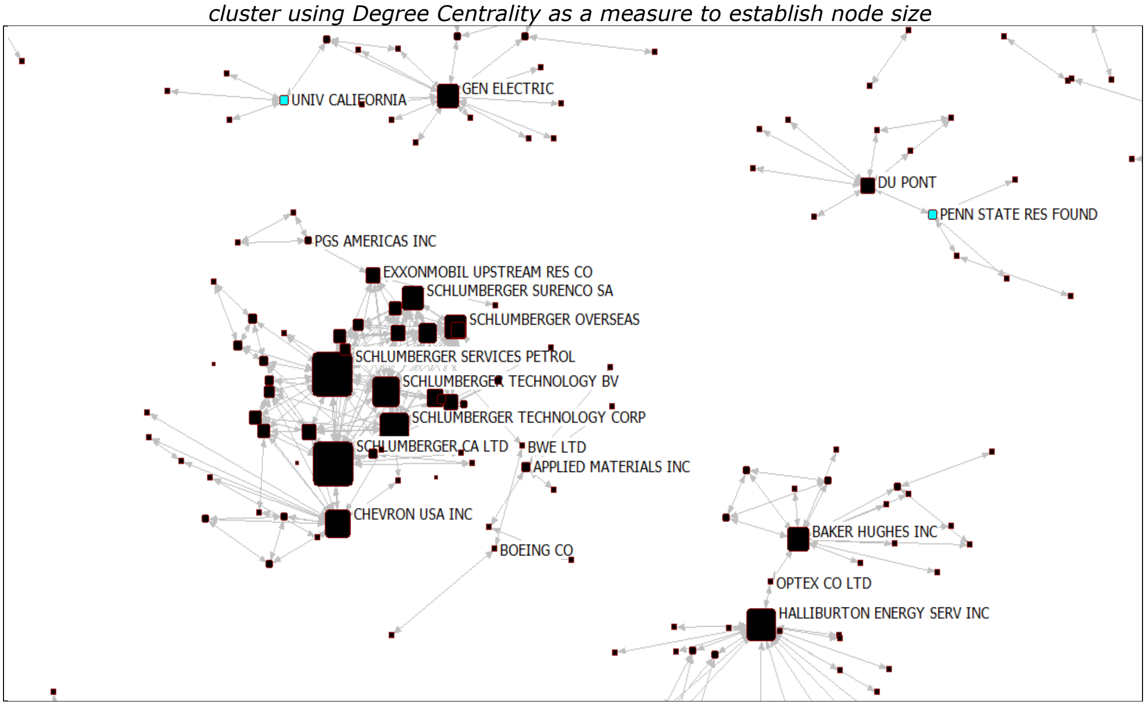


Source: Authors' own analysis

Lastly we note that for the US a similar picture appears as for the previous areas of Nano S&T and Materials Science, with large clusters including many foreign corporations (Figure 57). One obvious difference is however the absence of substantial academic and government involvement. Manufacturing technology seems to be, by and large, an industrial affair.

The main cluster in the US is, perhaps unsurprisingly, the domain of petroleum and exploration companies such as Schlumberger, Halliburton, Chevron etc.

Figure 57 – Patent application collaboration network in the US: Main Manufacturing & Processing network cluster using Degree Centrality as a measure to establish node size

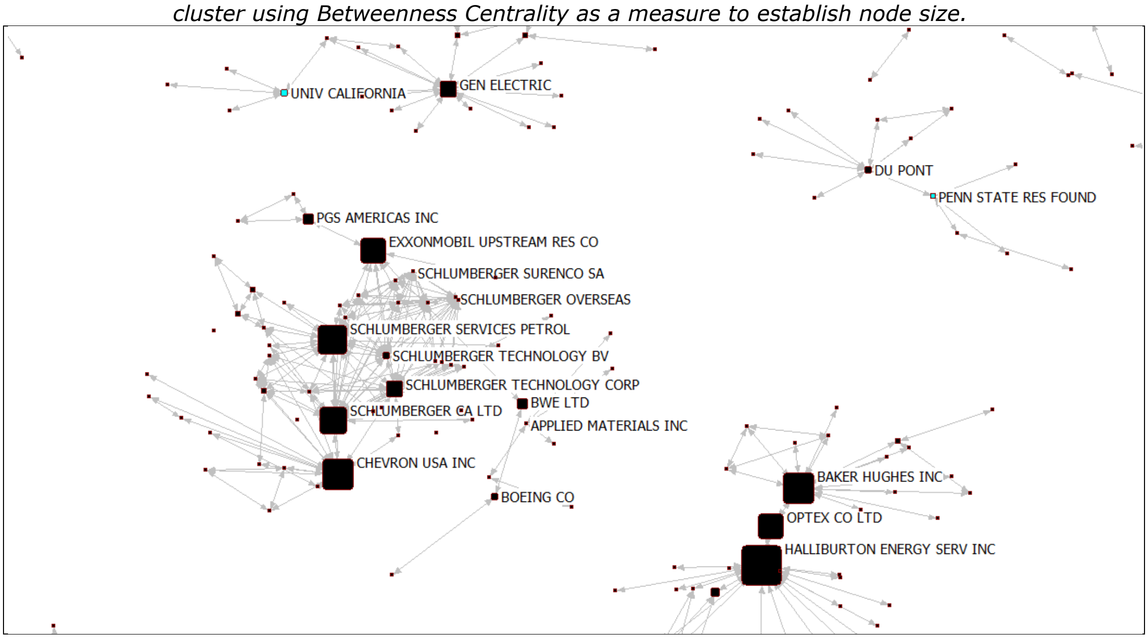


Source: Authors' own analysis

This perception is reinforced if we look at the number of patent applications per organization. Here Baker Hughes, an oil field services company leads by far with other well known international oil and mineral exploration companies leading the manufacturing and process technology patenting list. Previously leading firms like IBM and Applied Materials can now be found further down the list. While no academic and government organizations appear here. The University of California is the first, appearing at position 23 with 109 patent applications in this field.

If we know look at the access to knowledge visualization in Figure 58, using Betweenness Centrality as a measure we see something interesting. The access to knowledge between the two sub-clusters with the highest amount of patent applications of this main US network cluster is controlled by a Japanese firm (Optex).

Figure 58 – Patent application collaboration network in the US: Main Manufacturing & Processing network cluster using Betweenness Centrality as a measure to establish node size.



Source: Authors' own analysis.

4.2.4.2 Conclusions from the network analysis

From the fields and countries mapped and analysed we can draw some conclusions. We can see from the Figures and the Degree Centrality measurements that for countries like France, Germany, South Korea and Japan there is a clear innovation policy with differing degrees of state involvement. The US does not have such a clear policy; at least the mapping does not show this.

What is clear is that front-line technologies, in this case nano-science and technology is clearly driven by basic R&D with a large amount of academic and government involvement. This is probably quite natural as these technologies are still in a pre-mature, developmental, state. The area probably also lends itself best to practical policy solutions and government intervention at this stage in the development of the technology. Not all countries have the same degree of government involvement with the Asian countries having this to a lesser degree.

In a much more mature field such as Materials Science the picture differs to the extent that corporate involvement is taking the upper hand, which is particularly true for the Asian countries and the US. Smaller academic entities disappear from the networks although the large academic and specifically the government organizations remain and occupy strategic positions if we look at the control of knowledge flows thorugh the Betweenness Centrality measurements. This again is more noticeable in the European countries.

Lastly, Manufacturing technology R&D seems to be firmly in corporate hands where, with the exception of Germany and South Korea, government involvement is minimal compared to the other fields. Perhaps this is not surprising as manufacturing and process technologies are quite applied and as such the furthest away from basic science.
From the publication and patent application analysis we can also see that efficiency gains can be made by linking disparate cluster in Europe with one another at a

larger scale. Also a further opening up of the public R&D infrastructure to corporate R&D and creating relationships across national borders will bring Europe closer to the examples of the US and Japan.

4.3 Impact indicators

4.3.1 Number of institutions and firms in NMP

The number of institutions and firms active in NMP represent the competitiveness and capability in this sector. Given that it is difficult to enumerate organizations in NMP area, we use those in high-tech fields.

Top research institutions represent the capability of basic research, and top companies represent a measure of the competitiveness in technology application and commercialization. Table 9 below summarizes the top 2000 (EU and non-EU) firms by country. The US is the major contributor worldwide. The top EU firms are mainly from the UK, Germany and France. Apart from the US and Japan, other third countries do not seem to have many competitive top firms.

Table 9 [34]– Number of top firms in NMP (2005 – 2010)

	2005	2006	2007	2008	2009	2010	Average
US	587	563	543	531	504	487	536
UK	327	321	276	247	246	244	277
Japan	237	237	244	256	259	267	250
Germany	167	167	188	209	206	206	191
France	112	114	113	125	116	134	119
Sweden	81	75	77	70	76	74	76
Finland	70	67	60	58	56	52	61
Italy	40	48	51	57	53	55	51
Netherlands	44	50	49	53	52	56	51
Switzerland	37	39	41	38	38	40	39
Austria	28	31	30	32	31	29	30
South Korea	17	22	21	22	26	25	22
China	6	8	10	15	21	19	13
India	4	10	15	15	17	18	13
Israel	10	9	10	7	9	9	9
Brazil	3	4	5	3	8	9	5
Poland	2	2	4	6	5	9	5
Russia	1	1	3	2	3	2	2

Source: European Commission, JRC/DG RTD, The EU Industrial R&D Investment Scoreboards, 2006, 2007, 2008, 2009, 2010 and 2011.

Regarding top institutions, examples from two NMP fields were drawn (i.e. Material science and Nanoscience and technology) based on the publication numbers. Tables

[34] Data are summarized from the top 1000 EU and top 1000 non-EU companies.

10 and 11 are calculated from the world's top institutions (in terms of publication numbers).

In both fields (Material science and Nanoscience and technology), the US had the most top institutions in 1998 followed by Japan, but China surpassed them in 2010, in terms of numbers of top institutions as well as publication numbers. In general, the number of the world's top institutions from Europe slightly decline over time, which is mainly due to the increase of Chinese institutions.

Table 10 [35]– Publications in top institutions in materials science (2005 – 2010)

	2005	2006	2007	2008	2009	2010	Average
US	587	563	543	531	504	487	536
UK	327	321	276	247	246	244	277
Japan	237	237	244	256	259	267	250
Germany	167	167	188	209	206	206	191
France	112	114	113	125	116	134	119
Sweden	81	75	77	70	76	74	76
Finland	70	67	60	58	56	52	61
Italy	40	48	51	57	53	55	51
Netherlands	44	50	49	53	52	56	51
Switzerland	37	39	41	38	38	40	39
Austria	28	31	30	32	31	29	30
South Korea	17	22	21	22	26	25	22
China	6	8	10	15	21	19	13
India	4	10	15	15	17	18	13
Israel	10	9	10	7	9	9	9
Brazil	3	4	5	3	8	9	5
Poland	2	2	4	6	5	9	5
Russia	1	1	3	2	3	2	2

Source: Scopus - SciVerse Elsevier

[35] Summarized from the world's top 150 institutions with the most publication records in material science.

