Linking Science to Technology - Bibliographic References in Patents

Volume 9

Detailed analysis of the science-technology in the field of Nanotechnology

IMPROVING HUMAN RESEARCH POTENTIAL
AND THE SOCIO-ECONOMIC KNOWLEDGE BASE

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Volume 9

Detailed analysis of the science-technology in the field of Nanotechnology

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PREFACE

This report is one of a series of 9 volumes presenting the results of a study whose aim is to trace and quantify the linkages between scientific disciplines and fields of technology[1].

The study focuses on a specific form of S&T interaction: the presence of scientific research in the "prior art" description of a patented invention. It is a direct form of S&T interaction, which may be grasped through rich, plentiful, and directly available and accessible data: patents and publications.

Establishing this bridge enables one not only to trace the linkages between specific fields of technology and related science disciplines, but also to measure the science intensity of such linkages (in general, a higher number of science citations is observed when a particular technology field is more science-based). Moreover, as most scientific articles are published by universities and public research centres, and most patents are granted to industry, these linkages may provide an insight into the effectiveness of the interface between publicly funded research and the industrial exploitation of science.

The study forms a starting point for the qualitative understanding of the science-technology interaction by revealing networks and crossroads of scientific and technological activity. It may also provide insights into the rate and the speed of science diffusion into technology, as well as into commonalties within the science base that are relevant across different technologies, and that can help us to understand which technologies interact with one another to breed new hybrids.

The study is presented in 9 volumes :

Volume 1: Science and Technology Interplay : Policy relevant findings and interpretations
Volume 2: Methodological Framework
Volume 3: Literature Review
Volume 4: Detailed analysis of the Science-Technology Interaction in the field of Aeronautics & Space
Volume 5: Detailed analysis of the Science-Technology Interaction in the field of Biotechnology
Volume 6: Detailed analysis of the Science-Technology Interaction in the field of Environmental Technology
Volume 7: Detailed analysis of the Science-Technology Interaction in the field of Information Technology
Volume 8: Detailed analysis of the Science-Technology Interaction in the field of Telecommunication
Volume 9: Detailed analysis of the Science-Technology Interaction in the field of Nanotechnology

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[1] This study was financed by the European Commission contract number ERBHPV2-CT 1993-03 under the activity "Common Basis of Science, Technology and Innovation Indicators" (CBSTII) of the 5th RTD Framework Programme.

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PART I

PART II

LIST OF ABBREVIATIONS

CHI	: Computer Horizons Inc., Haddon Heights, NJ, USA
DST	: Decision Support Tool
EC	: European Commission
EPO	: European Patent Office
FhG	: Fraunhofer Gesellschaft, ISI Germany
IPC	: International Patent Classification system World Intellectual Property Organization
ISI	: Institute for Scientific Information
NPR	: Non-patent reference
REFI	: REference FIle (citations to other documents present in European patents)
S&T	: Science and Technology
SCI	: Science Citation Index $^{\text{ISI-Thomson}}$
USPTO	: United States Patent and Trademark Office

EXECUTIVE SUMMARY

In this report the science and technology interaction in the field of Nanotechnology is being presented and analysed. Nano-technology deals with materials having the following characteristics: they have at least one dimension of about one to 100 nanometers, they are designed through processes that exhibit fundamental control over the physical and chemical attributes of molecular-scale structures, and they can be combined to form larger structures. The intense interest in using nanostructures stems from the idea that they may boast superior electrical, chemical, mechanical or optical properties - at least in theory. No definition is satisfactory as it embraces so many fields – from electronics and physics, through biology and chemistry and on to mechanical engineering. The diversity of Nanotechnology is reflected in the classification of related technological inventions in the International Patent Classification (IPC), which accordingly, cuts across numerous classes. Therefore, in order to select the Nano-related patents a combination with a keyword-based patent search strategy has been applied (based on delineation made by recent research at the Fraunhofer Institute). This resulted in the retrieval of 1115 EPO (European Patent Office) and 514 USPTO (United States Patent and Trademark Office) Nano-related patents (the keyword searches were only performed in the title of the US-patents).

Based on the USPTO and EPO patent data, a steep increase in the number of patents and non-patent references (applications and grants) is observable during the early beginning of the 1990s. It is essential for a country's technological and economic performance to have access to relevant 'external' knowledge. Looking in that context at the number of NPRs present in patents, we see that based on the USPTO data, the NAFTA region, and especially the US, account for the highest share of NPRs. Based on the EPO data, the NAFTA region takes the lead until 1992. As from 1992, the EU-15 have been catching up and even managed to incorporate a higher science interaction in the following years. At a EU-member state level we see that in Nanotechnology, Germany, France and the UK hold the highest number of NPRs, just as they hold the highest number of patents. In regard of the latter, the US holds the highest number of Nano-patents, followed by EU-15 and the Developed Asian countries. Based on the EPO-date however the difference in performance is small. The patenting performance at the EPO counterbalances the home advantage of US-inventors in patenting at the USPTO. Over the period 1987-1996, the EU-15 holds 41% of all granted patents, whereas the NAFTA region accounts for 39% (based on the EPO data). The patenting success ratio of the EU-15 amounts to 1:3,11 vs. 1:3,66 for the NAFTA (1 patent granted per 3,11 applications). The EFTA countries seem also highly effective in that regard by obtaining 1 successful patent every 1,5 application. As far as the propensity-to-NPR is concerned (avg. number of NPRs per patent), the EU-15 and US patents interchangeably show the highest propensity. In 1995 (based on EPO data) EU-15 patents display a propensity of 2,96, whereas US patents and Japanese patents respectively display a propensity of 2,42 and 1,79 (cf. B3 and E3).

The science base of Nanotechnology, research of great importance for the of development the field, consists mainly of Chemistry, Physics, Materials Science, Multidisciplinary (in view of the still developing field of Nanotechnology during which development the research input is still coming from different backgrounds and disciplines), and Instruments & Instrumentation. The composition differs slightly depending on the source (EPO or USPTO) data (cf. C1 and F1). The patenting performance in Nanotechnology has been contrasted with the publication performance in the science base. In quite some science domains we see that EU-15 perform very well, in several instances even better than the US and/or Japan. As such, in terms of scientific performance, the EU-15 excels (cf. C2 and F2). This is also reflected in the Triad relationship when looking at the importance of EU research for the Triad partners (cross citation; cf. C5 and F5). Between 30%-to-35% of all paper citations present in US patents and Japanese patents concern EU-originated research. Thus, the utilisation of EU-research thus seems widespread thereby keeping in mind that EU-inventors also utilize EU-research in more than 40% of all science interactions. Also with regard to the composition of the European science base (degree of basic vs. applied research), it appears that Europe is able to provide in its knowledge 'needs'. Finally, based on the EPO data, EU-15 patents display a propensity-to-cite science that, in several years, is lower that in US-patents (cf. F3).

1 - INTRODUCTION

Wide-ranging socio-economic and technological transformations have caused European governments to reformulate their policies for government-supported scientific activity. The complexity of the socio-economic environment makes the identification of priorities in science and technology increasingly difficult. Moreover, the role of public basic science in technological evolution and development is becoming increasingly difficult to evaluate. A better understanding of the relationship between science and technology in general, and also in a field-specific context, may support EU-policy makers and experts in facing these challenges.

The present report, in which a field analysis of the Science and Technology interaction (S&T) will be presented, is related to a study funded by the European Commission (DG Research). As such it is part of the research priorities formulated in the 'Fifth Framework Programme' of the European Community for Research, Technological Development and Demonstration Activities (1998 - 2002). The general objectives of this study are: (1) the elaboration of a methodology for 'linking' scientific (sub)fields to fields of technology and the enrichment of such a methodology towards the creation of a decision support tool; (2) the deployment of the methodology to patents registered at the United States Patent and Trademark Office, the European Patent Office, and the Science Citation Index that covers a large part of mainstream scientific literature; (3) the in depth analysis of a number of 'relevant' technological areas. We shall touch upon the designed linkage methodology in section 2, in which we shall also reflect on a number of specific methodological issues.

The present report is related to the third objective and deals with the S&T interaction analysis in the field of Nanotechnology. 'Nano-technology deals with materials having the following characteristics: they have at least one dimension of about one to 100 nanometers, they are designed through processes that exhibit fundamental control over the physical and chemical attributes of molecular-scale structures, and they can be combined to form larger structures. The intense interest in using nanostructures stems from the idea that they may boast superior electrical, chemical, mechanical or optical properties - at least in theory.' (M. Roco, NSF – Nanotechnology Initiative)

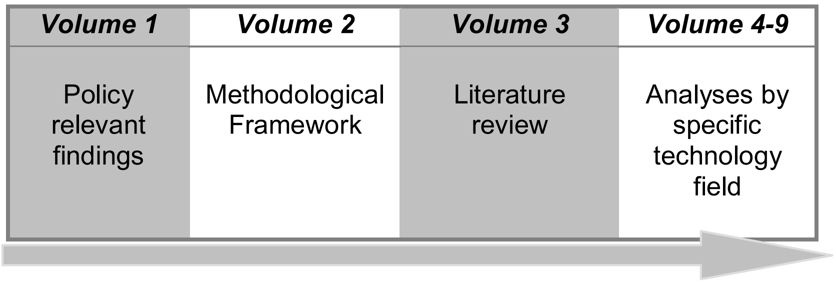
Another possible definition of Nanotechnology is given by Dr. Marc Van Rossum, head of Advanced Materials and Nanoelectronics research at IMEC, the Belgian microelectronics R&D institute: 'Nanotechnology has often been defined as the science of fabricating, characterising and using structures from the atomic scale up to 100 nanometers'. As Van

Rossum also commented, this definition, just like other ones, is unsatisfactory as it embraces so many fields – from electronics and physics, through biology and chemistry on to mechanical engineering. And that is exactly the difficulty that is currently faced when executing the S&T interaction analysis. The diversity of Nanotechnology is reflected in the classification of related technological inventions in the International Patent Classification (IPC), which accordingly, cuts across numerous classes. Therefore, the selection of patents related to Nanotechnology based on the IPC classification only, is a rather impossible task. Instead, a combination with a keyword-based patent search strategy has to be applied.

The process of selection of 'relevant' domains for further analysis has been concluded in close co-operation with the EC. Several perspectives have been involved. A first perspective was directly related to the results of the above-mentioned S&T linkage analysis, in which technological domains are connected to scientific areas. The intensity of the interaction had an impact on the selection process. A second perspective was related to the (future) relevance of specific technology domains from an EU policy perspective. To serve this purpose, the 6th Framework Programme of the European Community for Research, Technological Development and Demonstration Activities (2002-2006), several major foresight studies, and the programme of the US National Science Foundation have been studied and used as inputs. Areas of relevance that are analysed in the context of the present project, are: (1) Communication and Information Technologies; (2) Nanotechnology; (3) Intelligent Materials and New Production Processes; (4) Aeronautics and Space; (5) Food Safety and Health Risks; and (6) Sustainable Development and Global Change (energy, transport and environment).

Due to the modular structure of the reporting process of this project, the series of reports handling the field specific analysis will be focussing primarily on the quantitative description of the results obtained. Whenever methodological background is necessary for a thorough understanding of the results, this background will be provided. For a more comprehensive discussion of the linkage methodology, the overall results of its application and its expert validation, the selection process, or even the state of the art in the scientific background of the S&T interaction, we refer to the corresponding building blocks presented in figure 1.

Figure 1 – Overview of the different building blocks



In this report, we focus on the S&T interface in Nanotechnology, as measured via patents and scientific publications. The level of analysis will be the macro-level, implying that the analysis will be restricted to individual countries and regions that are of importance to the competitive position of Europe. A lower level of analysis, for example at the institutional level, could only be based on a specific and detailed knowledge of the country involved and is therefore left out of consideration. The results of the analyses are presented in two parts. Part I covers the results based on the United States Patent and Trademark Office patent data; Part II covers the results based on the European Patent Office patent data. In the coming section, we briefly elaborate on a number of methodological issues. We then turn to a detailed description of the results of the analyses.

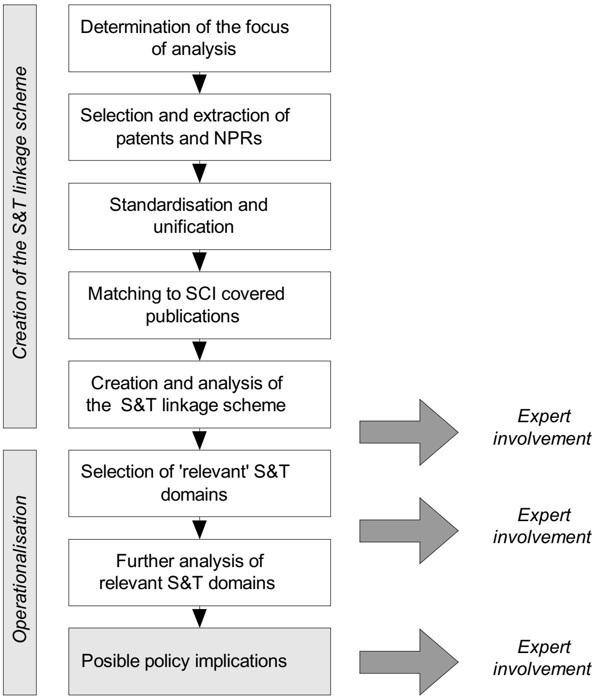
2 – SCIENCE AND TECHNOLOGY INTERACTION IN THE FIELD OF NANOTECHNOLOGY: METHOD, APPROACH AND RESULTS

2.1 Brief methodological notes

2.1.1 Science and technology linkage methodology

The developed S&T linkage methodology is based on non-patent references (NPRs) as units of analysis, and more specifically the citations to scientific journal publications, as they are the medium for communicating scientific findings in the academic society. The identification of NPRs and the subsequent identification of the ‘source’ publication in the Science Citation Index (SCI $^{\text{Thomson-ISI}}$) enable the broader interconnection of S&T fields, through respectively the IPC classification of the patent involved and the SCI-ISI (Institute for Scientific Information) journal classification system. Only the ‘front-page’ references are taken into consideration. Besides the SCI, we also make use of the patent data of the United States Patent and Trademark Office (*US Patent Bibliographic Data; 1978 onwards*), and the European Patent Office (*1978 onwards*). For the European patent data, the REFI file (*1978 onwards*), containing all patent and non-patent citations of European patent documents, has been additionally acquired. In figure 2 we present a comprehensive overview of the methodology and its components.

Figure 2 – Overview of the S&T linkage methodology



In general, two major phases can be distinguished. The first phase consists of a number of steps leading to the creation of S&T interaction model. The methodology can be applied repeatedly in order to update the S&T interaction scheme on a regular basis. The second phase includes a number of steps transferring the results of the first phase towards a more policy-oriented setting. This is a phase that is directly based on the analyses that will be presented in this report. Close co-operation with the EC-services has been ensured. The next paragraphs briefly explain the different methodological steps.

(1) Determination of the focus of analysis

This first methodological step consists of making a choice in the coverage of the S&T modelling. The analysis can be time- and/or field-related. The time span covers a period of 17 years (1980-1996), subdivided into 3 analytical benchmark time-periods of a different time-span (1984-1986, 1987-1991 and 1992-1996). By benchmarking the science and technology interaction over time, the co-evolution of the S&T interaction can be analysed.