Table 11 [36]– Publications in top institutions in nanoscience and nanotechnology in 1998 and 2010

1998				2010			
ranking	country	number of institutions	Number of publications of these institutions	ranking	country	number of institutions	Number of publications of these institutions
1	US	54	6937	1	China	34	18441
2	Japan	14	2816	2	US	42	16307
3	Germany	19	2125	3	Japan	13	6817
4	China	7	1289	4	South Korea	11	4149
5	UK	8	1207	5	France	5	2581
6	France	7	1204	6	Russia	2	2235
7	Russia	3	1154	7	UK	5	2057
8	Italy	6	706	8	Germany	5	1449
9	Israel	4	441	9	India	2	1278
10	Switzerland	3	389	10	Switzerland	2	775
11	Sweden	3	354	11	Sweden	3	738
12	Poland	1	215	12	Italy	1	670
13	South Korea	2	206	13	Netherlands	2	480
14	Netherlands	2	155	14	Poland	1	424
15	India	1	122	15	Brazil	1	394
16	Brazil	1	111	16	Austria	0	0
17	Austria	0	0	17	Finland	0	0
18	Finland	0	0	18	Israel	0	0

Source: MERIT nano publication database

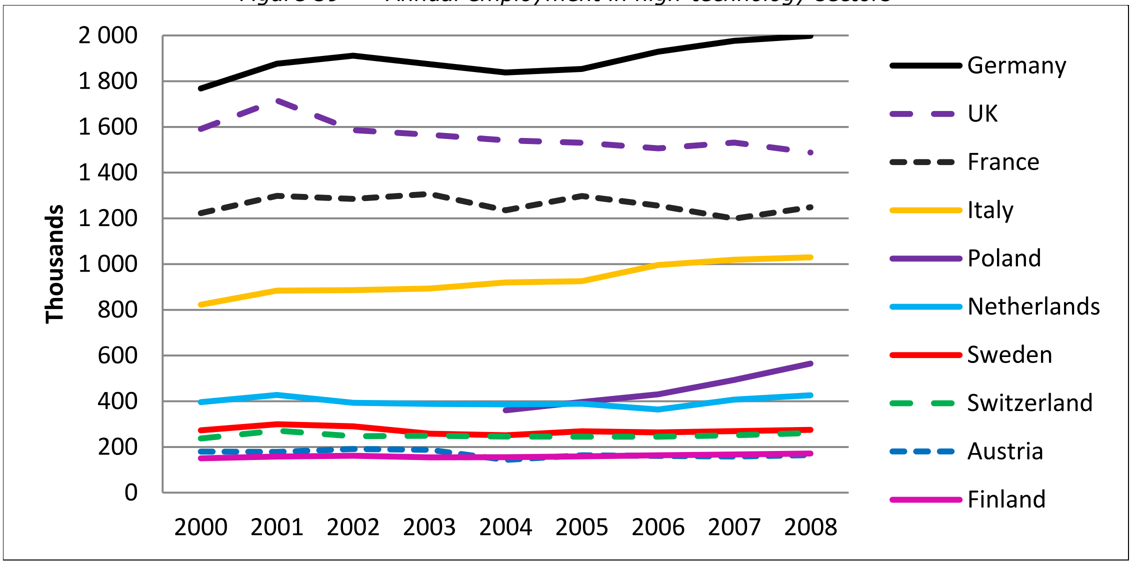
Compared to the top firms, research institutions in the third countries seem to catch up more quickly, in particular, in China and South Korea.

4.3.2 Employment in NMP

Figure 59 below shows annual employment in high-tech sectors for selected countries in the EU. Although the country totals are not surprising, the trends are so. Declining trends in France and the UK are of concern, although the increases for Germany, Italy, the Netherlands, and specifically Poland are promising.

[36] Summarized from the world's top 150 institutions with the most publication records in nanoscience and technology.

Figure 59 [37]– Annual employment in high-technology sectors

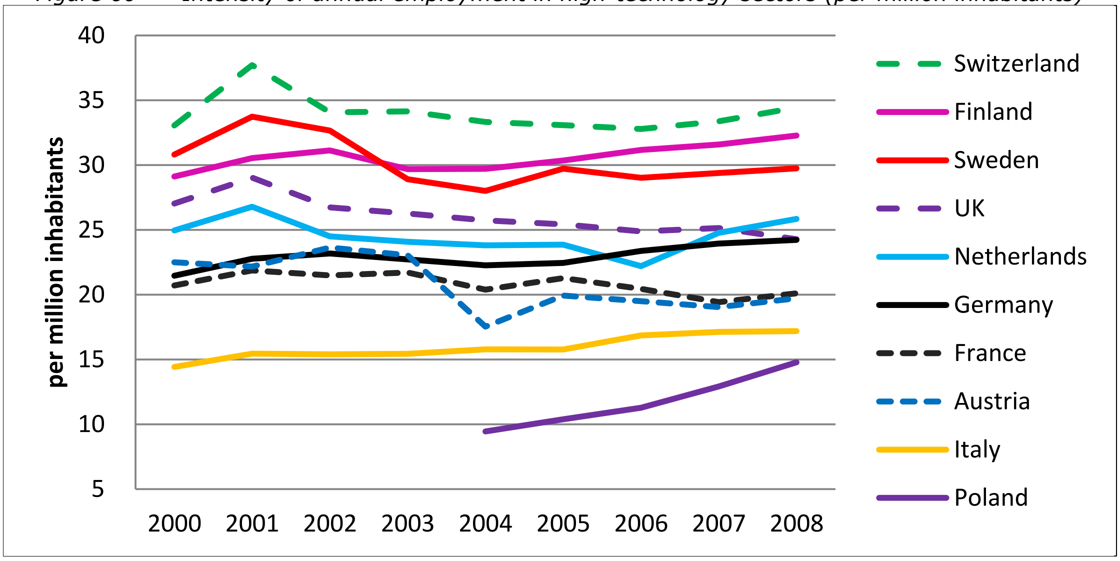


Source: EUROSTAT

Taking population into account, to provide a measure of intensity (Figure 60), a different conclusion can be drawn. Switzerland, Finland and Sweden are on the top first group, followed by the second group of UK, the Netherlands and Germany. France, Austria, Italy and Poland are in the third group.

[37]Note: 1) High-technology sectors are known as the sectors of high-technology manufacturing and knowledge-intensive high-technology services. 2) In the legend, the number behind each country's name is the average employment number for studied years. 3) No data for Poland during 2000 and 2003.

Figure 60 [38]– Intensity of annual employment in high-technology sectors (per million inhabitants)



Source: EUROSTAT

Some observations from the literature review are as follows:

Nanotechnology

- The U.S. National Science Foundation has predicted that 2 million nanotechnology workers will be needed by 2015 (Hullmann, 2006), (Roco, 2003), (Roco and Bainbridge, 2001), and (Allen, 2005). The breakdown of the estimated workforce is as follows:
- US: 0.8-0.9 million;
- Japan: 0.5-0.6 million;
- Europe: 0.3-0.4 million;
- Asia Pacific (excluding Japan): 0.2 million;
- Other regions: 0.1 million.
- It has been also estimated that nanotechnology will create another 5 million jobs worldwide in related fields and industries (Roco, 2003).

Materials

- In the material field, problems of young talent not entering materials technology are being faced (EuMaT, 2006).

Production and manufacturing

- In the period of 1990 to 2003, employment in manufacturing decreased in most countries: 29% in the UK, 24% in Japan, 20% in Belgium and Sweden, and 14% in France, and considerable decreases in the US in early 2000 (Bernard, 2009).

Some further development trends within NMP employment include the following:

- Increasing capabilities on high-added-value products and technologies.

[38] Note: 1) High-technology sectors are known as the sectors of high-technology manufacturing and knowledge-intensive high-technology services. 2) In the legend, the number behind each country's name is the average employment number for studied years. 3) No data for Poland during 2000 and 2003.

- The scientific engineering knowledge content of manufactured products was estimated to be around 16% in 2004, and will grow to at least 20% in 2020 (European Commission, 2004).
- Lower requirements for untrained workers, but increasing demand for highly educated and trained staff.
- In the US, manufacturing is holding its share of GDP, while the number of workers is falling. Productivity is increasing, but job opportunities are decreasing (Schwartz and Tkaczyk, 2003).
- According to the "Open consultation on the European strategy for nanotechnology" (Malsch and Oud, 2004) in 2004, 44% of 733 respondents expected a shortage of trained staff in nanotechnology within five years, 24% in five to ten years, and 3% after ten years.
- A recent EC-funded study (Gelderblom et al., 2012) concluded that employment increases, related to technological developments, are expected in companies involved in NMP. It also concludes that the growth will probably be highest in companies that are involved in a combination of N, M and/or P, compared to companies involved in only N or M or P. It is also stated that the expected growth related to NMP is strongest for functions in R&D, engineering, and design, showing that NMP mainly influences high-qualified job functions.

Skill shortages were also investigated in the survey performed in this project. Respondents were asked to identify if their organizations currently suffered from skill shortages. The results are summarized as follows:

- In general, the answers provided by large companies on specific skill shortages are well balanced, with almost same percentages identifying skill shortages as those saying they were not apparent;
- In general for SMEs, more respondents answered that they did not have such skill shortages;
- Companies which received funding (both public and venture capital funding) clearly have a higher ratio of answering that they did not have skill shortages than the general company sample.
- University and higher education show higher percentage of no shortages on S&T or Eng graduate and S&T or Eng PhD. However, research institutes show a higher percentage of shortages of these two types of skills;
- University and higher education organizations which received funding do not show significantly different skill shortages when compared to the average for these organizations;
- Research institutes which received public funding have a higher ratio of identifying skill shortages than the general sample for these organizations.

The survey also asked respondents to identify expected changes in different skill categories (in the next 5 years). The findings are as follows:

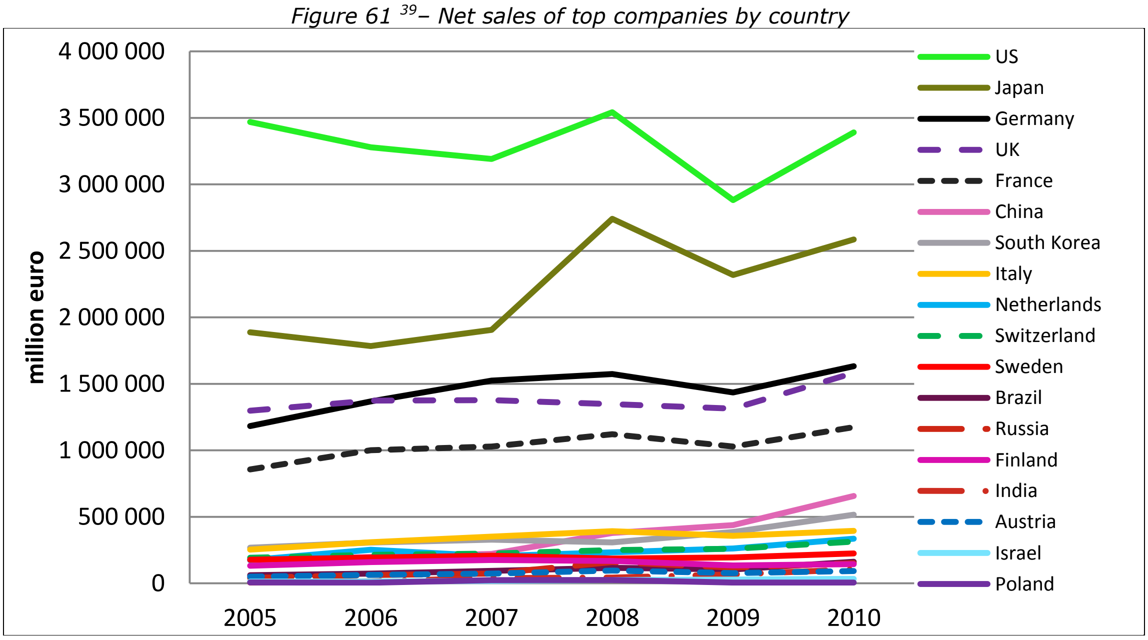
- Combining with the skill shortage analysis, although many companies (half of large companies and more than half of SMEs) indicate they do not have specific skill shortages, there appeared to be more agreement that there is an increasing trend in specific skilled staff requirements in the next 5 years;

- The increasing trend in SMEs greatly depends the funding. SMEs who received (public or venture capital) funding were more likely to state that they planned to increase their levels of higher skilled staff (i.e. S&T or Eng Graduate, and S&T or Eng PhD);
- Large companies who received public funding appeared to be less likely to plan an increase in skill requirements than average for these organizations;
- Academic institutes (universities, higher education and research institutes) do not show significant differences in planned staff changes with regard to funding received.