We consider the modelling of the S&T interaction for the period 1992-1996 as the 'actual' linkage scheme that can be used as an input for further analytical steps and policy issues. This period involves a sufficiently high number of NPRs (68% of all NPRs in the period 1980-1996). As the S&T interaction pattern remains rather stable over time, an actual linkage scheme is feasible due to its relative stability over time. For the analysis of Nanotechnology a slightly different approach had to be used. In view of the fact that Nanotechnology is a 'horizontal' field, implying that Nano-related patents are dispersed over many different IPC-classes, a separate S&T interaction linkage scheme had to be build. As such the analysis did not depart from individual IPC-classes only, but instead from a combined IPC-class / keyword based search strategy. Furthermore, in view of the relatively 'young' character of the field, no time restrictions have been applied. As mentioned at several occasions the main objective of this project is to map and monitor the widest possible science interactions.

(2) Selection and extraction of patents and NPRs

The objective is to select those patents, and the NPRs they contain, that comply with the field delineation criterion set in step 1. In the case of a field-related S&T analysis, IPC- and keyword-based search strategies may be applied intermittently, like in the case of Nanotechnology (cfr. paragraph 2.1.2). Within the diverse collection of NPRs, we specifically focus on journal citations. Scientific journal publications are the primary communication medium within the scientific community, and as such they are a proxy measure of scientific activity. The final aim has been to identify the 'source' publications covered by the SCI-data, through the application of a match-key based linkage approach.

(3) Standardisation and unification of Journal references

A complex parsing algorithm, based on a text analysis approach, has been designed in order to identify and parse the scientific journal references into a number of components such as {author name} and {publication year}. Grammatical deviations such as misspelling, misplaced points and/or commas, capital letters versus small letters made this operation complex and very time consuming. Several iterations proved to be necessary. From each journal reference, we identified and extracted {lead author name}, {publication title}, {journal title}, {volume}, {number/issue}, {publication year}, and {starting page}. Each text fragment has been assigned to one of these data types, after which they underwent a number of standardisations.

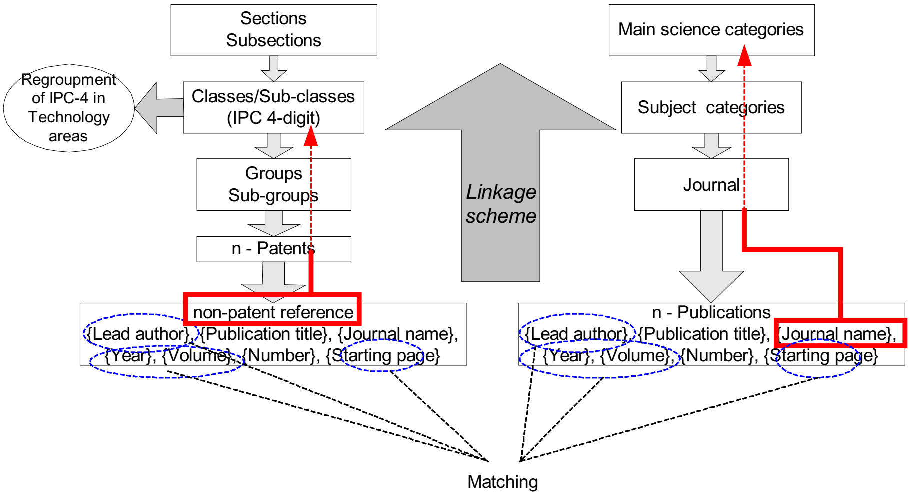
(4) Matching to SCI covered publications

The approach developed to trace the 'source' publication covered by the SCI, relies on a match-key based approach (based on the work of Luwel, 1999). The match-key is composed of a combination of the following fields {lead author name}, {publication year}, {volume} and {starting page} – see figure 2. As such, the use of the journal title for matching purposes, which displays misspellings, synonyms and even acronyms, could be avoided. Once the 'source' publication has been identified in the SCI, the related science field has been detected by tracking the SCI journal classification. The matching process was carried out in a number of iterations. Initially, all four fields were used in the composition of the match-key. In the subsequent three rounds, we interchangeably used one 'free-floating' field, except for the field {lead author} that was a fixed field in all rounds. The lead author's name has been reduced to the first six letters so that discrepancies between citation and 'source' publication could be prevented (Luwel, 1999). When all match-key fields coincided with the corresponding fields in the SCI, the journal citation in question was assumed to be uniquely linked to an SCI covered source publication.

(5) *Creation and analysis of the linkage scheme*

The last step in the first phase is the creation of the S&T interaction linkage scheme. Generally speaking, technology and science areas are being operationalised respectively by IPC 4-digit classes and SCI-ISI journal classification. Starting from the match between a specific journal reference, given in a patent, and the 'source' publication covered by SCI, we subsequently traced the IPC class of the patent involved and the science-domain classification of the journal in which the 'source' publication appeared. On this higher level of aggregation, S&T interrelation patterns become visible. The 'customized' S&T linkage approach in the case of Nanotechnology is illustrated in figure 3.

Figure 3 – Matching and S&T linkage procedure



In the present case, i.e. the analysis of the S&T interactions in Nanotechnology, the IPC-operationalisation would be meaningless, as there is simply no one-to-one relationship between those IPC-classes and the field of Nanotechnology. A substantial collection of Nano-'strange' patents would be included and defined as related to Nanotechnology. As a result, the operationalisation of the S&T interaction in terms of IPC-classes has not been performed. Instead, the identified science interactions have been directly related to the collection of patents representing 'Nanotechnology'. Looking at the classification on the science-side, the approach as depicted in figure 3 has been followed.

In phase 2 of the project, we focus on a number of policy 'relevant' domains for which a detailed analysis of the S&T interaction will be performed. The sixth in this series, i.e. the present report is devoted, concerns the field of Nanotechnology. The interim report 'Selection and validation of relevant scientific and technological domains based on S&T linkage modelling' contains detailed information on the selection and validation process (a short digital E-mail Delphi questionnaire has been developed in order to obtain broader expert-validation of identified S&T interrelations).

2.1.2 Method for composing the analytical data-set for Nanotechnology

Whereas for the analysis of the S&T interactions in Biotechnology, IT, Telecommunication, Environmental Technologies, and Aeronautics & Space, an IPC-class based clustering was used in order to compose the 'domain' of analysis (based on the classification scheme designed originally by the Fraunhofer Gesellschaft- ISI), this approach was not applicable in the case of Nanotechnology. The main reason is that Nanotechnology finds its roots and applications throughout the whole technological system, and as a result is also found across many IPC-classes in the patenting system.

The approach used for the analysis of the S&T interactions in Nanotechnology has been based on a combined IPC[2] / keyword search strategy. In the table below, an overview is provided of the IPC-classes involved in the patent selection process. As to the keyword-based approach, in order to provide the broadest basis for the S&T analysis, all patents were included in which the term '**nano**' was present, not only in the title of the patent, but also in the abstract[3] ('and/or' approach).

Table 1 – Overview of the different nano-related IPC-classes

IPC-subclass	*Description*	*Present in IPC-version*
A61K 009/51	Nanocapsules	6 (1995-1999) and 7 (2000 -)
G01N 013/10	Investigation or analysis of surface structures in atomic ranges using scanning-probe techniques	7 (2000 -)
G12B 021/00	Details of apparatus using scanning-probe techniques	7 (2000 -)

For the IPC-subclasses G01N 013/10 and G12B 021/00 almost no patents (EPO=0, US=2) have been retrieved due to the fact that these subclasses were only added to the IPC-system in the year 2000 (web-based searches confirmed this finding), with the introduction of the 7th version. In this respect, it should be pointed out that the INCENTIM database contains the full collection of US patents up to 1996, and of European patents up to 1997 (project window of analysis 1980-1996).

Based on this combined IPC-and-keyword search method, we managed to identify 1115 (app. 1098 keyword-based and 17 IPC-subclass based) EPO nano-related patents, and 514 (app.

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[2] The IPC-subclasses containing nano-related patents were provided by an EC-expert

502 keyword-based and 12 IPC-subclass based) USPTO nano-related patents (cf. footnote 2). The IPC-classification of nano-related patents is particularly of interest. Therefore, after having selected the corresponding sample of patents we again addressed this classification issue by studying the IPC-classification of the, in majority, keyword-based selected patents. In figure 4, we present an overview of the distribution of the USPTO nano-related patents over the different IPC-classes. In figure 5 a similar overview is provided but now for the EPO nano-related patents. Those figures show some striking similarities, though differences are present as well.

Figure 4 - Overview of the distribution of USPTO nano-related patents over IPC class (n=61% of all pats)

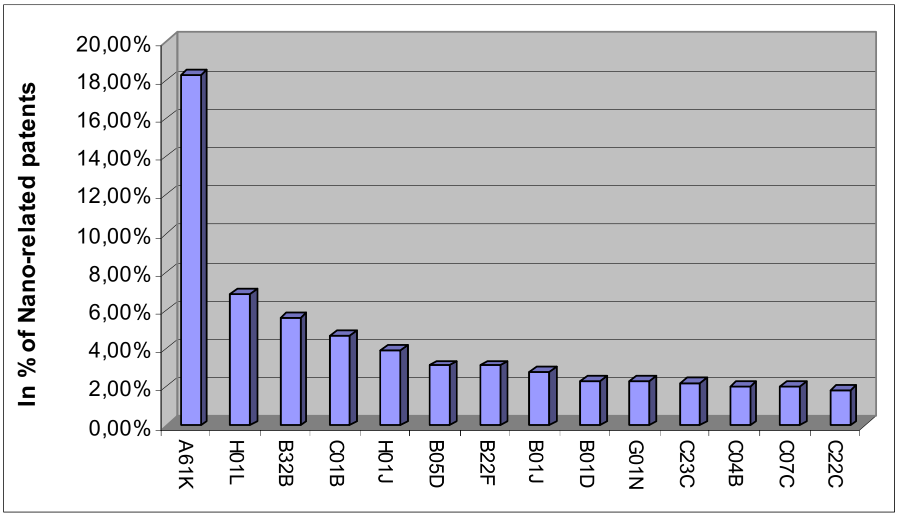
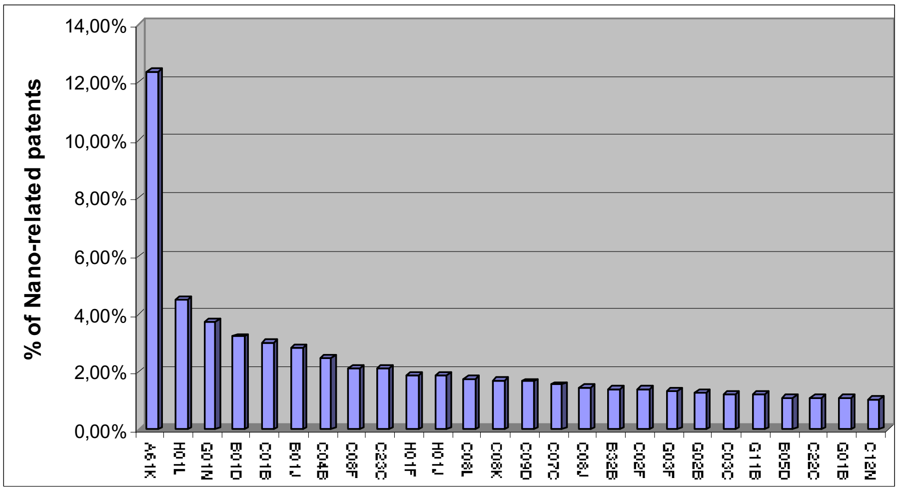


Figure 5 - Overview of the distribution of EPO nano-related patents over IPC class (n=60% of all pats)



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[3] Due to data limitations, the search for the term ‘nano’ in the patent abstract could only be performed for the European patent data and not for the USPTO data.

Apparently, the IPC classes that contain the highest number of nano-related patents, both in the EPO and USPTO systems, are A61K (Pharmaceuticals) and H01L (Semiconductor devices). In more general terms, we see that, based on the EPO data, 8 of these IPC classes are related to 'Macromolecular chemistry, polymers' and 'Materials, metallurgy'. Another 3 IPC-classes relate to 'Surface technology, coating'. The remaining nano-related IPC-classes are dispersed over a wide range of technology sub-areas.

A further statistical analysis of the top-14 USPTO and EPO nano-related IPC-classes leads to the finding that 9 of the 14 top-IPC-classes are shared between both patenting systems. Applying a non-parametric Mann-Whitney U-test to the rankings of the top-14 IPC-classes in both patenting systems, reveals no statistically significant ranking differences (M-W U-test: Z-value=1,23 - p-value=0,22, n.s.).

2.1.3 Analytical approach

The overall analyses will be presented in two broad parts. Part 1 will cover the pre-linkage statistics on non-patent citations, i.e. references to a collection of documents such as scientific papers, abstracts, conference proceedings etc. That will provide a first impression of the science interaction intensity of Nanotechnology and the key actors (countries) in the interaction. The second part will specifically handle the 'science' interaction in the field of Nanotechnology. This part is based on the 'post-linkage' results thereby enabling the identification of research areas of importance for Nanotechnology. The differences in the science interaction intensity of patents originating from several countries of interest will be extensively discussed, just as the type of research 'exchanged' between those countries and ultimately deployed in technological development. Furthermore, attention will be paid to the publication performance of the 'Triad' regions with respect to the so-called 'science associates', the key scientific areas linked to the development of Nanotechnology.

The geographical distribution of the results is done at two levels: the country level and the regional level (consisting of the countries agreed upon with the EC). At the country level, we limit the analysis to individual EU-15 countries, US and Japan: this is done in order to be able to provide so-called ''Triad'' comparisons between the three major competitive regional entities. The performance in and among the following regions is also analyzed: European Union, EFTA, Candidate countries, Other European Countries, NAFTA, ASEAN-4, South American countries, Developed Asian, China and Hong-Kong. When longitudinal insight is essential, we present the results over the time frame 1980-1996. In most cases, however, we present the results over the period 1987-1996. For comparative purposes, two time windows are isolated: 1987-1991 and 1992-1996. These are also the time windows used in the S&T linkage modeling.

The data presented below are based on the USPTO database, covering all patents granted by the United States Patent and Trademark Office. The country allocation is based on the nationality of the inventor that can be found in the inventor address. On the publication side, the country allocation is based on the institutional affiliation of the author. The data are further normalised by the number of patents of a country in a specific technology field and over a specific time period.

PART I OF THE RESULTS

BASED ON:

UNITED STATES PATENT AND TRADEMARK OFFICE (USPTO)

PATENT DATA (1980-1996)

3. RESULTS BASED ON THE USPTO DATA

A. Non-patent citation intensity of Nanotechnology

The first table (table 1) illustrates the evolution in the number of non-patent references in the field of Nanotechnology per year. The number of citations to the non-patent literature (collection of scientific papers, books, proceedings etc.) gives a first indication of the intensity of the non-technology interaction in this field. As can be seen, the number of non-patent references (NPRs) is rather limited.