4.3.3 Net sales

The EU Industrial R&D Investment Scoreboards (various years) were used to collect net sales information for the selected 18 countries. Top companies are often the world's largest high-technology corporations. Therefore the top 1,000 EU companies and top 1,000 non-EU companies were summed, to obtain the total net sales by country, as shown in Figure 61.

Figure 61 [39]– Net sales of top companies by country



Source: European Commission, JRC/DG RTD, The EU Industrial R&D Investment Scoreboards, 2006, 2007, 2008, 2009, 2010 and 2011

Figure 61 presents an interesting clustering of countries. During the whole period 2005-2010, the US was leading the market in an absolute dominant position, though its net sales value in 2010 is slightly lower than it was in 2005. Japan, Germany, the UK and France composed the second cluster till 2007. However, since 2008 Japan moved to the first cluster, closely following the US. The third cluster consists of the majority of the studied NMP countries. China, Brazil, Russia, India and Israel all experienced rapid growth, with an annual growth rate of 24.5%, 23.6%, 24%, 25.6% and 20.2%, respectively.

[39] Data are summed from the top 1,000 EU and top 1,000 non-EU companies.

4.4 Mixed indicator analysis

In order to link the output and input factors and display the performance metrics of multi-variables at the same time, mixed indicator analysis is now provided.

4.4.1 The radar charts for selected countries

NMP publications and patents are the two main output variables measuring the performance of NMP activities in different regions. The input factors include both NMP specific indicators (NMP funding) and general S&T indicators. NMP specific funding may offer a direct explanation for NMP output, but general S&T variables are also important, in particular when NMP specific data are unavailable and because the NMP concept is hardly used outside of Europe.

We have represented this analysis using radar charts. In these radar charts, output indicators are:

- NMP Publication intensity (publication numbers *per* million people)
- NMP Patent intensity (patent applications *per* million people)

Input indicators are:

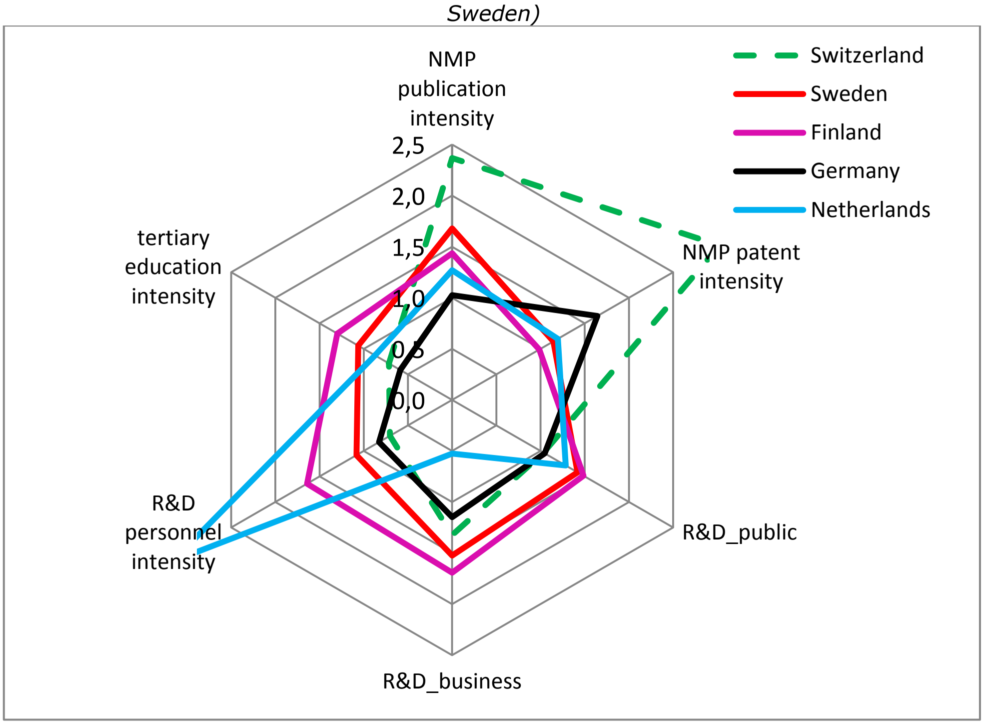
- R&D expenditure intensity - public sector (R&D expenditure percentage of GDP)
- R&D expenditure intensity - business sector (R&D expenditure percentage of GDP)
- R&D personnel intensity (R&D personnel *per* 100,000 inhabitants)[40]
- Tertiary education intensity (Number of students in tertiary education *per* million inhabitants)

To keep all variables on the same scale, the results of all the indicators are standardized for each country, namely the ratio to the mean is taken. The analysed European countries are classified into two groups, based on their NMP publication and patent intensities. The first group, including Switzerland, Sweden, Finland, Germany and the Netherlands, all have high NMP publication intensities and NMP patent intensities. The second group, Austria, UK, France, Italy and Poland, represent relatively low NMP publication and patent intensities.

In Figure 62 we see that Germany presents a high patent intensity, which seems to benefit more from a balanced development in the general S&T input environment, namely, R&D input and R&D personnel.

[40] Treated here as an input indicator.

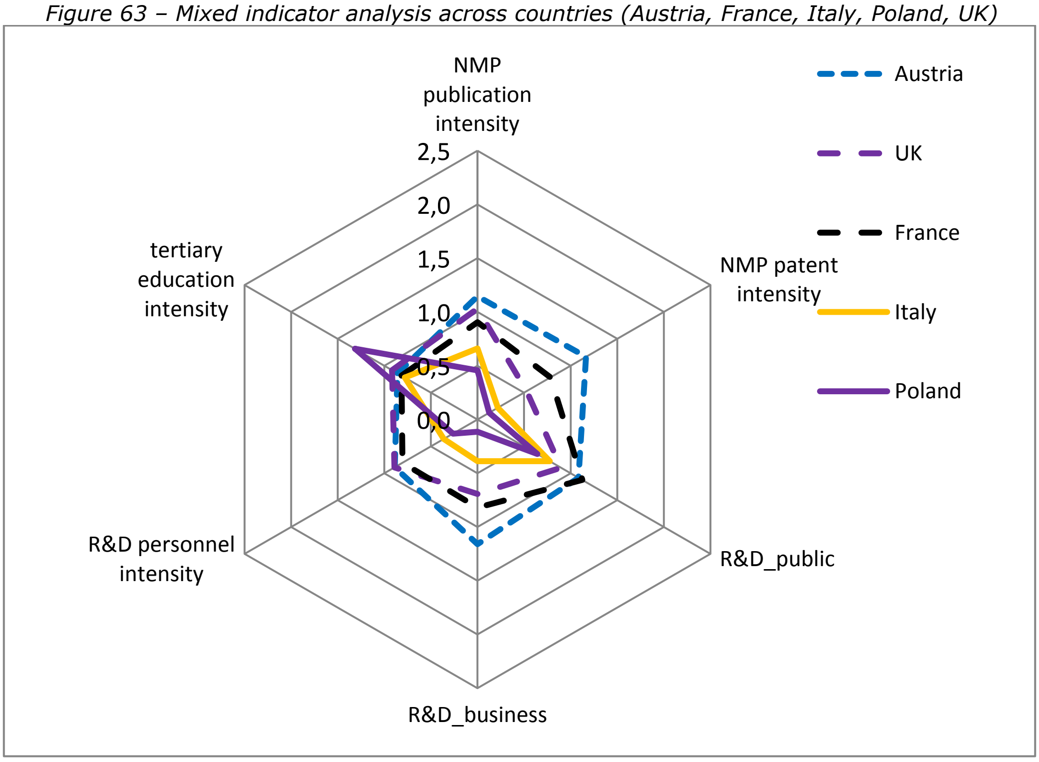
Figure 62 – Mixed indicator analysis across countries (Finland, Germany, The Netherlands, Switzerland, Sweden)



Source: Authors' own analysis

From Figure 63 we see that Austria, UK, France, Italy and Poland all have relatively average or low publication/patent intensity.

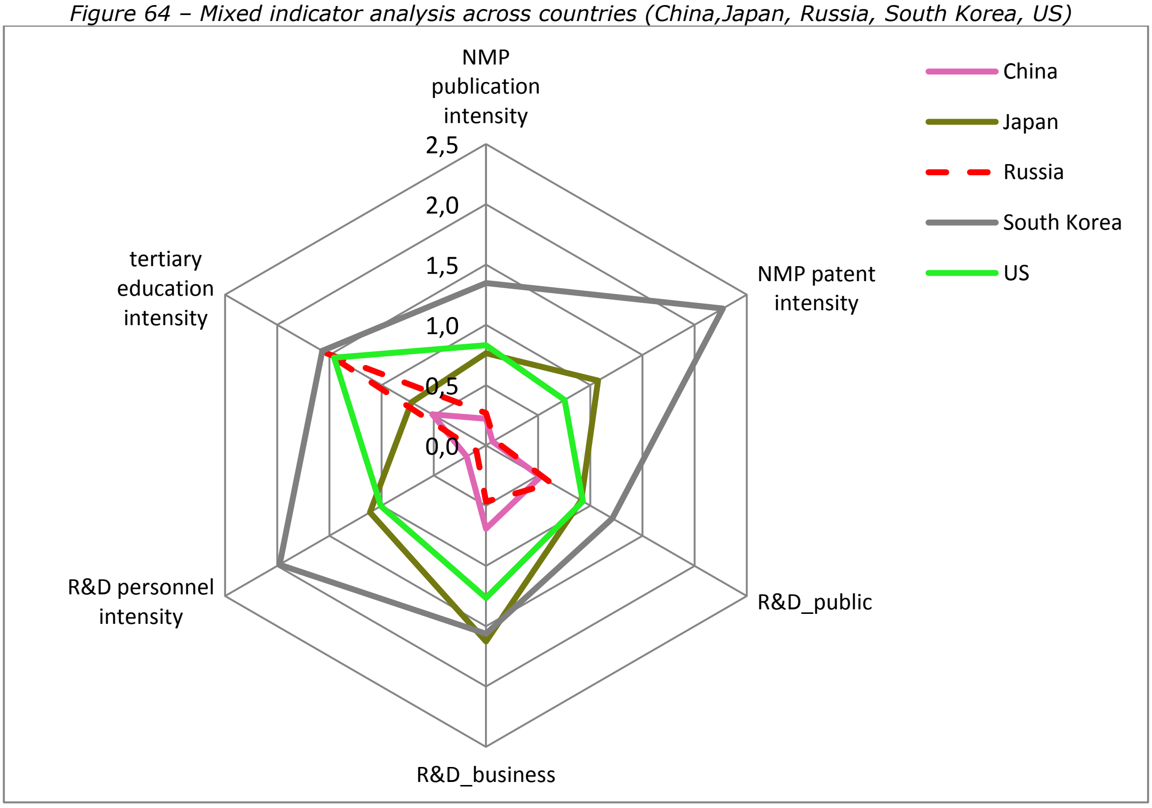
Figure 63 – Mixed indicator analysis across countries (Austria, France, Italy, Poland, UK)



Source: Authors' own analysis

As seen in Figure 64, in the Third countries, South Korea has an extremely high patent intensity. The US is similar to Germany, well balanced with most S&T indicators. China is located in the core of the chart, which indicates a situation of low intensity in most indicators.