Table 1 – Absolute number of NPRs per year in Nanotechnology

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
Nano	13	13	85	79	80	253	191	214	627	409
Overall	107060	125348	144998	155275	172802	218551	243784	292704	580805	306636
In %	0,01%	0,01%	0,06%	0,05%	0,05%	0,12%	0,08%	0,07%	0,11%	0,13%

In figure 6 and 7 the evolution of the non-patent references both in % of the number of references and in absolute number of NPRs, over time are illustrated. As to the share of Nanotechnology in the total number of NPRs, we see that a strong increase is visible, especially during the 1990s. A similar development can be observed with regard to the absolute number of NPRs (figure 7). The evolution in NPRs is, to a certain extend, directly related to the evolution in patents in this area (see also section B2).

Figure 6 – Yearly evolution in the share of NPRs in Nanotechnology (as % of total NPRs)

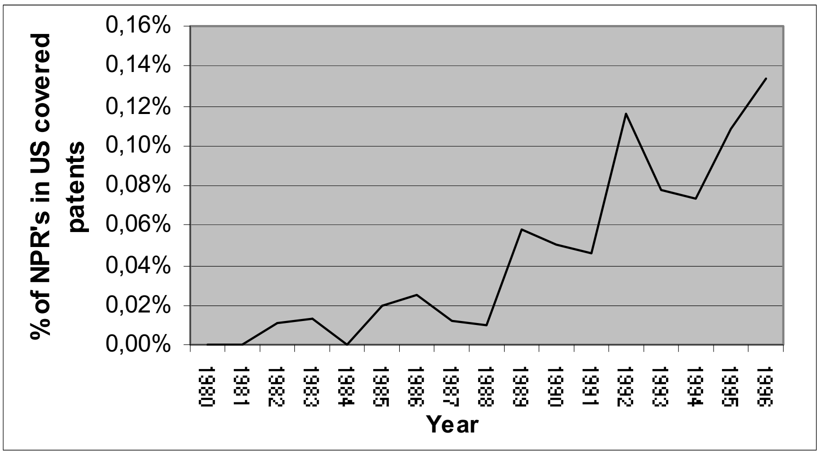
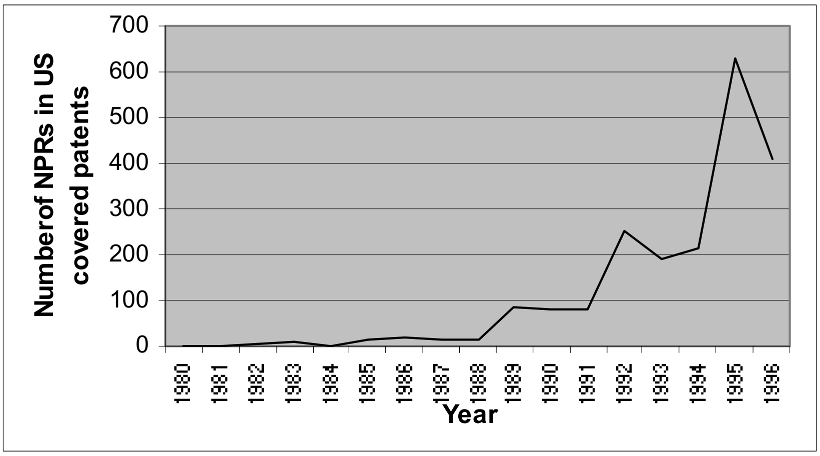


Figure 7 – Yearly evolution in the absolute number of NPRs in Nanotechnology



As already mentioned in the introduction to this report, the methodological approach used in order to arrive at the selection of patents related to Nanotechnology is only partly IPC-based. Whereas in the analysis of the other technology domains, substantial attention has been paid to the technology component analysis (at IPC 4-digit level) within each domain, these analyses can thus not be performed for Nanotechnology.

B. Geographical distribution of citations

B.1 Simple comparison of shares in citations

It is essential for a country's technological, and in the end economic performance, to have access to relevant 'external' knowledge. The number of non-patent references originating from outside the home country, in patent documents is an indicator of the degree to which this access is obtained. At the same time, it indicates whether the 'absorptive' capacity of a certain system of innovation is sufficient in order to 'absorb' possible scientific developments and turn them into technological applications and breakthroughs. The latter is also related to the broad variety of industry – academia co-operations that enable knowledge transfer between both the research and the more application-oriented communities. As we have seen, the share of Nanotechnology in the total number of NPRs lies yearly well below 0,25%. It has to be kept in mind that the nano-field as such is rather young and still in development which is reflected in a limited number of patents.

In table 2, we present the so-called 'market shares' of each region in the total of non-patent references. For example, in 1995, Europe accounts for 24,2% of all non-patent references in Nanotechnology, whereas the NAFTA countries (Canada, Mexico and the US) account for the vast majority of all NPRs with a share of almost 57%. To summarize, Europe performs better in terms of numbers of NPRs than the Developed Asian countries (Japan, South Korea, Singapore and Taiwan). The EFTA countries do not show a stable share in NPRs. In 1995 however, the EFTA countries account for 5,5% of all NPRs in Nanotechnology (see also figure 8). These shares however are biased by the number of patents owned by each region. In figure 9 we illustrate the evolution in NPR-shares among the 'Triad' regions. As will be seen further on, Europe's performance in terms of intrinsic NPR-intensity (per patent) shows a very different development than, e.g., the NPR-intensity of the Developed Asian countries and/or the NAFTA countries.

Table 2 - Regional NPR-shares in Nanotechnology (in % of world total)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	5,9%	0,0%	0,0%	2,4%	0,0%	0,0%	0,0%	0,0%	5,4%	0,3%
Candidate countries	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Other European Countries	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	3,1%	0,0%	0,0%
NAFTA	58,8%	50,0%	74,3%	90,5%	45,9%	82,4%	48,4%	82,6%	56,9%	71,3%
ASEAN-4	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	3,3%
South American countries	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Developed Asian	0,0%	0,0%	22,9%	7,1%	26,7%	6,0%	42,5%	12,8%	6,3%	0,8%
China and Hong-Kong	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
EU-15	35,3%	50,0%	2,9%	0,0%	26,7%	11,6%	9,1%	1,6%	24,2%	22,5%
US	58,8%	50,0%	44,3%	90,5%	45,9%	75,7%	48,4%	76,4%	56,4%	53,8%
Japan	0,0%	0,0%	22,9%	7,1%	26,7%	6,0%	42,5%	12,8%	6,3%	0,8%

Figure 8 – Regional comparison of the evolution in NPR-shares

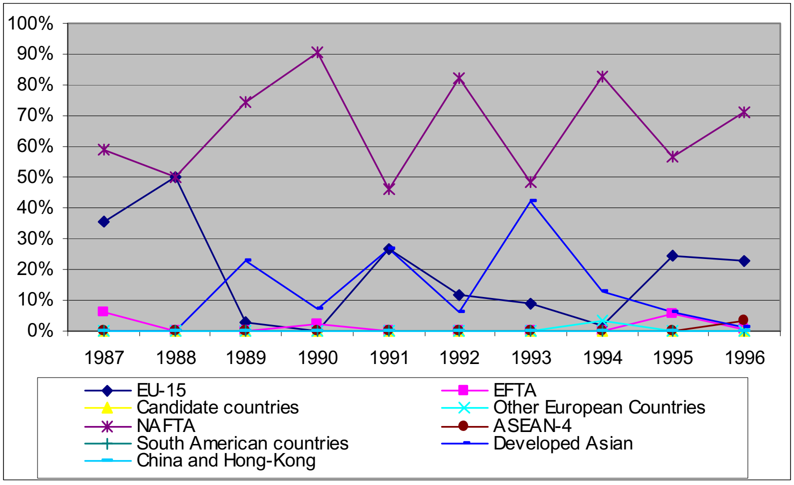
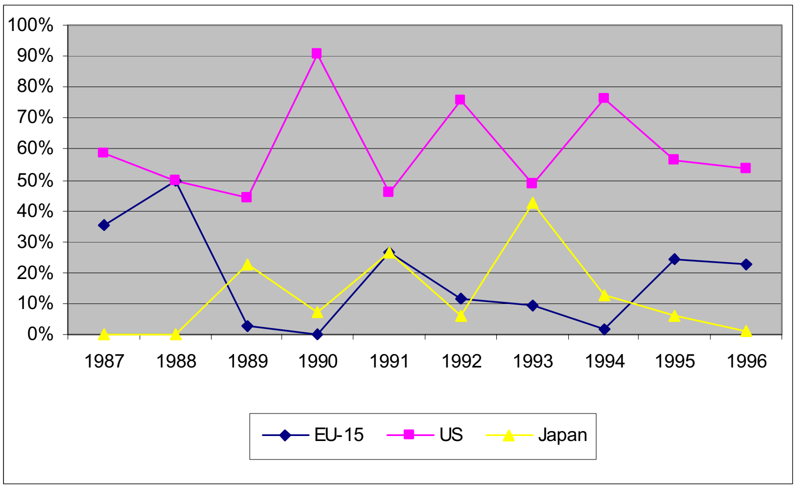


Figure 9– 'Triad' comparison of the evolution in NPR-shares



The distribution of NPR-shares across each European country can now be studied (table 3). Again, one should keep in mind the limited number of available and retrieved USPTO patents related to Nanotechnology. Germany, France and the UK hold the highest proportion of NPRs. It is interesting to mention that for several years the EU-15 contribution in NPRs depends on one single member state (e.g. UK in 1993). In figure 9 we have projected these results in a graph.

The fluctuations of the percentages per country in this table (and in the previous tables) remind the reader of the still emerging and embryonic nature of the nano-technology field, and as a consequence, of its probably incomplete and still highly volatile representation in the databases used and studied in this report.

Table 3 – NPR shares of EU-countries in the field of Nanotechnology (for EU as a total)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
A	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
B	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
D	0,00%	100,00%	50,00%	100,00%	57,14%	0,00%	0,00%	27,75%	29,63%	0,00%
DK	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
E	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	6,61%	2,22%	0,00%
EL	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
F	100,00%	0,00%	0,00%	0,00%	42,86%	13,79%	0,00%	7,05%	23,70%	100,00%
FIN	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
I	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
IRL	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	9,25%	0,00%	0,00%
L	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
NL	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	44,44%	0,00%
P	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
S	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
UK	0,00%	0,00%	50,00%	0,00%	0,00%	86,21%	100,00%	49,34%	0,00%	0,00%

B.2 Patenting activity in each of the regions in Nanotechnology

In table 4, we present the number of patents that each region holds in Nanotechnology. The vast majority of USPTO Nanotechnology patents are in hands of NAFTA, the Developed Asian countries, and the EU-15. The NAFTA countries are leading and hold the highest numbers of Nanotechnology patents, followed by the EU-15, and the Developed Asian countries (see table 5). At the ‘Triad’ level, we see that specifically the US and the EU-15 account for the highest number of patented technological inventions. In table 5, we show the shares in patenting per region. On average over ten years, the NAFTA region accounts for over 65% of all patents. EU-15 and the Developed Asian countries hold respectively 18% and 11% of patent market shares. Keeping in mind the “disadvantage” of European inventors and applicants in patenting “abroad” and specifically in the US patenting system, the position of Europe in Nanotechnology, taking into account the number of patents, is evolving in a positive direction, but still significantly lagging behind the position attained by US inventors.

Table 4 – Absolute number of patents per region

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	1	1	0	1	1	0	0	0	1	1
Candidate countries	0	0	0	0	0	0	0	1	0	0
Other European Countries	0	0	0	0	0	0	0	1	0	0
NAFTA	8	2	17	11	21	42	35	47	99	96
ASEAN-4	0	0	0	0	0	0	0	0	0	2
South American countries	0	0	0	0	0	0	0	0	0	0
Developed Asian	1	2	2	2	8	3	3	10	9	2
China and Hong-Kong	0	0	0	0	0	0	0	0	0	0
EU-15	2	3	5	2	3	9	7	20	20	18
US	8	2	15	11	21	40	35	44	97	89
Japan	1	2	2	2	4	3	3	10	9	2

Table 5 - Regional relative share in patents per region

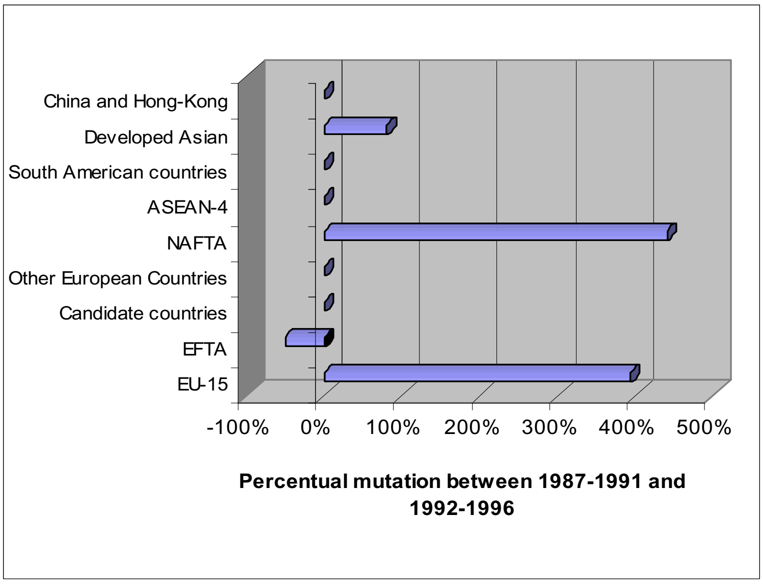
	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	8,33%	12,50%	0,00%	6,25%	2,94%	0,00%	0,00%	0,00%	0,74%	0,83%
Candidate countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,25%	0,00%	0,00%
Other European Countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,25%	0,00%	0,00%
NAFTA	66,67%	25,00%	70,83%	68,75%	61,76%	73,68%	74,47%	58,75%	73,33%	79,34%
ASEAN-4	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,65%
South American Countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Developed Asian	8,33%	25,00%	8,33%	12,50%	23,53%	5,26%	6,38%	12,50%	6,67%	1,65%
China and Hong-Kong	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
EU-15	16,67%	37,50%	20,83%	12,50%	8,82%	15,79%	14,89%	25,00%	14,81%	14,88%
US	66,67%	25,00%	62,50%	68,75%	61,76%	70,18%	74,47%	55,00%	71,85%	73,55%
Japan	8,33%	25,00%	8,33%	12,50%	11,76%	5,26%	6,38%	12,50%	6,67%	1,65%

We now look at the situation in Europe (table 6). The contribution to Europe's overall patenting performance by the member states is unequally distributed. France and Germany (with respectively 39 and 27 patents in the 10-year time window) are by far contributing most to the EU-15 overall total. Spain and the UK follow with respectively 8 and 7 issued patents. One should again keep in mind that the number of patents is retrieved by a combined IPC-class and keyword-based analysis; for the US-patents, the latter one could only be performed in the title-text (and not the abstract, which was not available in the database used). As a consequence, cross-country comparisons can only be performed with great caution.

Table 8 – Absolute number of patents per EU-15 country

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
A	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	1	0	0
D	0	3	1	0	2	4	0	11	4	2
DK	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	2	1	4
EL	0	0	0	0	0	0	0	0	0	0
F	2	0	2	2	1	5	4	4	11	8
FIN	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	1	0	1
IRL	0	0	0	0	0	0	0	0	2	0
L	0	0	0	0	0	0	0	0	0	0
NL	0	0	0	0	0	0	0	0	0	3
P	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0
UK	0	0	2	0	0	0	3	1	2	0
EU-15	2	3	5	2	3	9	7	20	20	18

Figure 10 – Relative increase in the number of patents obtained between 1987-1991 and 1992-1996



(1) The regions that show no mutation had no patents during the period 1987-1991. Several of these regions, however, managed to obtain 1 or 2 patents during the second period of our observations.

In figure 10, the change in patenting performance between 1987-1991 and 1992-1996 is presented. The NAFTA countries, like the EU-15, have managed to strengthen their patent portfolio by a factor 4 during the second period. The Developed Asian countries only slightly managed to increase their number of patents, whereas the EFTA group did not succeed at all in following this trend and actually saw its patenting performance decrease by 50%. Undoubtedly, the rapid developments in the field of Nanotechnology are related to suitable technical instrumentation in combination with the increased attention the field received in the second period. The question also remains whether the regional patenting offices are in a position to timely acquire the necessary expert knowledge in order to evaluate Nano-related (or in more general terms, emerging technology related) patent applications.

B.3. Regional comparison of the NPR intensity

After having presented the performance of the various countries with regard to the absolute number of NPRs and absolute number of patents, we now turn to the average number of citations per patent, an indicator that will reveal more about the degree to which a region’s patents frequently interact with information disclosed on non-patent documents. In table 10, we have related the number of patents belonging to a region to the number of NPRs traced in those patents: i.e. the propensity to NPR (average number of NPRs per patent) per region.

Table 10 – Average number of NPRs per patent per region

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	1,00	0,00	0,00	2,00	0,00	0,00	0,00	0,00	51,00	2,00
Candidate countries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Other European Countries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	8,00	0,00	0,00
NAFTA	1,25	4,00	6,12	6,91	2,95	5,90	4,40	4,53	5,39	4,45
ASEAN-4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	10,00
South American countries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Developed Asian	0,00	0,00	16,00	3,00	4,50	6,00	45,00	3,30	6,56	2,50
China and Hong-Kong	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
EU-15	3,00	2,67	0,80	0,00	12,00	3,89	4,14	0,20	11,35	7,50
US	1,25	4,00	4,13	6,91	2,95	5,70	4,40	4,48	5,45	3,62
Japan	0,00	0,00	16,00	3,00	9,00	6,00	45,00	3,30	6,56	2,50

It appears that country groups with a high number of NPRs or a high number of patents do not necessarily display the highest NPR intensity (see table 10). If we omit the outlier of the Developed Asian countries in 1993 (45 NPRs on one patent), then the average number of NPRs for the EU-15, the Developed Asian countries, and NAFTA varies around 4 (range: from 4,1 to 4,5). This implies that the average number of NPRs between the major “Triad” regions is almost equal. In figure 11 and 12, we respectively illustrate the development of the NPR-intensity by region and by ‘Triad’ countries.

Figure 11 – Evolution in the NPR intensity per region

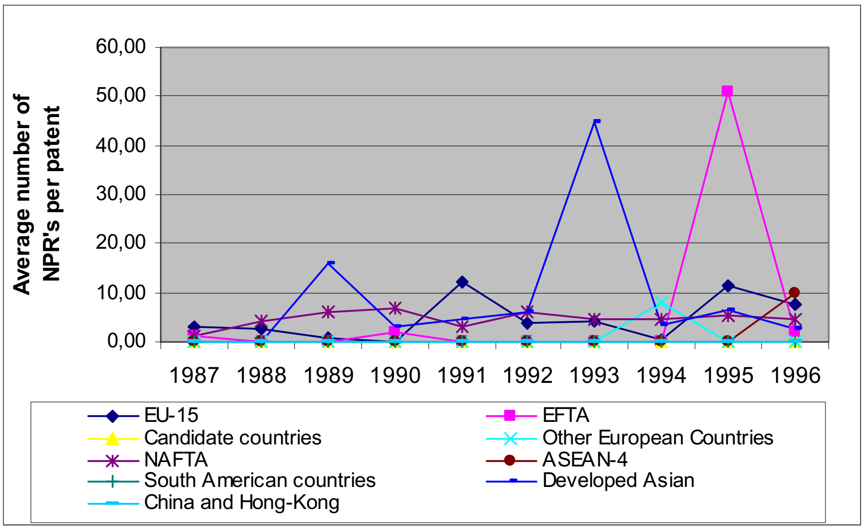
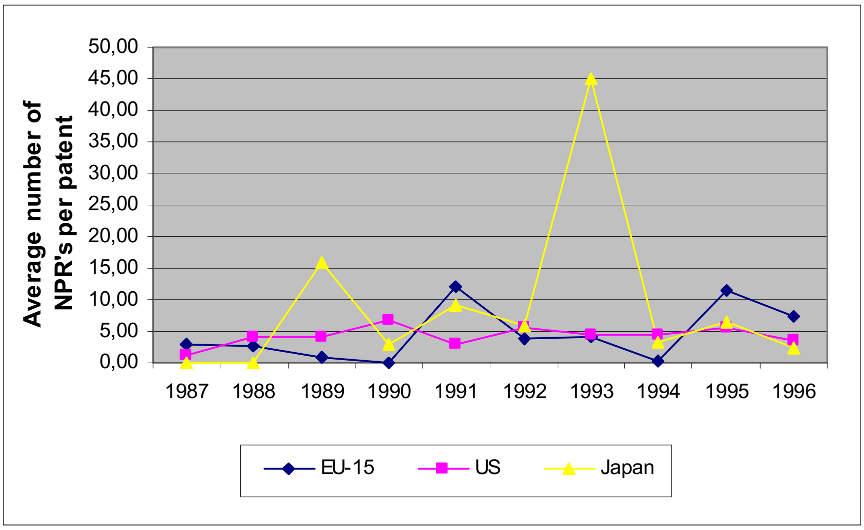


Figure 12 – Evolution in the NPR intensity for each of the 'Triad' regions

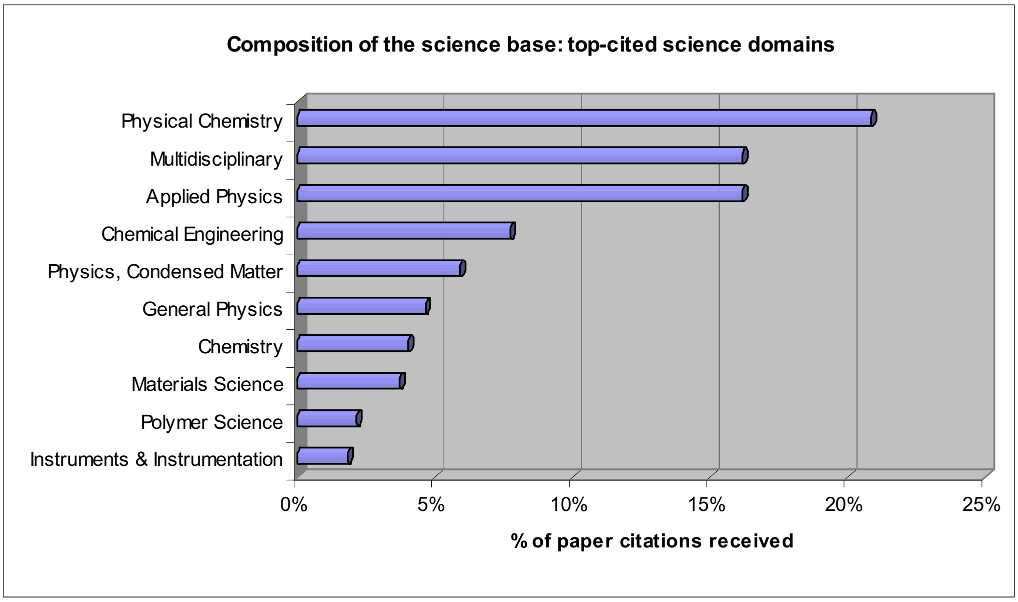


C. Analysis of the S&T interaction in Nanotechnology

C.1. Research areas of importance for Nanotechnology

Through application of the S&T linkage methodology, the science associates of Nanotechnology, i.e. the science areas of importance for the development of the field, have been analysed. In figure 13, the 10 most important science areas related to Nanotechnology are presented according to their importance, i.e. based on the percentage of total science citations received. These 10 domains account for almost 85% of all science interactions, implying that the science interaction can be characterised as rather concentrated. Nevertheless, the total number of interacting science domains is 38. In appendix 1 we present a complete overview of the science associates of Nanotechnology.

Figure 13 – Science associates of 'Nanotechnology'



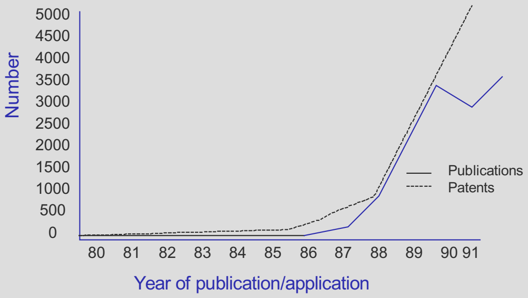
The most important area of research, as measured by the number of science references identified, is Physical Chemistry that receives almost 21% of all paper citations. Multidisciplinary research, of great importance during the emerging and pacing phase of a technology, similar to Applied Physics, both receive 16,15% of all science interactions. The science field of Chemical Engineering accounts for 7,76% of all science interactions. Furthermore, Condensed Matter Physics accounts for 5,9%, General Physics for 4,66%, Chemistry for 4,04%, Materials science for 3,73%, Polymer science for 2,17%, and finally, Instruments & Instrumentation accounts for about 1,86% of all science interactions.

C.2 Regional publication activity in the major ‘science associates’ of Nanotechnology

In this section we shall elaborate on the publication activity of each of the ‘Triad’ regions in the science domains that are related to the field of Nanotechnology, and in that sense are of importance for the future development. Studying the S&T interaction through the ‘direct’ approach as illustrated in this report, does not imply that the identified interactions can be considered as causal (see textbox 1). Substantial methodological problems have to be kept in mind (see other reports on this project as well). As many researchers have argued on many occasions, though, the identified interactions at higher levels of analysis do reveal a network of existing relations between areas of science and technology that influence each other in their development. At this higher level of analysis, identification of the science bases of specific regions and technologies is feasible. In the previous section, the science domains relevant to the evolutions in the area of Nanotechnology were presented and discussed. In section B.2 we presented the patenting activity of each of the regions of interest to the present report. We now turn to the publication base. Keeping in mind that (in several cases) the number of interacting science fields for a certain IPC-class based component technology exceeds 100, a threshold has been set to analyse only those science areas that account for more that 5% of all science interactions of the component technology being examined (read: 5% in terms of paper citations).

Textbox 1

One of the indirect approaches for studying the S&T interaction is the so-called parallel observation of patenting and publication activity. This approach compares the co-evolution of patents and publications in time (Schmoch, 1997). According to Rappa & Debackere (1992), the parallel development of publications and patents can be considered a strong indication for a close interaction between academic and industrial researchers, and thus as a result, on a higher level of analysis an indicator of the science and technology interaction. 'The comparison of time series for longer observation periods supports the understanding of the interaction between industrial and academic research and thereby the process of technology generation' (Schmoch, 1997, p. 110). This however implies a thorough analysis of the technology involved, and of the factors influencing the emergence and evolution of a certain technology. An example of parallel observation in the field of Neural Network technologies is shown below.



As it appeared, the simultaneous take-off of both graphs around 1987 is due to the (re-) discovery of a learning algorithm that had major implications for the performance in the field of neural networks. In the subsequent period, starting around 1990, we see that scientific publications start evolving differently than the patents. This might imply a breach or a shift in the 'close' S&T interaction observed until then. A methodological problem of this approach is the equivalent definition of a technology field in patent and publication databases (classification problem). In the present report we present the ingredients necessary for the parallel observation after identifying the science areas of importance for Nanotechnology through the direct linkage approach. The publication activity is then subsequently analysed in those science field of interest. These science domains however remain quite broad. We introduce the parallel observation approach as a supplement to the direct linkage approach.

The science fields of Physical Chemistry, Multidisciplinary, Applied Physics, Chemical Engineering, and Condensed Matter Physics each account for more than 5% of all science interactions. In view of the assumed importance of the research performed in these areas for the development in Nanotechnology, the publication performance of the 'Triad' regions in these domains is highlighted in the subsequent paragraphs.

Science Domain: Physical Chemistry (290)

Table 11 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	5376	5612	5778	6112	7321	7205	8810	8619	9137	8343
US	3124	3352	3541	3690	4381	4284	4614	4659	4523	4432
Japan	1192	1116	1308	1212	1542	1637	2049	1804	2286	1964
World	14229	15215	16145	16488	19400	18842	21959	21449	23102	20981

Figure 14 – Evolution in the publication activity of each of the 'Triad' regions

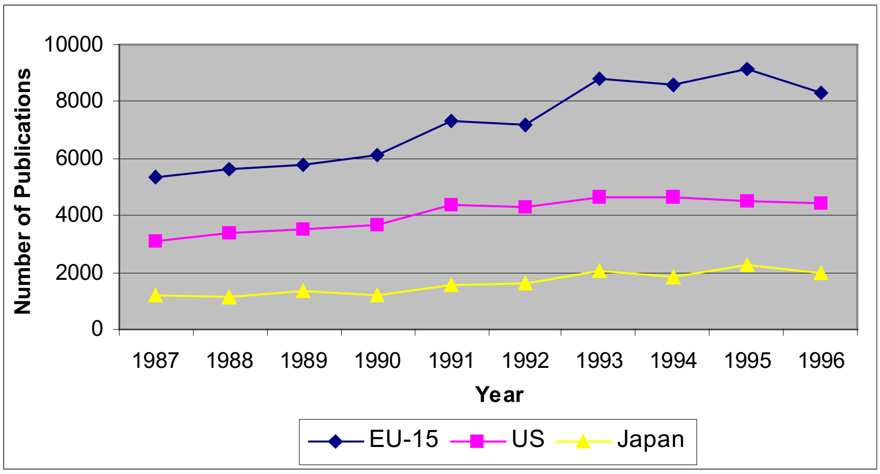
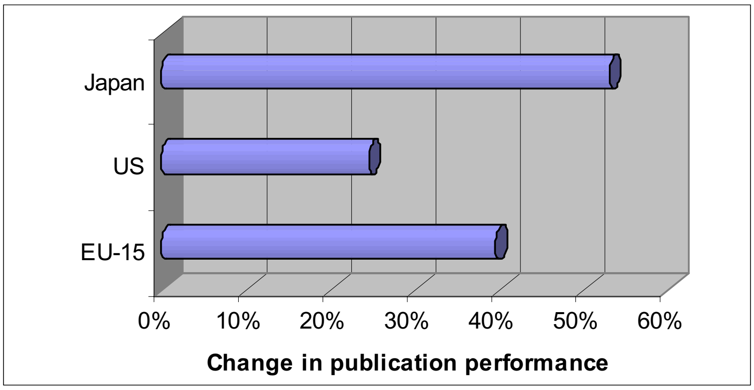