Figure 64 – Mixed indicator analysis across countries (China,Japan, Russia, South Korea, US)



Source: Authors' own analysis

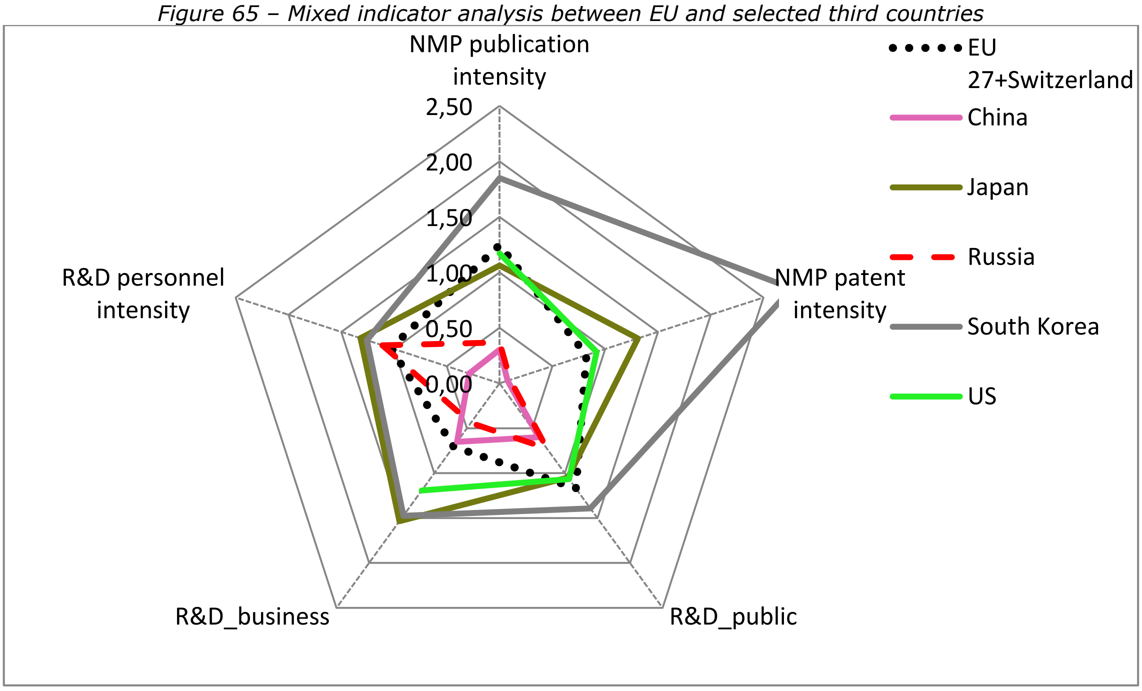
4.4.2 Comparing the EU position with others

To have a better understanding of the position of EU as a whole, a comparison between EU 27+ Switzerland and its main competitors can be provided. (Due to the fact that not all the data in the previous charts are available for the whole EU, Figure 65 covers only 5 indicators. Due to the lack of R&D personnel per 100,000 inhabitants (which was used in the previous section) for the EU27, here we use a slightly different R&D personnel intensity, i.e. R&D personnel per thousand labour force.

Radar charts are used to represent the data. The variables are the same as in the previous graphs, with the exception of the tertiary education indicator that is not covered below.

Figure 65 clearly shows that the EU as a whole is weak in NMP patenting, in particular a much lower patent intensity than South Korea, Japan and the US is observed. The intensity of NMP Publication, R&D in public sectors and R&D personnel is performing well in the EU. It is higher than the global average, while the R&D intensity in business sector is much lower than three main competitors, i.e., Japan, South Korea and the US.

Figure 65 – Mixed indicator analysis between EU and selected third countries



Source: Authors' own analysis
Note: The number for R&D personnel intensity in the US is lacking in this Figure

4.5 Scientific output: Regression analysis (EU vs. non-EU)

In this section we have applied regression analysis to measure the contribution of input factors to a given output, *e.g.*, the scientific publication numbers. The output variable examined here is the scientific publication [41], and the input factors are education, researchers, and total intramural R&D expenditure in business, government and higher education sectors. The panel data set covers 15 countries, and the time span is 9 years, 2001-2009.

Taking the country scale into account, intensity variables have been adopted. The list is as follows:

- Publication intensity - publication records per 100,000 inhabitants;
- Tertiary education intensity - number of student in tertiary education per 100,000 inhabitants;
- R&D Researcher intensity - number of R&D researchers *per* 100,000 inhabitants;
- GERD_business – total intramural R&D expenditure in business sector (% of GDP);
- GERD_government - total intramural R&D expenditure in government sector (% of GDP);
- GERD_higher education - total intramural R&D expenditure in higher education sector (% of GDP).

[41] The publication number for each country is a sum of three sectors, nanoscience, material science and bio-technology.

Both fixed-effect [42] and random-effect [43] regressions have been run, and then the Hausman test has been applied to choose the more efficient model. (The variable of R&D Researcher intensity was taken out in the final regression due to its auto-correlationship with education factor). The results of the regression analysis are provided in Table 12.

The total number of observations is 135: 15 countries and 9 continuous years. F test #is statistically significant at 99% level (P value is 0.0000). R squared is 0.95, meaning about 95% of the variance is explained by the model. As shown in Table 12, in order to compare EU with non-EU countries, EU and non-EU dummies were applied, and hence we have the coefficients for these two groups separately. The regression results show that education and R&D investment in the business sector are significant in EU countries. In contrast, R&D investment in the government and higher education sectors is insignificant in EU countries. This indicates that, in EU countries, tertiary education and R&D investment in the business sector contributes significantly to the scientific publication output. In non-EU countries, all the estimates are significant, which indicates that all these independent variables in the model are influential factors to publication output.

Table 12[44] – Regression analysis results

Variables	Regression Coefficients	Standard error
EU_education	0.2589	(0.0911)**
EU_GERD_business sector	0.1857	(0.0769)**
EU_GERD_government sector	-0.5849	(0.0659)
EU_GERD_higher education sector	0.1424	(0.1101)
Non EU_education	0.6490	(0.0819)**
Non EU_GERD_business sector	1.2959	(0.0944)**
Non EU_GERD_government sector	0.4191	(0.1299)**
Non EU_GERD_higher education sector	-0.7158	(0.0972)**
y 2	0.0095	(0.0222)
y 3	0.1341	(0.0232)**
y 4	0.1377	(0.0234)**
y 5	0.1645	(0.0239)**
y 6	0.2560	(0.0244)**
y 7	0.2901	(0.0254)**
y 8	0.3335	(0.0270)**
y 9	0.4062	(0.0330)**
Constant	-3.0256	(0.8208)**

[42]Which assumes that omitted variables differ between cases but are constant over time.

[43]Which assumes that omitted variables are constant over time but vary between cases.

[44]Note: 1) Standard errors in parentheses, *significant at 5% level, and ** significant at 1% level. 2) The variable of R&D researcher was dropped out due to its autocorrelation with education factor. 3) 15 countries are included. Brazil, Israel and India are not covered due to lack of the data. 4) y2 –y 9 are year dummies.

Variables	Regression Coefficients	Standard error
Observations	135	
Number of countries	15	
R-squared	0.9514	
Hausman Test	Prob>chi2=0.0000	
Fixed or Random effect	Fixed effect model (FE)	

Source: authors' own calculation

Comparing EU and non-EU countries, the coefficient values for education and R&D investment in the business sector are both higher in non-EU countries. This implies that the input factors of (tertiary education and R&D investment in business sector) are more productive and efficient in non-EU countries. On the contrary, public R&D contributes to scientific production only in non-EU countries. This result, to some degree, is in line with Guellec and van Pottelsberghe de la Potterie (Guellec and van Pottelsberghe de la Potterie, 2004),in that the impact of business R&D has increased over the past 20 years, whereas that of public R&D has decreased.

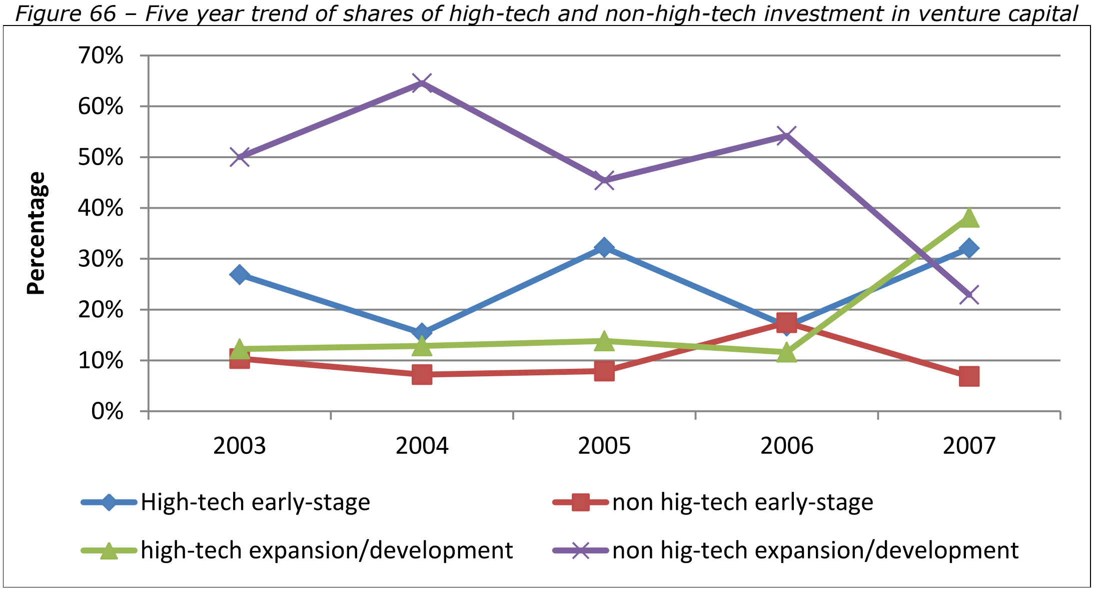
It is worthwhile to notice that the result of high coefficients of input indicators in the third countries is mainly due to the high scientific efficiency - publications per mill euro funding - in some developing countries like Brazil and India. However, if we look at the individual countries, in terms of publication efficiency, some European members perform better than the third countries.

4.6 Investment trend: High-tech vs. non high-tech

The project team investigated the share of high-tech versus non high-tech investment for venture capital within the EU between 2003 and 2007 (see Figure 66), and observed that although the non high-tech investment is dominant, there is an increase in the level of high tech venture capital investment within this period (both for early and expansion stages). High-tech expansion outperforms non high-tech expansion in 2007, with a percentage of 38.2% and 22.9% of venture capital respectively. The share of high-tech early-stage has been almost always higher than that of non high-tech early-stage, and even more so in 2007 (the high-tech early-stage share reached 32.1% and that of non high-tech early stage dropped to 6.9%).

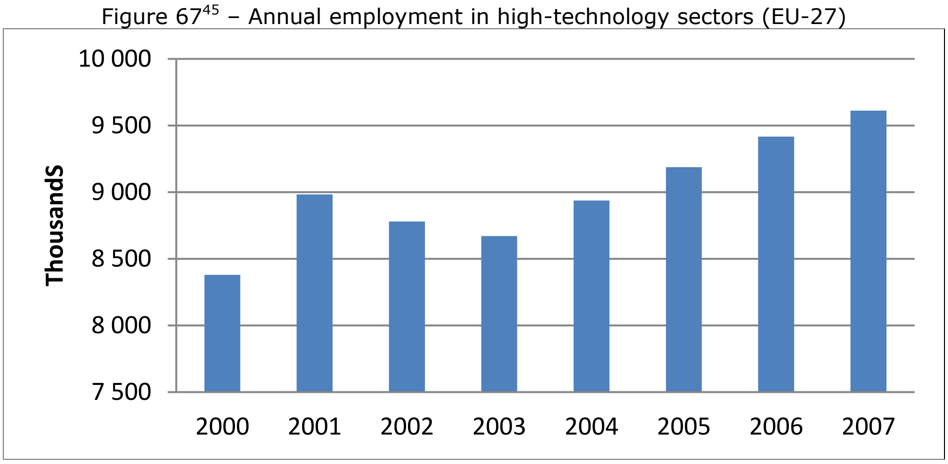
Annual employment in high-technology sectors within the EU-27 showed a steady increase between 2000 and 2007, as indicated in Figure 67. Thus the levelling off or decline for some of the larger Member States has not overly influenced the EU-27 as a whole. There is apparently a large enough buffer or a geographical redistribution within the EU to make up for employment reductions in larger countries.

Figure 66 – Five year trend of shares of high-tech and non-high-tech investment in venture capital



Source: EVCA Yearbook, 2008

Figure 67[45] – Annual employment in high-technology sectors (EU-27)

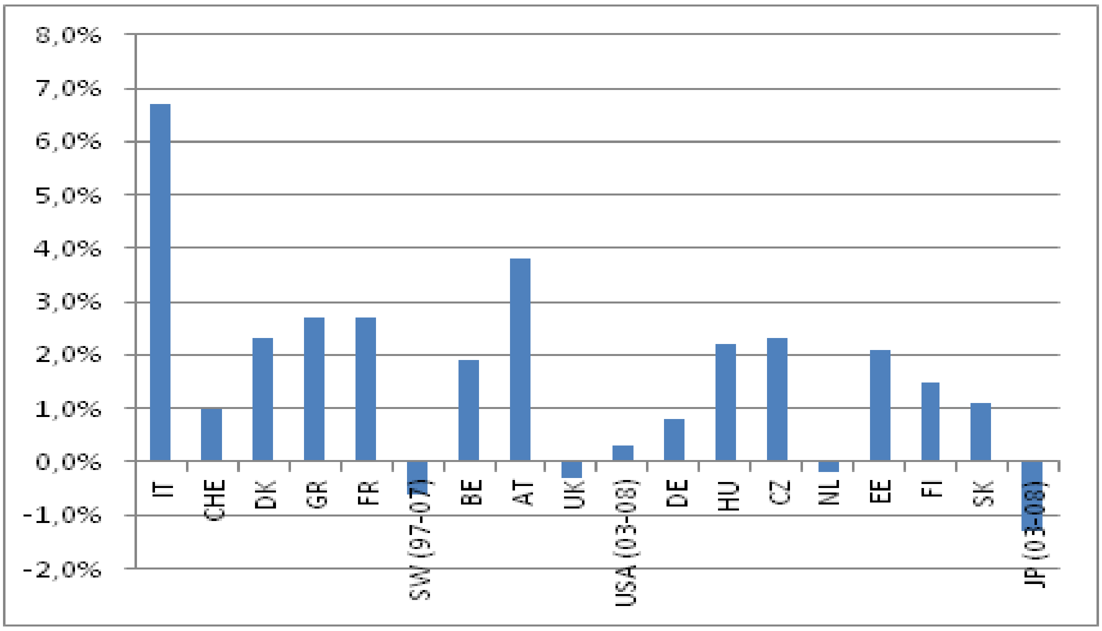


Source: EUROSTAT

Comparing human resources in S&T (HRST) growth in the manufacturing industry in Figure 68 (not including services) for the years 1998-2008 for some of the EU-27 and selected third countries, a slightly different picture can be seen. It is noticeable that the growth reported above is partly attributable to the service industry, and that some countries, such as Sweden, the Netherlands and the UK, are specifically dependent on services for their high-tech sector employment growth.

[45] High-technology sectors are known as the sectors of high-technology manufacturing and knowledge-intensive high-technology services.

Figure 68 – Human resources in S&T growth in the manufacturing industry, average annual growth rate for 1998-2008



Source: OECD, ANSKILL Database (internal use only), June 2011, OECD Science, Technology and Industry Scoreboard 2011

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

The ultimate goal of this project is to identify areas where and the ways in which the EU can make a difference to the successful exploitation of NMP technologies for economic and societal benefit. To do so, the project has looked at a number of quantitative and qualitative indicators to allow analysis to be performed on the situation within 18 different countries, the various factors that impact on these indicators and thus influence the outcomes of policy on NMP, and as a result identify cases of best practice. Through this, the project is in a position to make suitable recommendations for intervention.

The project has investigated the evolution of NMP in terms of:

- Nanosciences and nanotechnologies;
- Materials;
- New production processes.

NMP has been a flagship thematic programme within the Framework Programme since FP6. The rationale behind the NMP programme has been to invest in cross-cutting technologies that can support innovation in a number of key industrial sectors. Key because they address Grand Societal Challenges, or are seen as a means for economic growth and maintaining economic and technological superiority over other nations (thus benefiting the wider European society). In this sense NMP is a toolbox which can be dipped into to develop new approaches or provide solutions to problems within most (if not all) industrial sectors. As a result many calls are launched in partnership with other thematic and sectorial programmes, such as Energy, Health, and Environment.

The EU is unique in having such a programme. Thematic programmes based on specific technologies exist in other world regions, including EU Member States; however they tend not to be so broad, and so nanotechnology programmes exist in countries such as the US, Germany, France, and India, and advanced materials programmes in many others.

However, many countries do not choose to invest in specific technology-driven programmes. The UK and Japan for example theme their funding programmes around Societal Grand Challenges, such as reducing greenhouse gas emissions, improving sustainability (across many different sectors) and addressing the needs and issues of an ageing population. In this context NMP has an obvious key role to play, however, any and all technological solutions to the issues at hand are also investigated within the programmes.

NMP has direct and indirect input to a number of different industrial and business sectors. This was investigated in terms of 14 such sectors: Agrifood & biotech; Construction; Electronics; Energy; Environment; Health & medicine; Transport; ICT; Materials; Photonics; Security; Space; Manufacturing & process technologies; Measurement & analysis.

In this project the relevance of NMP to different types of organizations across 18 different countries has been investigated. The nature of the investment (both financial and human resources) has been studied in terms of what the outputs and impacts have been of that investment. It has attempted to normalise data across a set of indicators, in order that comparisons between different policies, strategies and even attitudes between countries and organizations can be studied. Ultimately its goal has been to illuminate the differences between different countries that give rise to the different outcomes observed.

Significant funding has gone into NMP (1.4 B€ in FP6 and an estimated 3.5 B€ in FP7). Historically much public funding in Europe has gone towards fundamental research, however with FP7 the focus was put on engaging SMEs as these are the key innovators, with the result that some 8,900 SME participants accounting for 15.3% of the total budget was realised by the end of 2011. The question is 'has this translated into desired impacts of economic growth and market opportunities?'

The data from this project would indicate that this may not be the case. The following sections provide comparison between different countries and the EU in terms of a number of indicators.

The impact of policy and strategy was assessed for each NMP thematic area in different industrial sectors. The indicators used were divided into input, output and impact indicators:

- Inputs: These include the external drivers of innovation. They are represented by four indicators measuring external influence over NMP R&D and Innovation. This group of indicators includes: Education; Public finance; Venture Capital; Industrial R&D expenditures.
- Outputs: This dimension refers to the outputs from firms and research organizations. They are represented by four indicators: NMP scientific publications (in both quantitative and qualitative aspects); NMP patents; Research intensity; and Open Innovation Schemes, Linkages and R&D Collaborations.
- Impacts: This dimension tries to capture, on the basis of data availability, the impacts of NMP activities. They are represented by the following three indicators: Numbers of institutions and firms in NMP, Employment, Sales and Market Shares.

The project chose to engage only with senior representatives of organizations as this ensured greater understanding of high-level strategy.

5.1 Conclusions from the different indicators

The indicators for this study were chosen based on available knowledge and what were perceived to be a natural flow-through of input to impact. As discussed in Chapter 2 (methodology) and as appropriate throughout this report, there were a series of issues with data collection which meant that some of the analysis could not be performed to the depth originally hoped. However, for other indicators additional data was found to be available so that the project analysis could go beyond the originally anticipated level.

In the sections below we examine each of the indicators to draw conclusions and comparisons of the EU with other countries, what the strengths and weaknesses of each are, and what data is missing.

5.1.1 Education

This is an important primary input indicator. The availability of a trained and educated workforce is a necessity for new developments to be successfully exploited. We approached this indicator using a number of data sources: aggregated data on graduate numbers from a variety of sources (Eurostat, OECD, UNESCO), degree courses and graduate numbers from selected universities in the countries under study, and demands from employers responding to the online survey.

We found that in general the number of S&T graduates as a percentage of the population in Europe has been increasing over the last 10 years and has, in 2008 and 2009, been higher than both Japan and the US (with Member States such as Finland, France and the UK significantly higher). While the EU lags countries such as South Korea, Russia and US in terms of numbers of students in tertiary education per unit population, it has more graduates in S&T than the US and Japan (1.43% compared with 1.03% and 1.42% respectively). This suggests that overall there is a pool of suitably qualified individuals to meet the needs of industry. However, these needs are varied both in terms of quantity of graduates and in terms of specific skill sets. Unfortunately, one of the key aspects of the education indicator (graduate destination) which would answer this (albeit retrospectively) was not available from most universities. Thus it is not clear whether these graduates were eventually employed in an industry related to their field of study, continued in Higher Education relevant to their degree (e.g. a PhD or MSc/MEng), moved into a completely different field, re-trained for another career, or were unemployed. This presumed sufficiency of graduate talent is against a backdrop of evidence from industrial respondents to the survey that showed an expectation of a need for further trained graduates within the next 5 years (this observation is supported by another EU study (Gelderblom et al., 2012)).

When we looked at individual degree courses and graduates from different universities, we observed a range of different degree courses on offer that are relevant to NMP. While it is difficult to make direct comparisons we can note that many US courses have a strong application focus, for example all except one of the universities studied had degree courses in bioengineering, and several taught courses in different aspects of manufacturing. In South Korea, India, and China we observed a large number of applied engineering courses. This is quite different from European universities where such courses tend traditionally to be limited to technical universities, and in many cases other universities provide degree courses more aligned with traditional disciplines (although these have multiple, optional modules). We did however identify a number of universities in most of the countries studied that provide interdisciplinary degrees in nanoscience or nanotechnology (both at undergraduate and postgraduate levels). Overall this suggests that in the many Higher Education establishments in Europe there remains a focus on teaching the traditional science and engineering subjects. The application fields (particularly processing and manufacturing) are left largely to technical universities which, while of the same calibre, are much fewer in number than traditional universities in most EU Member States. While this is not necessarily an issue for R&D as a whole, it could have ramifications for the supply of sufficient numbers of suitably trained graduates for the continued exploitation of NMP technologies, which have large interdisciplinary requirements with an application focus. A notable exception to this is Italy, where all the universities investigated provided a large number of different applied subjects (particularly in engineering and materials science).