Table 12 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	37,78%	36,88%	35,79%	37,07%	37,74%	38,24%	40,12%	40,18%	39,55%	39,76%
US	21,96%	22,03%	21,93%	22,38%	22,58%	22,74%	21,01%	21,72%	19,58%	21,12%
Japan	8,38%	7,33%	8,10%	7,35%	7,95%	8,69%	9,33%	8,41%	9,90%	9,36%

Figure 15 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Multidisciplinary research (350)

Table 13 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	4473	4516	4011	4043	4145	4138	4108	4182	3799	3429
US	6851	6522	6422	6731	6768	6724	6864	6779	6614	6228
Japan	410	350	407	515	432	477	557	442	519	395
World	18726	17857	17008	17296	16421	15664	15397	15398	14908	12975

Figure 16 – Evolution in the publication activity of each of the 'Triad' regions

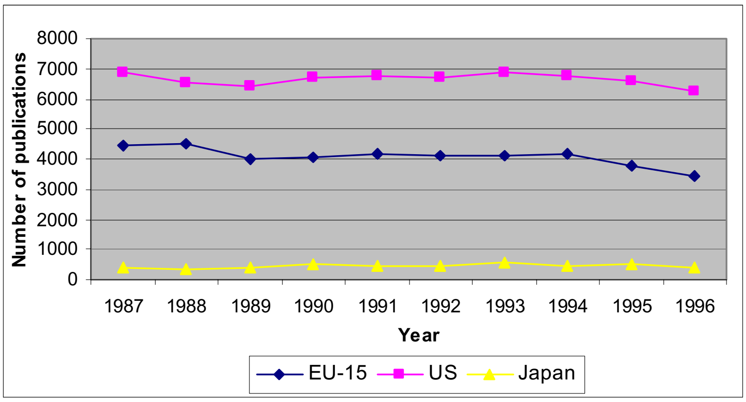
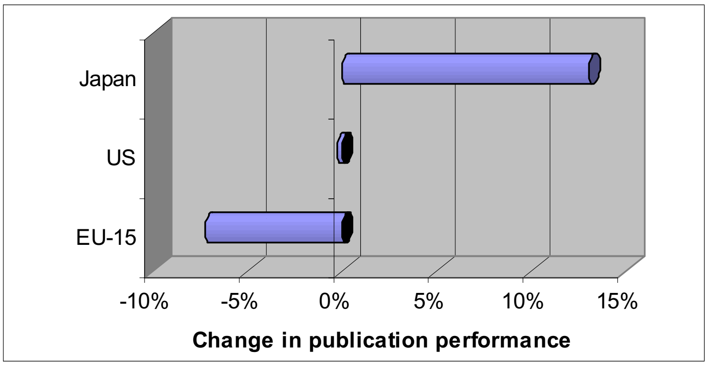


Table 14 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	23,89%	25,29%	23,58%	23,38%	25,24%	26,42%	26,68%	27,16%	25,48%	26,43%
US	36,59%	36,52%	37,76%	38,92%	41,22%	42,93%	44,58%	44,03%	44,37%	48,00%
Japan	2,19%	1,96%	2,39%	2,98%	2,63%	3,05%	3,62%	2,87%	3,48%	3,04%

Figure 17 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Applied Physics (370)

Table 15 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	3134	3708	3381	3663	4254	4243	4917	6138	5388	5375
US	4606	5268	5219	5334	6148	5368	5785	5610	5036	4814
Japan	2377	1998	2510	2392	3451	2676	3369	3506	3135	3490
World	13978	15396	15750	16128	18990	16830	19188	21814	19354	19692

Figure 18 – Evolution in the publication activity of each of the 'Triad' regions

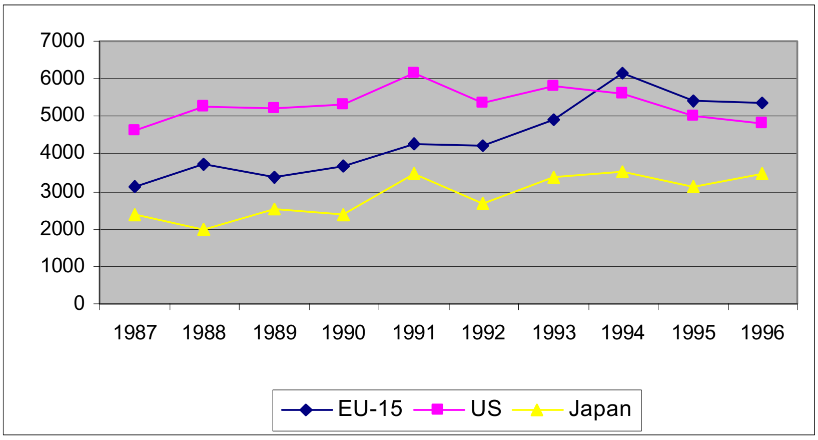
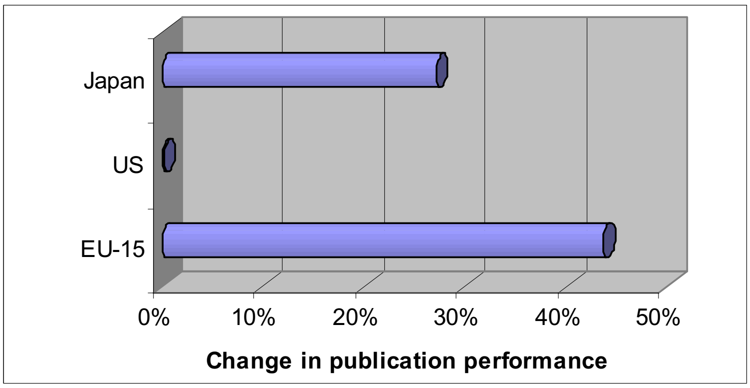


Table 16 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	22,42%	24,08%	21,47%	22,71%	22,40%	25,21%	25,63%	28,14%	27,84%	27,30%
US	32,95%	34,22%	33,14%	33,07%	32,37%	31,90%	30,15%	25,72%	26,02%	24,45%
Japan	17,01%	12,98%	15,94%	14,83%	18,17%	15,90%	17,56%	16,07%	16,20%	17,72%

Figure 19 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Chemical Engineering (310)

Table 17 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	1541	1367	1540	1474	1760	2011	2174	1926	2345	2677
US	2186	1956	1817	1760	1838	1895	1811	1796	1833	1944
Japan	502	615	613	550	590	690	626	798	687	995
World	5862	5631	5685	5605	6191	6601	6672	6692	7121	7898

Figure 20 – Evolution in the publication activity of each of the 'Triad' regions

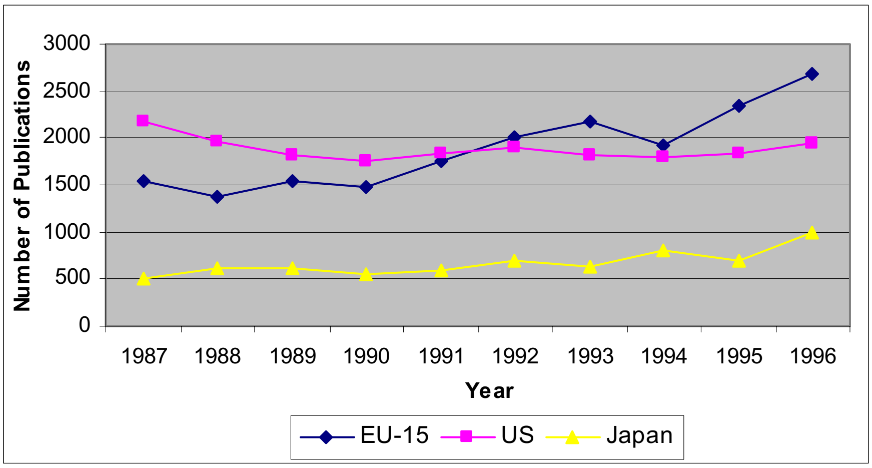
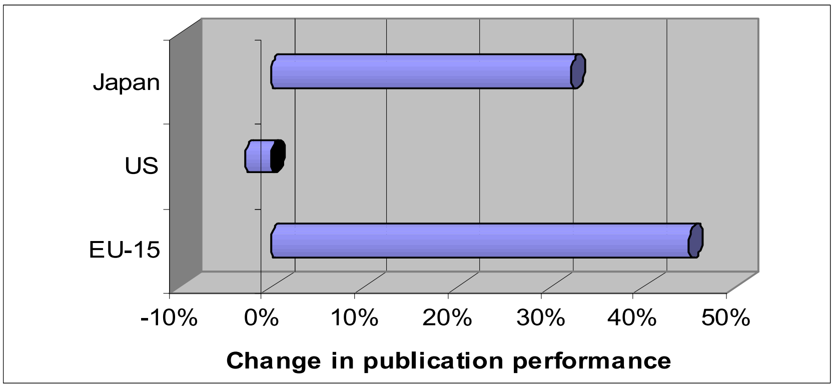


Table 18– 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	26,29%	24,28%	27,09%	26,30%	28,43%	30,47%	32,58%	28,78%	32,93%	33,89%
US	37,29%	34,74%	31,96%	31,40%	29,69%	28,71%	27,14%	26,84%	25,74%	24,61%
Japan	8,56%	10,92%	10,78%	9,81%	9,53%	10,45%	9,38%	11,92%	9,65%	12,60%

Figure 21 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Condensed Matter Physics (372)

Table 19 – ‘Triad’ comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	3564	4401	5449	5311	5117	6183	6148	7193	6391	6344
US	2522	3061	3214	3052	3083	3325	3423	3664	3143	2688
Japan	588	785	1155	1245	943	1280	1531	1637	1516	1780
World	10902	13215	15127	15519	14430	16426	16964	19144	17205	16617

Figure 22 – Evolution in the publication activity of each of the ‘Triad’ regions

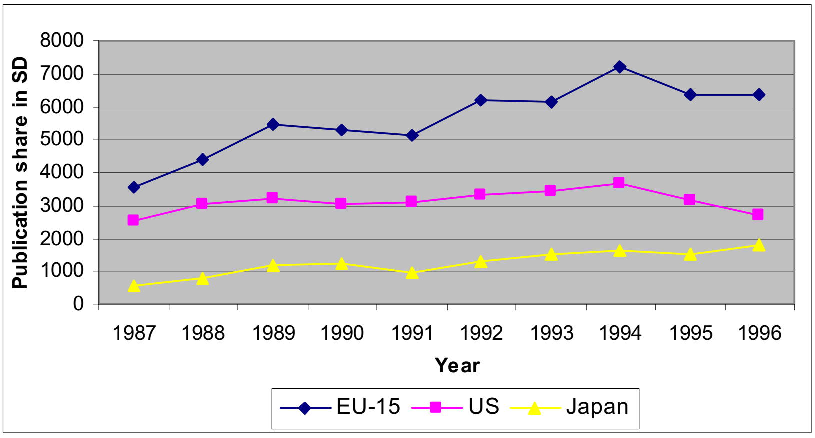
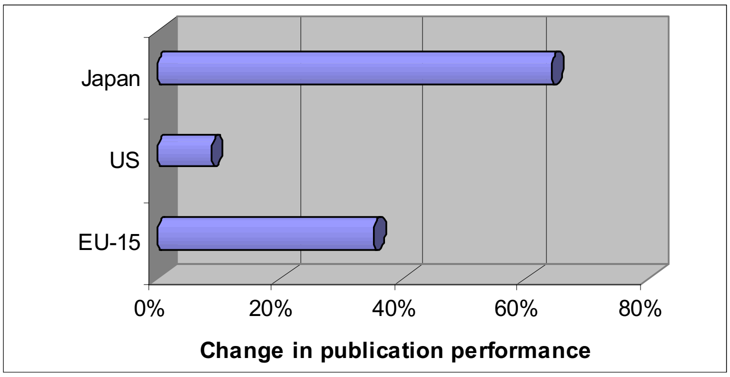


Table 20 – ‘Triad’ comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	32,69%	33,30%	36,02%	34,22%	35,46%	37,64%	36,24%	37,57%	37,15%	38,18%
US	23,13%	23,16%	21,25%	19,67%	21,37%	20,24%	20,18%	19,14%	18,27%	16,18%
Japan	5,39%	5,94%	7,64%	8,02%	6,53%	7,79%	9,02%	8,55%	8,81%	10,71%

Figure 23 – Change in the publication performance of each of the ‘Triad’ between 1987-1991 and 1992-1996



C.3. Science linkage intensity at the country and region level

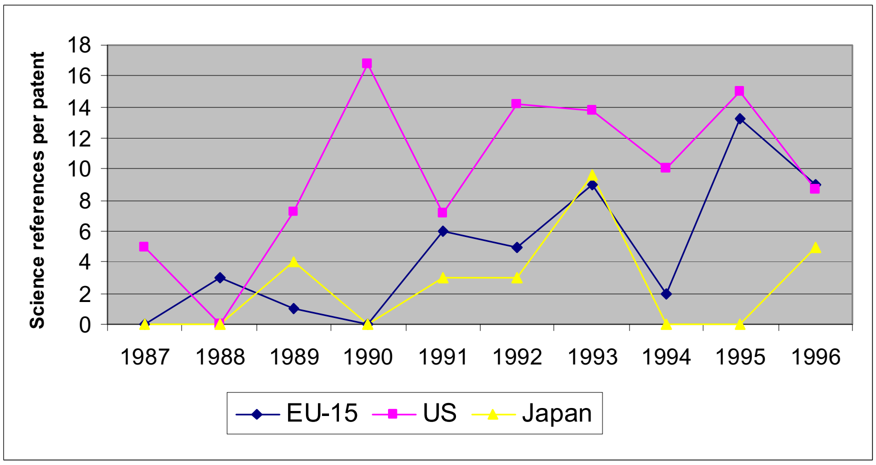
In the remainder of this report, the discussion will focus on the citations to scientific publications. As already mentioned, the NPR intensity can be seen as a first stable indicator of the degree of science dependency. The citations to scientific publications, however, are more directly connected to the intensity of the science interaction, as these publications are the main medium of disclosure of scientific findings within the scientific community. In table 21 we present the science linkage intensity, i.e. the average number of scientific papers cited in patents, of respectively EU-15, US and Japan originated patents. The period of analysis is 1987-1996.

Table 21 – Average number of paper citations per patent on a country level

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
D	0,00	3,00	0,00	0,00	6,00	5,00	0,00	0,00	12,00	8,00
E	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	5,00	0,00
F	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	10,00
IRL	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	8,00	0,00
NL	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
UK	0,00	0,00	1,00	0,00	0,00	0,00	9,00	2,00	28,00	0,00
EU-15	0,00	3,00	1,00	0,00	6,00	5,00	9,00	2,00	13,25	9,00
US	5,00	0,00	7,29	16,75	7,17	14,20	13,75	10,00	15,00	8,70
JP	0,00	0,00	4,00	0,00	3,00	3,00	9,67	0,00	0,00	5,00

The highest and most stable propensity-to-cite science ratio (i.e. the average number of paper citations per patents) is observed for the US-originated patents. European patents, as from 1991 onwards, also have a quite high number of paper citations per patent. The evolution in European patents however is more turbulent. Japanese patents also contain significant paper references in a number of years. Figure 24 gives the evolution in the science interaction intensity for each of the 'Triad' regions.

Figure 24 – Science Linkage (SL): comparison of the number of citations per patent for the 'Triad' regions



C.4. Research orientation of Nanotechnology (basic vs. applied)

Research orientation of Nanotechnology

By tracing the citation to papers in patents one is able to learn more about the research orientation of a certain technology. The approach applied here is based on the detection of the journal name in which a cited paper has appeared. The SCI-classification of journals into broader science is based on the content of the journal, and not of the individual paper. This also applies to the classification of the journals by research type as designed by Narin et. al. (CHI). This classification system has been applied in order to identify the research type cited by inventors in the field of Nanotechnology. Each of the SCI journals is assigned one of four levels in a spectrum that ranges from basic, untargeted research to applied, targeted research.

Patents in the field of Nanotechnology show substantial science interaction intensities. As to the research orientation of the field (see textbox), it appears that applied research-targeted basic research plays the most important role, followed however by more fundamental or basic research. By observing the research-type composition for the period 1992-1996 (see table 23), we see that more than 36% of the science interaction concerns basic scientific research. In other words, 36% of the papers cited by the actors (inventors, examiners etc.) in the patenting process in Nanotechnology concerns basic research. In 53% of all science interactions, applied research - targeted basic research, i.e. basic research with an applied focus, is cited. In less than 1% of all cited papers, applied research is involved. Finally, engineering science-technological science is the type of research disclosed in almost 10% of all cited papers.

Benchmarking these findings with the distribution of the type of research cited over the period 1987-1991 (table 22), reveals a similar pattern as to the research orientation of Nanotechnology. During that period, basic science accounts for more than 35% of all citations, applied research for 0%, targeted basic research for almost 46%, and finally engineering science-technological is the type of research cited in 19% of all journal citations. Compared to the first period of observation, the importance of basic scientific research has increased slightly over the second period. The importance of applied research-targeted basic research increased by almost 8%. Engineering science-technological science lost importance in the second period, its presence decreased by more than 9%. Nanotechnology, as it is an emerging and still developing field, still is mainly basic research/applied basic research oriented.

Table 22 - Characterisation of the science interaction of patent in Nanotechnology (1987-1991)

Type of research cited	*1987*	*1988*	*1989*	*1990*	*1991*	*Total*
Applied research-targeted basic research	50,00%	33,33%	38,46%	57,14%	47,62%	45,83%
Applied technology	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Basic scientific research	50,00%	33,33%	38,46%	28,57%	33,33%	35,42%
Engineering science-technological science	0,00%	33,33%	23,08%	14,29%	19,05%	18,75%

Table 23 - Characterisation of the science interaction of patent in Nanotechnology (1992-1996)

Type of research cited	*1992*	*1993*	*1994*	*1995*	*1996*	*Total*
Applied research-targeted basic research	37,93%	33,33%	66,67%	63,97%	54,72%	53,52%
Applied technology	3,45%	0,00%	0,00%	0,00%	1,89%	0,70%
Basic scientific research	44,83%	52,63%	22,22%	31,62%	28,30%	36,27%
Engineering science-technological science	13,79%	14,04%	11,11%	4,41%	15,09%	9,51%

C.5. Cross-national citation behaviour (or the geographical distribution of the knowledge spill-over)

A highly interesting feature of the science and technology interaction pertains to the analysis of the relation between individual countries in terms of knowledge ‘providers’ and knowledge ‘users’. A knowledge ‘user’ country is defined as the country of origin of the patent. At present, this is operationalised via the inventor country of the patent. A knowledge ‘provider’ is then defined as the country(ies) of origin of the scientific publication(s) cited in the patent documents, at present operationalised as the country of the institutional affiliation of the author(s) on the cited scientific publications. This type of analysis illustrates the knowledge flows (in the form of citation spill-overs) between countries. We discuss two tables: one table is based upon the science - technology interaction analysis for the period 1987-1991 (table 24) and one table is based on the 1992-1996 period (table 25). In this analysis, we have chosen to study the interactions between the ‘Triad’ regions, i.e. the US, EU, and Japan. The percentages are based on the total number of science interactions a country accounts for (the row total). Please note that the ‘EU’-country group is present as an institutional affiliation in the tables. The table should be read as follows. By choosing a country in one of the rows of the table, one can establish the origin of the science interaction for that specific country by looking at the corresponding countries in the columns. For example, German inventors (row: ‘D’) cite EU-originated publications in 75% (EU 37,5% and D 37,5%) of all their paper citations, implying that for technological development in the area of Nanotechnology, Germany is to a large extent EU-oriented (1987-1991). Japanese research is not cited in German patents, implying that Japanese research is less accessed by German inventors, even though Japanese research in Nano-related areas is significant (cf. C.2.) In the subsequent period, 1992-1996 we observe that research from multiple origins is cited in German patents. At the same time, the importance of US-research in German technological activity has increased from 25% to almost 35%. The limited number of identified science interactions in the nano-field has to be kept in mind when interpreting these results, though.

Table 24 – Overview of the cross citation practice between EU-15 countries, US and Japan (1987-1991)

From : inventor country (technology origin)[1]

To : author institutional affiliation country (science origin)

	D	EU	UK	JP	US
D	37,50%	37,50%	0,00%	0,00%	25,00%
UK	0,00%	50,00%	50,00%	0,00%	0,00%

1. *The absence of the other European countries implies that no science interactions were present for these countries*

Table 25 – Overview of the cross citation practice between EU-15 countries, US and Japan (actual period 1992-1996)

From : inventor country (technology origin)[1]

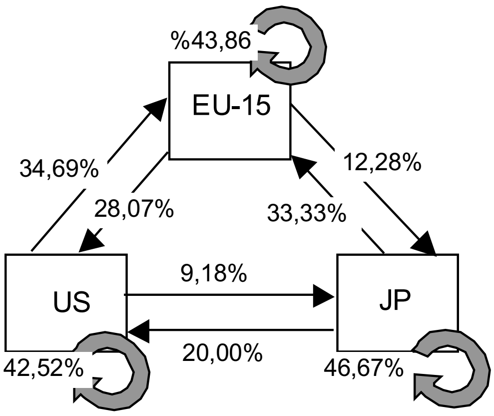
To : author institutional affiliation country (science origin)

	D	E	EL	EU	F	I	UK	JP	US
D	13,04%	4,35%	4,35%	21,74%	4,35%	0,00%	0,00%	4,35%	34,78%
E	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
F	0,00%	0,00%	0,00%	21,43%	7,14%	7,14%	7,14%	7,14%	21,43%
IRL	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	50,00%
UK	17,65%	0,00%	0,00%	23,53%	0,00%	0,00%	5,88%	29,41%	23,53%

1. *The absence of the other European countries implies that no science interactions were present for these countries*

In general, the importance of US-research for European technological development has grown in the period 1992-1996. Nevertheless, we also observe a significant self-citation frequency in European patents. European research related to Nanotechnology does play an important role in European technological development, and is ‘utilized’ accordingly. In figure 40, we have summarized this knowledge transfer/exchange between the ‘Triad’ regions for the period 1992-1996.

Figure 25 - 'Triad' comparison of knowledge 'providers' and 'users' in % for the period 1992-1996



Whereas European patents cite US-originated research in 28,07% of all their science citations (EU-invented patents citing scientific literature), 34,69% of all science citations in US-invented patents originates from EU-science bases. This implies that the importance of European science for US technological development in Nanotechnology is substantial, a finding that can be contrasted with the publication performance of the EU-15 countries in the science domains associated with Nanotechnology. US research is of great importance for Japanese technological development (20%) just as European research is (33,33%). Japanese research is only marginally cited by US- and European inventors (respectively 9,18% and 12,28%).

Almost 43% of all relevant knowledge employed in US-technological development is also from US-origin. European inventors 'utilize' European research in more than 43% of all science citations, which supports the previous conclusion that European research is of significant importance to European technological development. Japanese inventors utilize their own research in almost 47% of all paper citations.

C.6. Type of research cited by the 'Triad' regions

Whereas the previous sections focused on the origins of the cited papers and their "parent" patents in order to obtain a first insight into the spillovers between and the self-sufficiency of individual countries and regions (in the sense of acting as knowledge 'providers' and 'users' for technological development), the next sections will further analyze the specific type of research exchange within and between the 'Triad' regions. As already highlighted in section C.5, the majority of the papers cited in Nanotechnology concern applied research-targeted basic research. But, also basic research occupied a prominent position. Figures 26 to 28 illustrate (in detail) the variability in the type of research cited by each of the major regions.

Figure 26 - Evolution in the type of research cited by European inventors (EU-15)

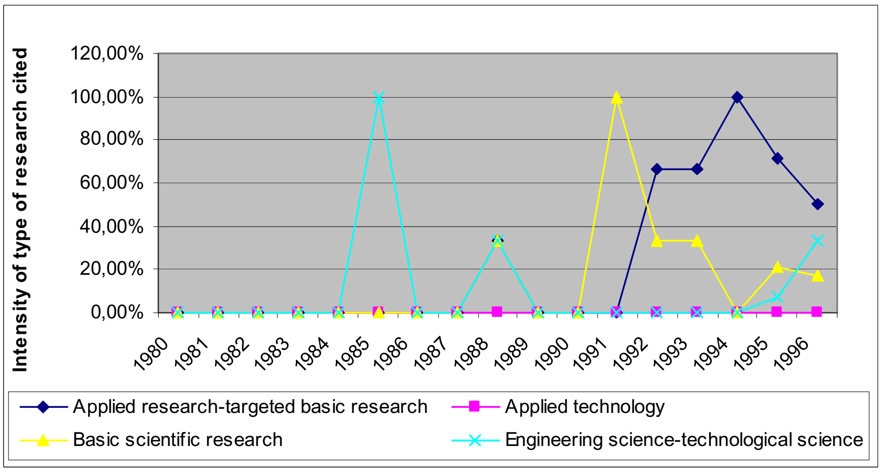


Figure 27 - Evolution in the type of research cited by US-inventors

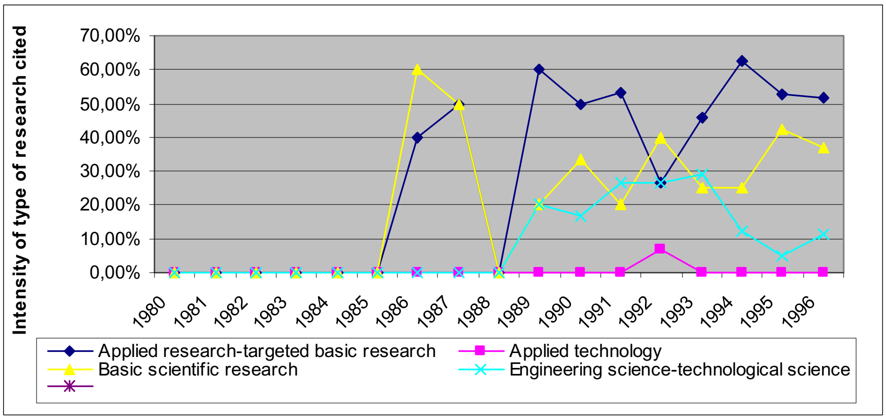
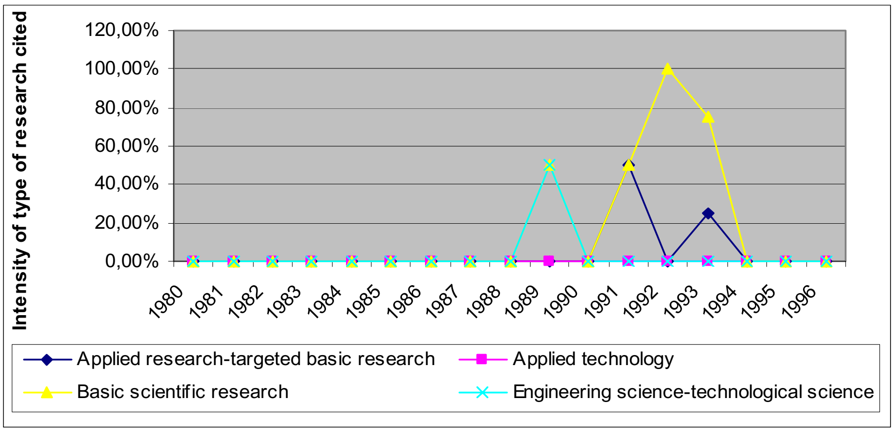


Figure 28 - Evolution in the type of research cited by Japanese inventors



C.7. Type of research and local citation spill-over between the 'Triad' regions

In section C.5, we discussed the intensity with which EU inventors cite US and Japan originated research. We also analysed the importance of EU research to respectively the United States and Japan. As a provider of technology relevant research (as measured via citations), the EU-15 countries play a role of significant importance. EU research is utilised to a high degree, not only by EU inventors, but also by US and Japanese inventors.

Looking at the patenting performance presented in table 4, we see that Europe occupies a second position lagging behind the United States that holds the majority of the patents issued by the USPTO in the field of Nanotechnology. In this section, the characteristics of the knowledge exchange between the 'Triad' regions is now further analysed and refined in terms of the type of research that is utilized and produced by the respective regions.

In other words, the relationship between 'providers' and 'users' of specific types of research along the continuum 'basic' to 'applied' is now examined. In figures 29 to 31, we present the origin of the type of research constituting the science base of each of the 'Triad' regions. Note that the lack of data in a specific type of research in the graphs implies that (for that specific region), no citations to that specific type of research have been observed.