With regards to availability of specific data on graduate numbers, we found that the following countries provided information for different degree courses: China, Japan, UK, Finland, Switzerland, and Germany. Other countries did not provide such information, or if so it was either aggregated (as in France) or subject to the policies of the individual university. In any case, the data was incomplete and direct comparison between countries proved impossible.

In conclusion this indicator provides useful knowledge, although inconsistencies in the availability of data across different countries limit its impact in this analysis. There is very little information on graduate destinations (which is an important aspect of this indicator, identifying need, or lack of need for specific skills). Thus there needs to be a concerted effort to understand supply and demand. Data on graduate destinations was only available from certain Japanese universities, with universities in other countries providing more generic data (based on total graduate numbers, sometimes by university sometimes nationally, if at all). One notable, recent development is in the UK, where a government sponsored website has been launched allowing individuals to compare courses offered in different disciplines from different universities, and assess graduate destinations[46].

5.1.2 Public finance

National investment in R&D can be measured by GERD (gross domestic expenditure on R&D), which comprises public (government and higher education), business, and not-for-profit private investment. The EU has consistently R&D in the public sector at a high level compared with other countries (Figures from EUROSTAT indicate an average of 0.68% GDP in the EU compared with 0.6% in the US and 0.64% in Japan, over the period 2001-09). Member States which invest more than this include France, Germany, Finland, Sweden, and the Netherlands. In contrast the UK, Italy, and Poland invest lower than average amounts. South Korea is the only selected Third country to invest more (0.76%).

Public funding has been received by 65% of the organizations responding to the survey, and of these 94% had received grants and 13% loans. All types of organizations apply for public funding, with applied research being the most common reason. Of those replying to the survey, novel materials and nanotechnology were the most important themes (for both private and public organizations) in the NMP field.

The main issue that organizations had with accessing funding was the long review phase before funding was awarded (more so than call topics, finding suitable partners, or the burden of reporting). Regarding European organizations, national funding appears to be more important than European funding, with some interviewees stating that they make use of EU funding for international collaborations and for research activities that are not core to their business. This suggests that, whilst it is important, the programme is not thought to be able to fully help in achieving the organization’s goals (for technical and/or IP reasons), or that the process of securing funding is perceived as too difficult or just poorly

[46] http://unistats.direct.gov.uk/

understood. One exception to this was in Italy, where several respondents stated that EU funding was more important than national funding.

Funding schemes for the different countries in this study were examined for their relevance to NMP and found to vary considerably (see Annex 4). It is extremely difficult to correlate NMP funding in the EU (primarily the Framework Programme) with that in Member States and Third countries. What we were able to do was identify the presence of specific NMP themes within programmes and sub-programmes in each country. While all aspects are present to a certain degree in each of the eighteen countries, only ten had dedicated programmes to each of N and M and P. Five of these were EU Member States (Finland, France, Germany, the Netherlands, and Sweden), and five were Third countries (Brazil, China, India, Japan, and US). The most prevalent theme was nanotechnology. All but Italy, Poland and the UK had at least one dedicated nanotechnology programme (the UK until recently had one, however this is now contained within other thematic programmes).

The source of funding for public research programmes also differs with most countries including some private investment, the main exceptions being Austria, the UK, and Brazil. This is interesting as PPP directly contributes to BERD, and is a means of effectively engaging industry and academia directly. In fact countries such as South Korea have a number of programmes that specifically support industry-academia collaboration for the purpose of knowledge transfer, and exploitation. France and Russia both mainly operate publicly financed programmes, but also have large PPP initiatives ('Investments in the Future' and 'RUSNANO' respectively) and in both cases the State takes equity in some of its investments.

In countries such as the UK and Japan, funding is more focused on challenge driven research, whereas Germany and the US (amongst others) operate large technology push schemes (such as for nanotechnology) to address multiple challenges. Other ways which are seen as significant public financing support for research include research tax credits and loans. For example, this was cited quite often by researchers in France.

In conclusion, NMP is an important part of public research funding programmes of each of the countries studied. However, the nature of NMP makes it difficult, and highly subjective, to extract the relevance of funding data from different countries to each component of NMP. Most countries are focused on thematic or grand challenge areas, and therefore use NMP as necessary to address these issues. Nanotechnology as the relative newcomer to the fold has perhaps more dedicated programmes, although this is not always the case (e.g. UK). With the exception of some of the broader nanotechnology programmes (e.g. those of the US, Israel, Germany), many technology-focused programmes are narrow in scope and contribute directly to the larger priorities of the particular country (e.g. advanced energy, sustainable manufacturing).

5.1.3 Venture capital

Venture capital is an essential part of the growth cycle for new enterprises. Within this project it was investigated at both early and growth stages. Globally, there has been a decline venture capital in the last ten years, and the EU as a whole is performing more poorly than the US, which continues to lead (the US had an average early-stage investment of 7.8% over the last 10 years, and a peak of

21.1% of GDP in 1999-2000, compared with the EU which had an average of 3.3% and a peak of 5.9% in 2000-2001). The European exceptions are Sweden, Finland and the UK which have remained relatively robust. From the survey only 17% (28) of respondents had received venture capital. Of these, 96% received venture capital for early stages, and 43% for later stages. With 5 of the respondents we received additional information, suggesting that venture capital was not difficult to obtain.

Venture capital investment is linked not so much with technologies, rather the products and eventual markets they will address. As such the issues facing venture capital investors in NMP technology companies are the same as for others. We interviewed a small cohort of venture capitalists in Europe (four). Most of their investments are for early stage and for three, NMP investments make up between 10 and 25% of their portfolios (the fourth put this Figure between 26 and 50%). Their views on the difference between venture capital funding in Europe and the US largely echo that reported in the literature: most venture capital investors are located in the US; and in general Europe appears to fare well in terms of venture capital investment, although the US leads. In Europe the UK, Germany and the Scandinavian countries are seen as the main recipients of venture capital funding.

Evidence from many sources indicates that venture capital is wary of long return on investment (ROI) times, and this has often been associated with nanotechnology specifically. However, the venture capitalists we interviewed indicated that it was the strength of the offering (market opportunity, management team, and exit strategy) rather than the specific underlying technology that was important.

In the NMP arena perhaps only venture capital investments in nanotechnology can be identified appropriately, due to the intense focus that it has received over the last decade or more, with many high profile investments being widely publicised such as A123 Systems (a US based company) and Oxford Nanopore (a UK based company). However, this is probably only achievable by looking at the large investments of those firms specialising in investment in nanotechnology (such as Nanostart and Nanodimension) (Crawley et al. 2012).

In conclusion, venture capital is important for the commercialization of new R&D, however it will be difficult to disentangle the value of the technology from other aspects that are generic to all venture capital investments, and therefore relate this to specific aspects of NMP (the exception perhaps being nanotechnology).

5.1.4 Industrial R&D expenditures

EU business invests relatively less in R&D than its counterparts in Third countries (an average of 1.19% of GDP versus 1.89% in the US, 2.52% in Japan, and 2.19% in South Korea). That said, business investment in R&D makes up the largest part of GERD in the EU (and in most other countries surveyed). Most countries have had a modest increase or little change in business enterprise R&D expenditure (BERD) between 2001 and 2009. However, Sweden has seen a 20% decrease, and the Netherlands a 16% decrease. The developing economies of Brazil, India and China have all exhibited the largest relative growth rates (over 25%) relative to their starting points, but still remain below others. In contrast, South Korea has increased its relative investment some 39% (and is now only behind Japan and Finland). Considering absolute levels of business investment in high tech R&D we observed that the US continues to dominate (900 B€ between 2005 and 2010), with the EU taking second place (Germany leading with 260 B€), followed by Japan 490 B€). Despite this increased investment, most countries, with the exception of the US, are demonstrating a decrease in industrial R&D intensity (defined as ratio of a company's investment in R&D relative to its sales).

The survey suggested a mixed message in terms of availability of funds and ability (or willingness) to re-invest in R&D activities, with SMEs tending to have the broadest approach (in terms of amounts and types of re-investment).

The data from EUROSTAT is aggregated, based on the performance Figures of leading companies, each of which may be aligned with multiple different markets and sectors. This is equally true of our survey data. Most of the organizations that responded to the survey or were interviewed align themselves with multiple aspects of NMP and the thematic areas, which makes attributing industrial R&D expenditure to these extremely difficult.

In conclusion, this is a useful indicator to examine the differences in investment trends between different types of organization, or different countries, but poor in terms of specific thematic areas.

5.1.5 Infrastructure

As previously noted, a full indicator on infrastructure was not developed. The following is based on the extensive collection of secondary data on available infrastructures in the selected countries.

The availability of facilities, expertise and capacity also has significant influence on the impact of investment in R&D. If we consider the costs of establishing and then operating world class facilities, which can run into hundreds of millions of euro per year, then it is clear that this is beyond the capacity of many countries, never mind regions within countries. Larger countries analysed in this report have significant infrastructure in a number of different sectors. There appears to be more frequent linkages between these infrastructures to create virtual networks that add value to the capabilities and capacities of each one alone. This can be achieved more easily in countries which perhaps have lacked large geographically co-located infrastructure. For example, the UK has recently launched a new initiative to create 'Catapults' or technology innovation centres, which are distributed across several sites, each already possessing a high level of competence in a particular service and thematic area; France has a long-term established and distributed infrastructure in the Carnot Institutes and the pôles de compétitivité, and Germany in the Fraunhofer Institutes (amongst others). However, many countries have also created (or supported the evolution of) super-clusters of industry, universities, and research institutes co-located to provide world class facilities and capacities. These include GIANT in Grenoble, the micro and nanoelectronics cluster in Dresden, and CERN in Geneva. Such infrastructure usually has both public and private finance behind it and in some cases from multiple countries. See Annex 5 for further information.

We have observed different strategies regarding the positioning of these infrastructures. Most are clearly aligned along specific technology themes (for example electronics, biomedicine) and thus provide targeted expertise and equipment to address technological aspects. However, some of the newly funded infrastructures are challenge-led (for example the UK's Catapults), which then bring together a number of different capabilities to address the needs of a specific challenge (e.g. sustainable energy production). These support the government's research programmes which as we have seen can have quite different approaches, even if general objectives (socioeconomic benefits) remain similar.

There is a question of how important infrastructure is to organizations. In total, 71% of respondents to the survey indicated they made use of infrastructure, with material and device testing and measurement facilities being the most important. Also, 29% made use of facilities in a country other than their own, although 87% used infrastructure located within their own organization. Few reported regular difficulties in accessing infrastructure (5%, and an additional 24% occasionally).

Information on infrastructure is readily available (after all, these are facilities open to external users), however comparing and contrasting the strategies and measuring the significance of each is more difficult. This can be achieved through analysing a mix of output and impact indicators associated with the infrastructure, in particular patents and publications, linkages (and co-localization) with other organizations, employment levels, turnover, new companies and products on the market. Such data requires analysis not just of the core infrastructure, but all the other organizations associated and dependent on it (to whatever degree). We have attempted to do this through our network analyses (presented in Section 4.2.4), which is discussed in more detail below.

In conclusion, this is a key indicator which provides a measure of the health of R&D innovation within a country and how embedded this is. However, it requires further detail on all the organizations associated with the core infrastructure and the impacts that each of these also bring. This data is available for some (e.g. GIANT has an investment of 1.2 B€ over 6 years and is expected to support 30,000 jobs in academia and industry).