Figure 29 – Origin of the research-type composition of the EU-15 science base in Nanotechnology (1992-1996)

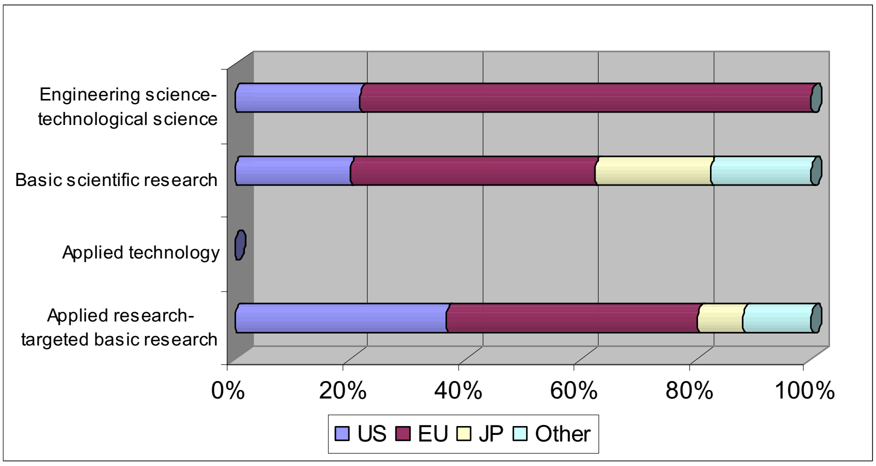


Figure 30 – Origin of the research-type composition of the US science base in Nanotechnology (1992-1996)

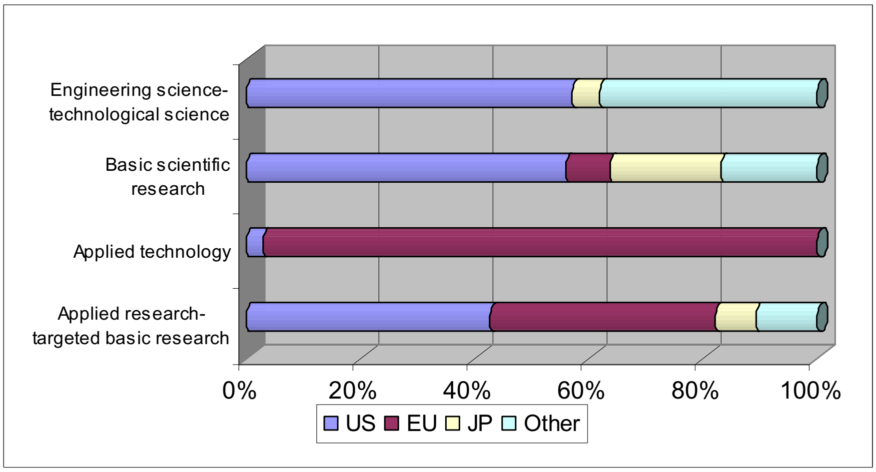
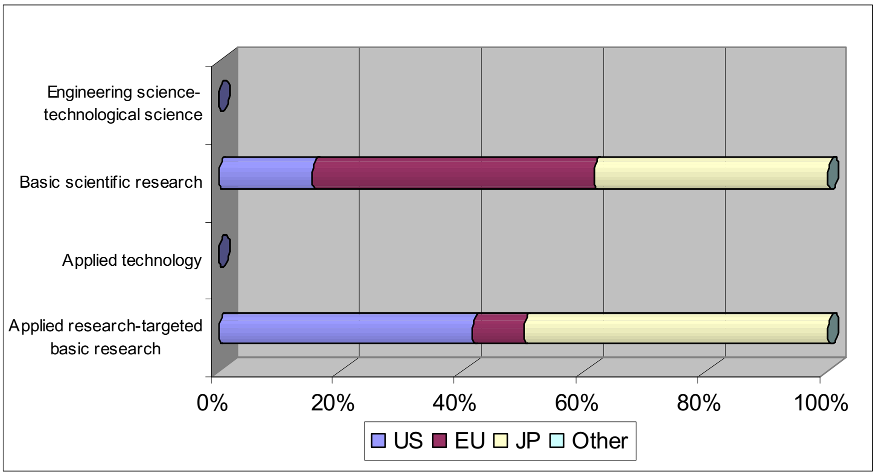


Figure 31 – Origin of the research-type composition of the Japanese science base in Nanotechnology (1992-1996)



The science base of a technology, as measured by the characteristics of the research cited in patents, can now be positioned along the continuum 'basic' - 'applied'. As seen in the graphs presented above, Europe succeeds in 'providing' in providing in a significant part of the research relevant for EU-technological development in Nanotechnology. In the composition of the science base, though, we also see a strong presence of US-originated research. In the US science base, we can observe that Europe plays a more modest role, except for the case of applied technology. A large part of the papers containing basic scientific research cited by Japanese inventors is from EU-origin. An interesting finding relates to the composition of the US science base, as well as to the composition of the EU-science base. An important role is played by the group of 'other' countries in both instances, especially with regard to basic scientific research. In the case of the EU-science base, Canada and Switzerland could be identified as the countries of origin of the 20% cited basic research. In the case of the US-science base, a wide array of countries could be identified, all of which make a marginal contribution.

PART II OF THE RESULTS

BASED ON:

EUROPEAN PATENTING OFFICE (EPO)

PATENT DATA (1980-1996)

4. RESULTS BASED ON THE EPO DATA

D. Non-patent citation intensity of Nanotechnology

In table 26 we illustrate the evolution in the number of non-patent references in the field of Nanotechnology per year. As already mentioned, the number of citations to the non-patent literature (collection of scientific papers, books, proceedings etc.) gives a first impression of the intensity of the non-technology interaction in this field. Also here, a steep increase is observable between 1991 and 1992 that continues up to 1996.

Table 26 – Absolute number of NPRs per year in Nanotechnology

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
Nano	89	126	106	113	168	236	356	392	452	476
Overall	32464	38174	43430	51591	53916	54910	57614	55747	59341	45935
In %	0,27%	0,33%	0,24%	0,22%	0,31%	0,43%	0,62%	0,70%	0,76%	1,04%

In figure 33 and 34 the evolution in the number of NPRs, both in % of the overall number of references, and in absolute figures, are illustrated. As to the share of Nanotechnology in the total number of NPRs, we see that a strong increase occurs, especially at the beginning of the 1990s. A similar evolution is noticed with regard to the absolute number of NPRs (figure 38). As mentioned previously, the evolution in NPRs is to a certain extend related to the evolution in patents (see also section E2), implying that if the number of patents increases, as a result, one may expect the number of NPRs also to increase.

Figure 33 – Yearly evolution in the share of NPRs in Nanotechnology (in % of total number of NPRs)

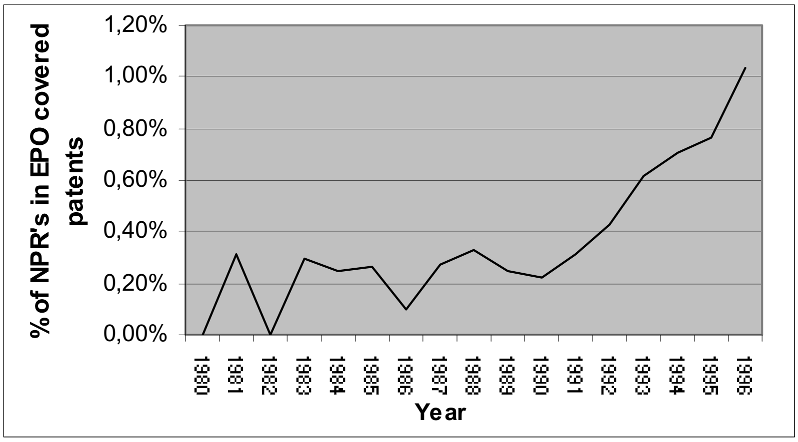
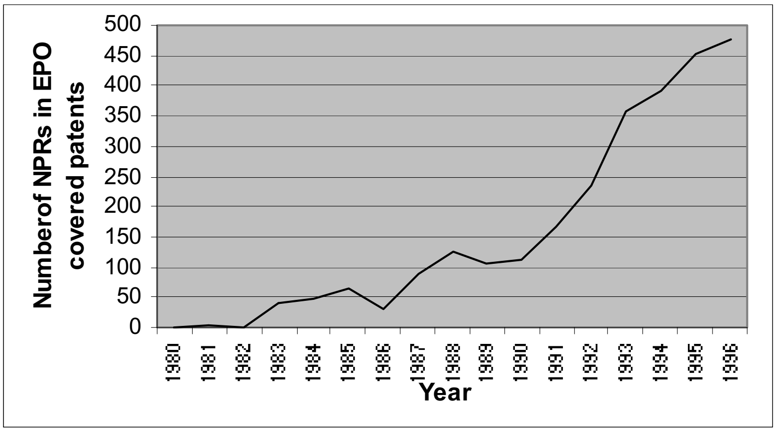


Figure 34 – Yearly evolution in the absolute number of NPRs in Nanotechnology



E. Geographical distribution of citations

E.1 Simple comparison of shares in citations

It is essential for a country's technological, and economic performance, to have access to relevant 'external' knowledge. The number of non-patent references in patent documents is an indicator of the degree to which this access is obtained. At the same time, it indicates whether the 'absorptive' capacity of a certain system of innovation is sufficient in order to 'absorb' possible scientific developments and turn them into technological applications and breakthroughs. The latter is also related to industry – academia co-operations that enable knowledge transfer between both research and more application-oriented spheres. As we have seen, the share of Nanotechnology in the total number of NPRs lies well below 0,15% (based on the EPO data) in any given year. In table 27, we present the so-called 'market shares' of each region in the total of non-patent references. In 1995 we see that Europe accounts for 45,03% of all non-patent references in Nanotechnology, whereas the NAFTA countries (Canada, Mexico and the US) account for 44,05%. Based upon the EPO data, the EU-15 perform slightly better in terms of numbers of NPRs than NAFTA and the Developed Asian countries (Japan, South Korea, Singapore and Taiwan). The EFTA countries hold a rather stable share fluctuating around 2%. It has to be kept in mind, however, that the number of patents owned by each region distorts these shares. In figure 35 we illustrate the evolution in NPR-shares among the 'Triad' regions. As we will see later on, Europe's performance in terms of intrinsic NPR-intensity (per patent) shows a very different development than for example the NPR-intensity of the Developed Asian countries and/or the NAFTA countries.

Table 27 - Regional NPR-shares in Nanotechnology (in % of world total)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	18,28%	1,59%	6,48%	0,00%	2,35%	2,50%	1,80%	2,75%	2,14%	1,16%
Candidate countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,83%	0,00%	1,77%	0,00%	1,74%
Other European Countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,52%	0,39%	0,19%	0,00%
NAFTA	53,76%	70,63%	62,04%	48,76%	49,41%	42,50%	41,24%	37,13%	44,05%	39,96%
ASEAN-4	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,52%	0,00%	0,00%	0,00%
South American countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Developed Asian	0,00%	3,17%	10,19%	13,22%	2,94%	11,25%	2,06%	5,70%	4,87%	17,37%
China and Hong-Kong	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
EU-15	27,96%	24,60%	21,30%	34,71%	35,29%	42,92%	48,71%	43,03%	45,03%	35,14%
US	53,76%	66,67%	54,63%	38,84%	47,06%	41,25%	39,18%	36,54%	43,47%	37,26%
Japan	0,00%	3,17%	10,19%	13,22%	2,35%	11,25%	2,06%	5,70%	4,87%	16,80%

Figure 27 – Regional comparison of the evolution in NPR-shares

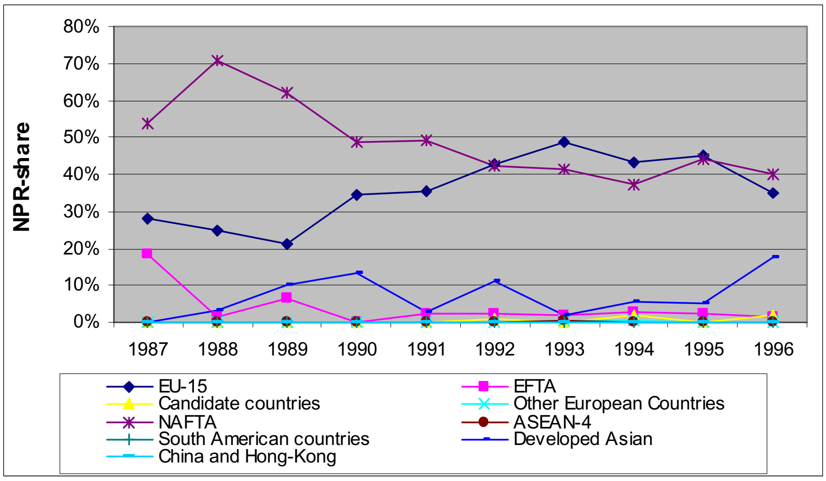
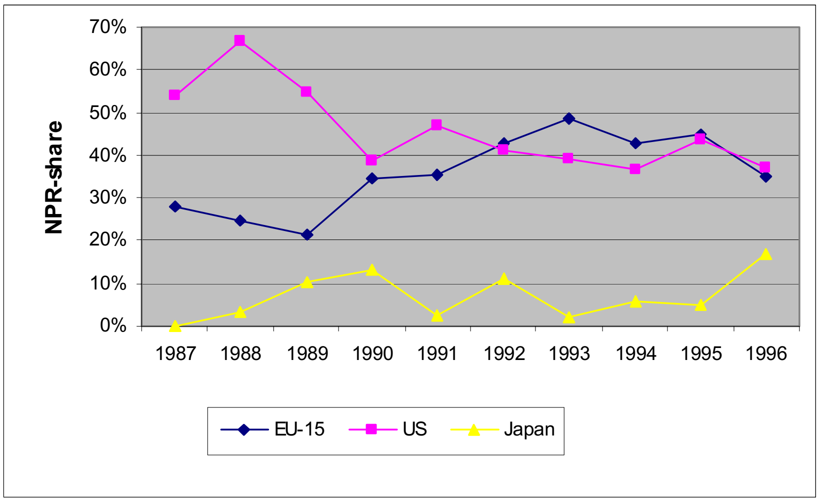


Figure 28– ‘Triad’ comparison of the evolution in NPR-shares



We now look at the distribution of NPR-shares per each European country (table 28). Germany, France and the UK hold the largest proportions of NPRs. An interesting development is the switch in highest NPR market-share between Germany and France during and after 1992. In the subsequent years, we see that Germany accounts for the highest number of NPRs. After 1992, a relatively high share in NPRs can also be attributed to Italy.

Table 28 – NPR shares of EU-countries in the field of Nanotechnology (for EU as a total)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
A	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,10%
B	0,00%	0,00%	0,00%	14,29%	0,00%	0,00%	0,00%	2,74%	4,76%	2,20%
D	11,54%	48,39%	8,70%	19,05%	40,00%	40,78%	14,81%	22,37%	55,41%	43,41%
DK	0,00%	0,00%	0,00%	9,52%	3,33%	0,00%	0,00%	0,00%	0,00%	0,00%
E	23,08%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	3,65%	3,46%	0,00%
EL	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,73%	0,00%
F	19,23%	9,68%	60,87%	14,29%	41,67%	49,51%	4,76%	22,83%	14,29%	10,44%
FIN	0,00%	0,00%	0,00%	0,00%	13,33%	0,00%	0,00%	0,00%	0,00%	0,00%
I	0,00%	0,00%	17,39%	0,00%	0,00%	0,00%	52,38%	4,11%	11,26%	4,40%
IRL	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
L	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
NL	0,00%	0,00%	0,00%	0,00%	1,67%	1,94%	0,53%	10,96%	0,87%	3,85%
S	0,00%	0,00%	13,04%	0,00%	0,00%	2,91%	0,53%	3,20%	0,00%	0,00%
UK	46,15%	41,94%	0,00%	42,86%	0,00%	4,85%	26,98%	30,14%	8,23%	34,62%

E.2 Patenting activity in each of the regions in Nanotechnology

In table 29a, we present the number of patent applications by each region in Nanotechnology. Subsequently, in table 29b the number of granted patents is presented. Looking first at the number of patent applications, we see that the majority of the applications stems from NAFTA, the Developed Asian countries, and the EU-15. Except for the years 1992 and 1994, for which we may conclude that EU-15 inventors perform better in terms of patent applications than their NAFTA colleagues (i.e. in number of patent-applications), in all other years the NAFTA inventors have filed the highest number of patenting requests at the EPO office. With regard to the successful patent applications, i.e. the patent grants, the situation is slightly different. The difference between the NAFTA and the EU-15 is marginal (6 patents more for the NAFTA region over a 10-year period). At a Triad-level comparison, we actually see that EU-15 holds in total 2 patents more the US-inventors (161 vs. 159). The Developed Asian countries account for 40 successful patents (Japan for 39 of them), whereas the EFTA region closely follows with 38 granted patents. The number of patent applications and grants seems to have taken a substantial growth since the beginning of the 1990s. In table 30a we present the patenting shares per region. On average over 10-year period, we observe that the NAFTA region account for almost 49% of all patent applications, whereas the EU-15 and the

Developed Asian countries hold respectively 35% and 8% on average. With regard to the granted patents (table 30b) the respective shares are 39% (NAFTA), 41% (EU-15), and 7% (Developed Asian). Even though the difference in patenting performance between the EU-15 and NAFTA regions is not that high when based on the USPTO data, it still confirms that the NAFTA, and mainly the US, perform well as 'foreign' patentors in Europe. As to the success ratio of the different patent applications, i.e. the effectiveness, we see that the NAFTA-inventors obtain 1 successful patent for every 3,66 patent applications; the EU-15 obtains 1 successful patent for every 3,11 patent applications. The respective numbers for the EFTA region and the Developed Asian countries are 1,5 and 2,5.