5.1.6 Scientific publications

This is an often used indicator to measure the quality and quantity of output from different organizations, regions and countries. Comparing countries with each other we can see that no single European country can match the output of the US or China, and that China has increased its output dramatically in all aspects of NMP, but particularly in nanoscience and nanotechnology, and material sciences. In terms of publication quality, we observe that China has increased in the last 10 years in all aspects of NMP (apart from nanoscience and nanotechnology), while European countries have either increased at a more modest level or stagnated. China is now second to the US in terms of publication quality in material sciences. In terms of other areas of NMP, European countries continue to perform well, leading in nanoscience and nanotechnology.

The leading EU Member States (Sweden, Finland, Netherlands, UK, Germany, France and Austria) are publishing more (per capita) than US, China and Japan (but less than Switzerland). With regards to patenting, only Germany is doing more per capita than the US (but still significantly lags Japan and South Korea). In terms of the specific NMP themes:

- The US still leads the field in terms of overall publication numbers in nanoscience and nanotechnology (over 25,000 in 2010), but is closely followed by China (approximately 24,000 in 2010, which has more than doubled in the last 5 years). Germany and Japan follow with less than 10,000 publications in 2010. In terms of publication quality (measured by the impact factor of the publishing journals) the US and EU countries lead, with none of the world's top 75 institutions in China.

- China leads publications in advanced materials (with approximately 50,000 in 2010) followed by the US (approximately 36,000 in 2010). All other countries are below 20,000. However, in terms of scientific quality, the US leads, followed by China, then Japan.
- Advanced manufacturing (sampled in terms of the following areas: machine tools, mechanical engineering, and production and processing) shows that China leads with nearly 2000 publications in 2010, followed by the US with 1000. Germany as the leading EU country has 337 publications. In terms of scientific quality the US leads in all components of advanced manufacturing, followed by Germany and China.

Most of the organizations responding to the survey have published in peer-reviewed journals within the last 5 years (83%), of these the majority (86%) co-published with other organizations.

The difficulty with this indicator is cleaning data sufficiently to unambiguously assign to specific technology domains. This has been performed for some technology themes such as nanoscience and nanotechnology. For others the thematic area can be so broad that there is a problem in excluding non-relevant information.

5.1.7 Patent applications

This is another indicator which is often used to benchmark different countries. However, its use comes with several caveats. Firstly, patents may be applied for in different countries to which the intellectual property (IP) was developed - essentially where the market is. For this reason, many patent applications are lodged with the US Patent Office. Secondly, many patents never lead to commercial products (and likewise many commercial products are not patented, but subject to trade secrets). In this context they do not always provide a strong correlation with economic value. However, they do represent a direct link to applied R&D as the first publicly visible outcome of research and development activities. They are a useful indicator as there is a large amount of data available from different patent offices around the globe, which is already aligned with many of the sectors and themes applicable to NMP, and they provide an indication of RTD intensity in different sectors. Overall, 80% of the respondents to our survey had lodged at least one patent application in the last 5 years (13% had lodged more than 50).

When investigating patent activity across all NMP domains, we observed that Europe continues to perform poorly against the US, and that the BRIC countries (in particular China) are continuing to improve their relative ranking. The performance of South Korea is of specific interest. In nanoscience and nanotechnology it now ranks as world number one, and in materials has substantially increased its share over the period 1998 to 2009, now ranking third behind US and Japan. Furthermore in contrast to a decline in patenting activities in the manufacturing field of the world leaders (US, Japan, and Germany), South Korea has also experienced an increase in annual output (from 303 in 1998 to 866 in 2009). All of these observations correlate well with the increased funding invested in R&D (GERD) throughout this period in South Korea. The strong academic and industrial ties (presented in the network analyses and discussed further below) also support this outcome.

Patent analysis is a powerful tool to assess innovation, and furthermore it provides an indication of the strength of collaboration between different organizations, something we have used in the network analyses presented earlier. Patents may not represent all innovation (which can take the form of trade secrets, which are never shared outside a company), however they are the most accessible. Further use of patent analyses will be important to determine the value added from these: Were they acted upon? Did they lead to commercial products or services? Were they licensed to another organization?

5.1.8 Research intensity

This indicator is essentially a composite drawn from publications and patents in R&D. For this indicator we calculated the output *per* capita and observed that many EU Member States actually outperform the countries that lead in terms of number of publications and number of patent applications. The trends are also interesting. In terms of NMP publications, all countries have increased or at the very least maintained (e.g. Russia) their per capita level over the period 1998 to 2009. In contrast most have seen a stable or declining rate of patenting over the same period. The interesting observation is again South Korea which has seen NMP patent levels rise almost 250% per capita over this period. BRIC countries also have seen a rise: Brazil (138%), Russia (372%), India (289%) and China (209%), although in absolute terms these are at least an order of magnitude lower than South Korea.

In conclusion, this is a highly valuable indicator, however its true worth is in marrying the relevant datasets and this requires significant dissection or disaggregation.

5.1.9 Open innovation schemes, links and R&D collaborations

This is a powerful indicator to measure the strength of linkages between different organizations (private and public) and from that be able to infer the impact this has on different outputs. We performed network analyses using the co-applicants of patents as an indication of collaborative innovation. This provided a means of measuring information flow between different organizations and determining who is important (in terms of overall output) as well as who has access to knowledge (and networks of other organizations). This was an intensive exercise and so we limited the analysis to those countries with organizations demonstrating the highest degree of collaboration: France, Germany, South Korea, Japan, and the US. The importance of different organizations within each of nanoscience and technology, materials, and manufacturing and processing was assessed by the prominence of an organization within that technology area and country (measured in this case by the number of different co-applicants it has on its patents). This is known as Degree Centrality. Each organization's importance was also assessed in terms of connections within that network, termed Betweenness Centrality, which assesses the importance of that organization as the link between two other organizations (i.e. controls access to knowledge).

The three different themes investigated are also interesting in terms of their maturity and commercial applicability, and therefore expected importance to academia and industry; with at the one end nanoscience and nanotechnology as a developing area, materials as an established but obviously research intensive area, and manufacturing of greater interest to industry.

We observed a stark contrast between the two European countries studied. While France had prominent nodes on the global scale (particularly for nanoscience and nanotechnology) and well established national networks for all three areas, these tended to be dominated by government institutes (CNRS in particular), and although linking well with French industry, they do not link significantly outside France. Germany in contrast had more dispersed networks, still containing government institutes, but with more industrial participation, and importantly strong links to organizations in other countries (particularly the US). Interestingly, the Fraunhofer Gesellschaft in Germany plays a key role in networking other organizations, despite not having nearly as many patents as the leading French institutes (CNRS and CEA, which at least for nanoscience and nanotechnology, are two of the top three organizations in the EU (ObservatoryNANO, 2011[47]). This observation could be seen as Fraunhofer having a much more effective means of distributing knowledge to industry (which has the means to act upon it).

Considering the Asian countries, we observed a much larger involvement of industry at the heart of the different networks. In particular in South Korea, Samsung plays a key role in linking both industry and academia together in quite broad networks across all three themes. In addition, Samsung provides links into the US landscape for both nanoscience and nanotechnology and materials. Also in Japan, there is a dense network including government institutes and industry for the materials and manufacturing areas (nanoscience and nanotechnology is dominated by institutes).

The US has a strong mix of different types of organization in its networks across all three themes, and in the same way as Germany has a dispersed network of several different hubs. The US networks contain several different foreign companies in each of the three themes.

The manufacturing and processing network analysis is interesting in that we observed more industrial leadership, which breaks down national barriers, and for example we start to see greater connectivity between French companies and those in other countries.

In conclusion, this indicator provides a number of useful insights, particularly identifying existing networks that have evolved through collaborations, and are therefore the foundations of an innovation culture, allowing knowledge to flow effectively out to industry which can then turn it into commercial products.

5.1.10 Sales and market shares

The US dominates sales for high technology companies followed by Japan, and then at some distance Germany (with approximately half the value). Japan has seen the

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[47] 'Patents: an indicator of nanotechnology innovation'

most dramatic increase in overall sales values (up some 500 B€ between 2005 and 2010). The BRIC countries, while having a more modest overall sales figure, have seen dramatic growth rates of more than 20% per annum. This follows a dip in 2009 for all countries and a resurgence in 2010. From our survey 64% of respondents provide commercial products or services based on NMP. Of these, 81% have launched a new product or service within the last 5 years.

This is perhaps the most important socio-economic impact indicator for governments. However, it is probably one of the most difficult to measure, if it needs to be assigned to a specific thematic area or technology, and linked with an earlier intervention. Such socio-economic impacts have multiple causalities, not just technological interventions and specific funding schemes, but diverse aspects including the regulatory environment, consumer demand, licensing agreements, and other upstream economic inputs and outputs. Only by addressing the various interconnectivities of upstream elements, can there be a true understanding (or appreciation) of the routes necessary to bring about the observed impact.

5.1.11 Companies and institutes

Companies and organizations are involved in very many different thematic areas (from our survey 63% are active in three or more sectors, only 25% are restricted to a single sector). Of those organizations responding to the survey 87% stated that novel materials were of moderate or high relevance to their organization, 85% for nanotechnology, and 78% for novel manufacturing processes.

Regarding the location of the top high technology companies in 2010 we observed that the US continues to dominate with 487 of the top 1,000 non-EU companies (followed by Japan with 267). In contrast to its high level of output (in terms of publications, and more recently patents), China performs poorly in this ranking (19 of the top 1,000 non-EU companies). In Europe the situation is more evenly distributed with 244 of the top EU high technology firms in the UK, 206 in Germany, and 134 in France.

These observations are perhaps not that surprising – Europe, the US, and Japan have had high-technology economies for more than half a century, whereas South Korea can measure this in terms of a few decades, and the emerging economies have, relatively speaking, only being engaged in these areas for a short period. What is clear is that the prominence enjoyed by the UK and the US is being eroded (in 2010 there were 25% fewer UK and 17% fewer US companies within the top 2000 than in 2005), and that all the Asian countries studied in this project have shown consistent gains (China and India in particular have increased 3 to 4-fold). In Europe, Germany alone shows strong and steady gains (23% since 2005).

Top institutes for nanoscience and nanotechnology and for material science (measured in terms of publication output) show an Asian and US dominance, which even collectively, the EU Member States represented in this study could not match.

This indicator provides a useful measure of the capacity a country or region has to perform in a particular thematic sector. However, given that most organizations are involved in multiple sectors it can be difficult to disentangle data to determine true capacity in a particular thematic area. It is also important to correlate such analysis with the quality of output and impact indicators (and the level of additional support, e.g. infrastructure).

5.1.12 Employment

Considering the responses to the survey, most organizations currently do not have skill shortages but those in industry (particularly SMEs receiving funding) do foresee an increased need in the next 5 years, at all levels. The increasing numbers of graduate students suggest that this demand will be met, however some organizations noted specific shortages in skilled staff. Examples included competency in fabrication and manufacturing, physical and material sciences. This expected increase in employment in NMP-related fields is also forecast by another recently completed EC study that focused on these specific issues (Gelderblom et al., 2012).

In general we observed a mixed picture in Europe for employment in high technology sectors with declines for France and the UK, but increases for Germany, Italy, the Netherlands and Poland. The Scandinavian countries and Switzerland continue to dominate in terms of numbers of high technology employees per capita.

As noted for indicator 1 (Education), there is a lack of information regarding graduate destination, which makes it difficult to predict (at the moment) whether the correct types of graduate are being produced, and thus whether successful NMP outputs will lead to increased employment of European graduates (closing the circle). Many universities engage directly with industry to ensure that this is the case from a supply and demand perspective, however this can in general only be done from a limited perspective (either geographically or industry sector focused).

For employment it is difficult to assign numbers to individual sub-themes within NMP and to different industrial sectors, because of the nature of various industries and the reliance on aggregated data. However, we could observe an increase in employment in high technology industries across the EU between 2000 and 2007 (data beyond this was not available). For many Member States this is due to an increase in employment in service industries, and some, such as the UK, Sweden and the Netherlands, have experienced a decline in manufacturing jobs over the same period (although not as substantial as Japan). To place this in the context of our survey, 31% of respondents indicated that more than half of their staff were involved in NMP R&D activities (while 46% had less than 25% of staff involved in NMP R&D activities). In total 18% of staff from the respondent organizations were non-technical.

This is however a useful indicator as it provides information on the capacity of different organizations to effect change. It also provides information on employment trends which can feedback globally to universities allowing them to make informed decisions regarding course content. The main issue is providing data on a sufficiently large number of organizations with sufficient detail to distinguish between thematic and skill needs.

5.2 General conclusions

Overall, the picture in the EU suggests some inefficiency in the whole input-output-impact process. The analyses performed within this project support the view that the EU is doing well in terms of high impact science and technology research, but continues to be poor at translating this into commercial activities. It leads the way in terms of graduate numbers, public investment and several Member States are performing well in terms of business investment and venture capital for NMP. In terms of output it continues to perform well for publications (in terms of quality, if not quantity), however it lags behind Third countries with regards to patents (particularly in nanoscience and nanotechnology).

There are world class clusters of activity in Europe and the prevailing trend is to build these further both through co-location of research and industry and through strategic partnerships between leading institutions. Networks of facilities appear in a number of different countries, from the established poles de competivites and Carnot institutes in France, and the Fraunhofer Institutes in Germany, to the new 'Catapults' in the UK and the collaboration between Swiss facilities in the Competence Centre for Materials Science and Technology (MMCX). Comparing the different NMP themes, the EU appears to be performing better in Material Science relative to the others.

However, mixed indicator analysis linking input (funding, R&D personnel, and tertiary education) with output (publications, and patents) for the EU and for selected Member States and Third countries revealed that the EU is not as efficient at either the Member State level or as a collective as the best Third country (South Korea). We observed that European countries such as Germany and Switzerland publish and patent relatively efficiently based on funding input and level of R&D personnel compared with countries such as the Netherlands and the UK, however the EU as a whole has a lower patenting intensity to South Korea, Japan, and the US; and lower publication intensity to South Korea (it has a similar level to that of the US). Interestingly, South Korea had an extremely high patent activity compared to its input factors (several times that of Japan, the next intensive).

When it comes to impacts, how is the EU doing? Our network analyses would suggest that the EU model could benefit from more industry involvement in knowledge generation and exploitation to improve the efficiency of public funding. Comparing the situation in Germany with France, German institutes are patenting less, but networking more with industry than their French counterparts. German networks also appear to be more international in their membership. The level of patents held by the two key French institutes (CNRS and CEA) and the lack of connectivity of the CEA in particular (as measured by the Degree Centrality and Betweennness Centrality) suggests that knowledge could be more efficiently distributed. This could be a result of the institutional requirements for generating (and managing) that knowledge, or that it has limited worth to others.

While we were unable to perform this analysis on other countries, it is interesting to note that from a global perspective, no UK (as the next largest EU economy) nodes appeared in any of the three thematic areas. Although the UK appears to retain a large number of high-tech firms, this number is steadily decreasing at a time when investment in public R&D, publications and patenting are all lower than both Germany and France.

Putting this altogether, there appears to be some key lessons that the EU can learn from other countries. Funding must be focused on innovation, which needs industry as its final recipient. Government funded organizations must therefore link effectively with industry to ensure that knowledge transfer occurs. This cannot work in an ad hoc manner through the creation of new projects and short-lived consortia, but must be anchored in something long-lasting, i.e. infrastructure. The networks we observed through the patent co-applications suggest, but do not prove, that the success being enjoyed by the economies of Japan, South Korea and the US is, at least partially, due to this strong embedded collaboration between different public and private entities. Policy in these countries, both in terms of public funding and other fiscal support, helps focus this collaboration towards industrial output. Importantly this collaboration is not restricted to that country, but looks outwards to where the best opportunities lie. Comparing France and Germany, who invest comparable amounts of public money in NMP, we see evidence of a different model for industrial collaboration in the two countries, which must at least partially explain the differences in NMP impact, given the relative strengths of both countries' public research and infrastructure.

South Korea can be considered as an exemplar of what could be the right approach. It is continuing to increase investment (both public and private), which in turn continues to strengthen links between public research and industry, and this linkage seems well aligned with its infrastructure. There appears to be good knowledge flow between South Korean organizations and this translates as a rapid increase in patenting, although not to date a comparable increase in top firms.

5.3 Recommendations

The following recommendations derive from our observations on weaknesses and data gaps in the indicator analyses. They also encompass, through the analyses performed within the study, a number of policies that could be implemented to improve the exploitation of NMP technologies within the EU.

5.3.1. Recommendations for further indicator development

From the analyses performed within this study we can make the following recommendations to improve data collection for indicator analysis:

Indicator Development Recommendation 1: Centralise collection of national data

- There are different levels of available data in the different countries, with some aggregated, or differently labelled, others confidential or with limited availability. This missing data prevents a full impact assessment, limiting the ability to measure socioeconomic impacts. An improvement in this situation would require effort by the EC through the Member States to ensure that a wider and more comprehensive set of data is captured – i.e. centralised data collection and derogation to Member States. Additionally, it should be noted that NMP is poorly understood by organizations, making data collection difficult. This, and its broad nature, makes comparison between sectors and countries difficult.
- Substantial commitment is thus needed from organizations to supply all relevant information, to ensure that there can be comparison between

sectors and between countries. Important areas include employment and sales/market share.

Indicator Development Recommendation 2: Collect centralised data from universities on graduate numbers and destinations by discipline.

- This would allow comparison between different countries and different disciplines, helping to identify whether graduates were meeting a real need that matches what they were trained for.
- In conjunction with employer needs there would be less risk of future skills gaps (which would need to be filled from overseas).
- This could also equip EU graduates with better employment prospects outside the EU, and allow them to bring new knowledge back to the EU at a later date.

Indicator Development Recommendation 3: Re-assess data being sought from firms to fill knowledge gaps

- Direct information from firms is perhaps the most important to assess the impact that NMP is having on the business environment.
- Market research companies are already providing data on this, but this is highly subjective (either from the market researchers' perspective or that of the stakeholder providing the input).
- Additional information requests through the Innovation Scoreboard survey could help achieve this.

Indicator Development Recommendation 4: Focus on specific areas rather than NMP in general

- NMP is an EC definition, and poorly understood by many other organizations, including those in the Member States. Investigating NMP as a whole can be regarded as potentially too broad, such that it may be better to concentrate on value chains leading to identifiable products. NMP has an impact in these (along with other types of technological and non-technological interventions). This would then support collection of data for some of the important impact indicators.
- Much of the information sought is from industry, which focuses on products and services and makes use of technologies to achieve them. There is thus a potential benefit in focusing on the value chains on which industry is based.

Indicator Development Recommendation 5: Perform further network analyses on different Member States, and over different time periods

- The network analyses provide an objective means of assessing the innovation landscape in different countries. However, these need to be performed on different countries to understand where exisiting collaborations could be strengthened and supported towards better exploitation of knowledge.
- There also needs to be effort expended on linking funds and policy impact on each of these nodes to understand the effectiveness of each, and therefore prepare better future policy interventions.
- Finally the network analyses could be deepened to include specific measures of impact at each node, through more detailed, longitudinal surveys of the organizations involved. This will involve specific engagement with leading personnel at each node to understand

strategies adopted, and the metrics employed to quantify successful developments.

5.3.2 Policy Recommendations

While we cannot unequivocally state that the different elements observed in the leading Third Countries (South Korea, Japan, and the US) directly lead to the economic growth and industrial strength in NMP observed in each, it is clear that they provide an environment conducive to this outcome. This leads to the following policy recommendations to better support the development of similar environments within the EU:

1. Targeted support to nodes within the EU which already demonstrate strong industrial and international networks.
    a. The network analysis already performed has identified nodes and organizations which are producing the greatest output and largest impact. Further extending this analysis and fine-tuning it as appropriate to different technology/industry sectors/grand challenges will highlight the presence of further nodes in different Member States, allow a comparison of these, and provide evidence of what is working.
    b. These nodes should be the focus of new developments including knowledge distribution and commercial exploitation.
2. Better support and coordination of infrastructure between Member States, to ensure complementarity and reduce the potential for duplication.
    a. Infrastructure forms the scaffold on which the collaborative nodes are based. This strategy should have at its heart anticipated industry needs; so that the nodes continue to grow in a manner that supports future knowledge dissemination and exploitation.
    b. These should build upon the evidence base from national networks and look at the international components or opportunities within each. For example involvement in ETPs and other EU-wide and international efforts. Best practice can be taken from the analysis of national networks as described above (1).
3. Longer term funding strategies for industrial R&D, thus allowing such nodes to grow and deliver stronger impacts (i.e. better support for the whole innovation cycle).
    a. There needs to be greater alignment of such infrastructure with the Strategic Research Agendas of the relevant European Technology Platforms, providing greater continuity than can be achieved with research funding programmes alone.
    b. These need to be reviewed regularly and benchmarked against competing networks in Third Countries.
4. Greater focus on supporting and measuring longer-term impacts within R&D programmes.
    a. This might include new funding models to support demonstration and exploitation (for example working with Venture Capital and other types of private investment) and measurement of the growth and composition of supported nodes.
    b. It might also include new metrics that are not as easy to quantify, because they may take several years following the initial funding to come to fruition (e.g. licensing, services, product sales). However,

funding (direct or indirect) could be contingent on the annual reporting of these.

5. Stronger links between EU and Member State funding; in the short term to add value to the Member State funding (which is the primary source of funding for most organizations), and in the longer term to move more organizations towards the use of European funding to realise their core R&D objectives.
    a. Core R&D for many EU organizations is not currently funded through the EU instruments, which raises the possibility of duplication of effort between Member States.
    b. Aligning funding programmes would support synergies and the longer-term development of international networks.
6. Holistic approach to supporting future training requirements.
    a. A skilled workforce is essential to realise the opportunities provided by NMP RTD.
    b. Coordinated information sharing between Higher Education and industry, and development of training programmes based on this exchange is the most effective way of ensuring that such a skilled workforce is maintained.
    c. While we are currently within an economic downturn, most industrial respondents (particularly from SMEs) perceive a need for trained personnel within the next 5 years.

In general these recommendations should be effected at the EU-level, using EU funding; however the collusion of Member States, and in some cases development of specific, complementary national policies will be required.

In addition to these specific policy recommendations, further work to fully map out the differences between Third Countries (in particular South Korea) and the EU should be undertaken. These would have the purpose of quantifying the significance of different elements observed in the network analysis on the industrial and economic output of South Korea and other countries. A further dissection of the significance of the differences in composition between the networks in Germany and France (and by extension to other Member States) is also warranted. This work can be further supported through improvements to data gathering and indicator analysis that are described in Annex 6.

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The study aims to compare, assess and monitor the progress of European NMP research vis-à-vis Third countries (Associated States and other Third countries), and establish the position of the EU in the international context, in the fields of NMP research and its industrial applications, to support policy making.

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