Table 29a – Absolute number of patents per region (*Patent Applications*)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	6	1	3	3	2	8	8	10	4	12
Candidate countries	0	0	0	0	0	2	0	3	0	1
Other European Countries	0	0	0	0	0	0	1	2	1	1
NAFTA	36	31	43	40	48	61	83	70	94	112
ASEAN-4	0	0	0	0	0	0	1	0	0	0
South American countries	0	0	0	0	0	0	0	0	1	0
Developed Asian	0	7	4	16	5	16	7	12	14	21
China and Hong-Kong	0	0	0	0	0	0	0	0	0	0
EU-15	23	15	18	29	29	69	49	101	78	90
US	36	28	36	36	44	60	78	67	92	105
Japan	0	7	4	16	4	16	7	12	14	17

Table 29b – Absolute number of patents per region (*Patent Grants*)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	2	0	5	2	8	3	4	1	4	9
Candidate countries	0	0	0	0	0	0	0	0	0	0
Other European Countries	0	0	0	0	0	0	0	0	0	0
NAFTA	3	10	9	4	12	13	15	41	29	31
ASEAN-4	0	0	0	0	0	0	0	0	0	1
South American countries	0	0	0	0	0	0	0	0	0	0
Developed Asian	0	5	0	0	1	1	4	19	4	6
China and Hong-Kong	0	0	0	0	0	0	0	0	0	0
EU-15	6	11	10	8	7	7	24	17	33	38
US	3	10	9	4	12	13	15	37	26	30
Japan	0	5	0	0	1	1	4	19	3	6

Table 30a - Regional relative share in patents per region (*Patent Applications*)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	9,23%	1,69%	4,35%	3,23%	2,22%	5,13%	5,23%	4,81%	2,00%	4,96%
Candidate countries	0,00%	0,00%	0,00%	0,00%	0,00%	1,28%	0,00%	1,44%	0,00%	0,41%
Other European Countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,65%	0,96%	0,50%	0,41%
NAFTA	55,38%	52,54%	62,32%	43,01%	53,33%	39,10%	54,25%	33,65%	47,00%	46,28%
ASEAN-4	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,65%	0,00%	0,00%	0,00%
South American Countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,50%	0,00%
Developed Asian	0,00%	11,86%	5,80%	17,20%	5,56%	10,26%	4,58%	5,77%	7,00%	8,68%
China and Hong-Kong	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
EU-15	35,38%	25,42%	26,09%	31,18%	32,22%	44,23%	32,03%	48,56%	39,00%	37,19%
US	55,38%	47,46%	52,17%	38,71%	48,89%	38,46%	50,98%	32,21%	46,00%	43,39%
Japan	0,00%	11,86%	5,80%	17,20%	4,44%	10,26%	4,58%	5,77%	7,00%	7,02%

Table 30b - Regional relative share in patents per region (*Patent Grants*)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	18,18%	19,23%	8,33%	57,14%	10,71%	16,67%	2,04%	5,13%	12,33%	0,00%
Candidate countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Other European Countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
NAFTA	27,27%	38,46%	37,50%	28,57%	42,86%	54,17%	30,61%	52,56%	39,73%	36,47%
ASEAN-4	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,18%
South American Countries	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Developed Asian	0,00%	19,23%	0,00%	0,00%	3,57%	4,17%	8,16%	24,36%	5,48%	7,06%
China and Hong-Kong	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
EU-15	54,55%	42,31%	41,67%	57,14%	25,00%	29,17%	48,98%	21,79%	45,21%	44,71%
US	27,27%	38,46%	37,50%	28,57%	42,86%	54,17%	30,61%	47,44%	35,62%	35,29%
Japan	0,00%	19,23%	0,00%	0,00%	3,57%	4,17%	8,16%	24,36%	4,11%	7,06%

We now look at the situation in Europe (table 31a and 31b). The contribution to Europe's overall patenting performance, by the member states, in terms of applications and grants as well, is unequally distributed. In terms of patent applications we see that France, Germany and the UK file the highest number of patents. Of interest is also the "high" number of Italian patent applications in 1993 (10 applications). Among the smaller countries one should pay attention to the number of applications of The Netherlands, Belgium, Spain, and Sweden. Turning to the number of granted patents (table 31b), we see that France, Germany, and the UK are leading with respectively 58, 46, and 28 patents. Among the "smaller" countries, the

Netherlands follow with 15 patents over the decade 1987-1996. It should be pointed out that cross-country comparisons in terms of patenting efficiency and/or effectiveness are not the objective of this study. Therefore no comments can and/or will be made on these issues.

Table 31a – Absolute number of patents per EU-15 country (Patent Applications)

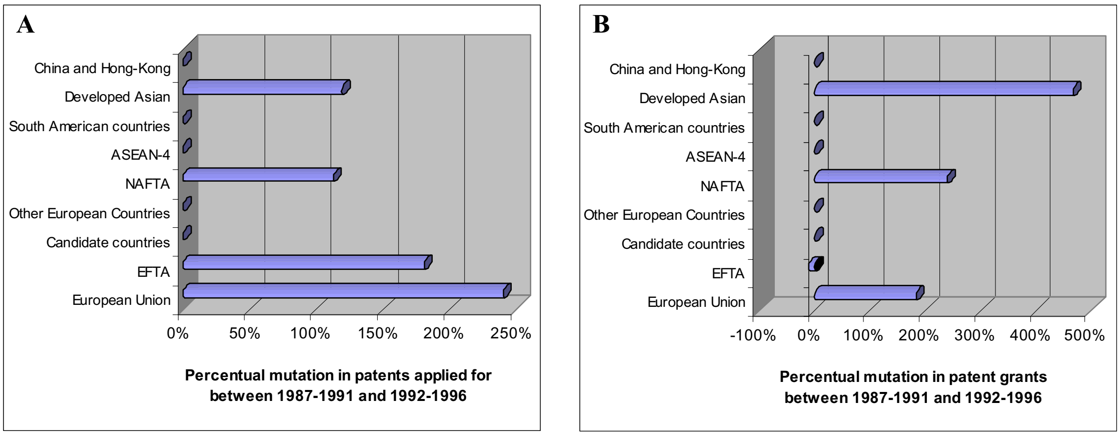
	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
A	0	0	0	0	0	0	0	0	0	1
B	1	0	0	4	0	2	0	2	3	3
D	4	7	2	8	14	27	17	28	42	32
DK	0	0	0	1	1	0	0	0	0	0
E	2	0	0	0	0	1	0	4	1	2
EL	0	0	0	0	0	0	0	0	2	0
F	10	3	9	5	11	33	7	30	16	24
FIN	0	0	0	0	2	0	0	0	0	2
I	0	0	1	1	0	0	10	3	2	7
IRL	0	0	0	0	0	0	0	0	0	2
L	0	0	0	0	0	0	0	0	0	0
NL	0	0	2	0	1	4	1	9	2	4
P	0	0	0	0	0	0	0	0	0	0
S	1	0	3	0	0	1	1	5	0	0
UK	5	5	1	10	0	1	13	20	10	13
EU-15	23	15	18	29	29	69	49	101	78	90

Table 31b – Absolute number of patents per EU-15 country (Patent Grants)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
A	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	2	0	2	0
D	0	2	2	3	3	0	8	5	10	13
DK	0	0	0	0	0	0	0	0	1	0
E	0	0	0	0	2	0	0	0	0	0
EL	0	0	0	0	0	0	0	0	0	0
F	0	0	3	4	1	6	7	7	13	17
FIN	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	1	2
IRL	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0
NL	2	4	3	0	0	0	6	0	0	0
P	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	1	0	0	3	0	0
UK	4	5	2	1	0	1	1	2	6	6
EU-15	6	11	10	8	7	7	24	17	33	38

In figure 29 (A) we present the shifts in patent application performance between 1987-1991 and 1992-1996. As we can see the EU-15 almost tripled the number of patent applications at the EPO in comparison to the period 1987-1991. The EFTA countries increased the number of patent applications by 180% (from 15 in period 1, to 42 in period 2). The Developed Asian countries just like the NAFTA countries almost doubled the number of patent applications in the second period. Undoubtedly, the fast developments in the field of Nanotechnology are related to the advent of suitable technical instrumentation in combination with the increased attention the field received in the second time period. As far as the success ratio of the patent applications is concerned (29B), we see that the Developed Asian countries improved their number of patents granted by realising a growth of 467% in comparison to the first period. Equally important is the growth in the number of granted patents realised by the NAFTA countries (approx. 240%: from 38 successful patents in period 1 to 129 patents in period 2). Not far behind are the EU-15 that managed to increase their patent portfolio by almost 190%.

Figure 29 – Relative increase in the number of patent applications and grants between 1987-1991 and 1992-1996



- Regions displaying no mutation in patenting performance did not account for any patents (applications or grants) in the period 1987-1991

E.3. Regional comparison of the NPR intensity

After having presented the performance of the various countries in regard of the number of NPRs, patent applications and number of patents granted, we now turn to the average number of citations per patent, an indicator that will reveal more about the degree in which regional patents frequently interact with information disclosed in non-patent documents. In the remainder of this report, whenever we use the term ‘patents’, we refer to the patents ‘applied for’ and thus not necessarily granted yet. This is in line with the main interest in this study, which is to uncover the widest possible network, and subsequent analysis, of S&T interactions in Nanotechnology. A central role is dedicated to the knowledge “flows” in the patent documents. In table 32, we have related the number of patents to the number of NPRs displayed in those patents: i.e. the propensity to NPR (average number of NPRs per patent).

Table 32 – Propensity to NPR per region

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EFTA	2,83	2,00	2,33	0,00	2,00	0,75	0,88	1,40	2,75	0,50
Candidate countries	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00
Other European Countries	0,00	0,00	0,00	0,00	0,00	0,00	2,00	1,00	1,00	0,00
NAFTA	1,39	2,87	1,56	1,48	1,75	1,67	1,93	2,70	2,40	1,85
ASEAN-4	0,00	0,00	0,00	0,00	0,00	0,00	2,00	0,00	0,00	0,00
South American countries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Developed Asian	0,00	0,00	2,75	1,00	1,00	1,69	1,14	2,42	1,79	4,29
China and Hong-Kong	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
EU-15	1,13	2,07	1,28	1,45	2,07	1,49	3,86	2,17	2,96	2,02
US	1,39	3,00	1,64	1,31	1,82	1,65	1,95	2,78	2,42	1,84
Japan	0,00	0,00	2,75	1,00	1,00	1,69	1,14	2,42	1,79	5,12

Country groups with a high number of NPRs and/or patents do not necessarily display the highest NPR intensity. If we do not consider the outlier of the Developed Asian countries in 1993 (45 NPRs per patent), then the average number of NPRs for the EU-15, the Developed Asian countries, and NAFTA varies from 2-to-3. This implies that the average number of NPRs between the major competitive three regions is more or less equal. In figure 30 and 31 we visualise the respective development of the propensity to NPR by region and by 'Triad' countries.

Figure 30 – Evolution in the propensity to NPR per region

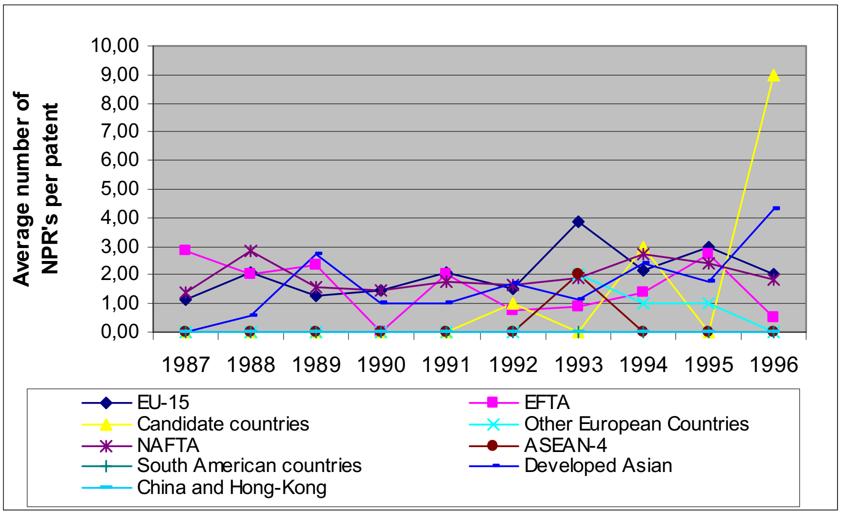
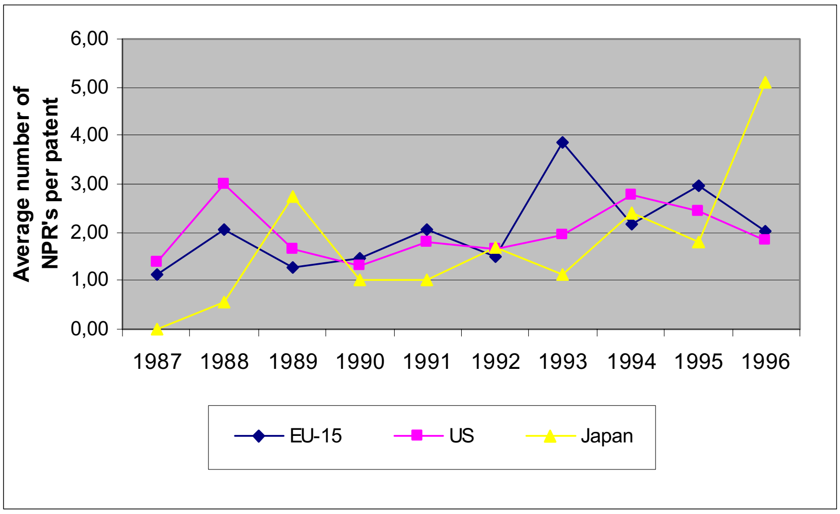


Figure 31 – Evolution in the propensity to NPR for each of the 'Triad' regions

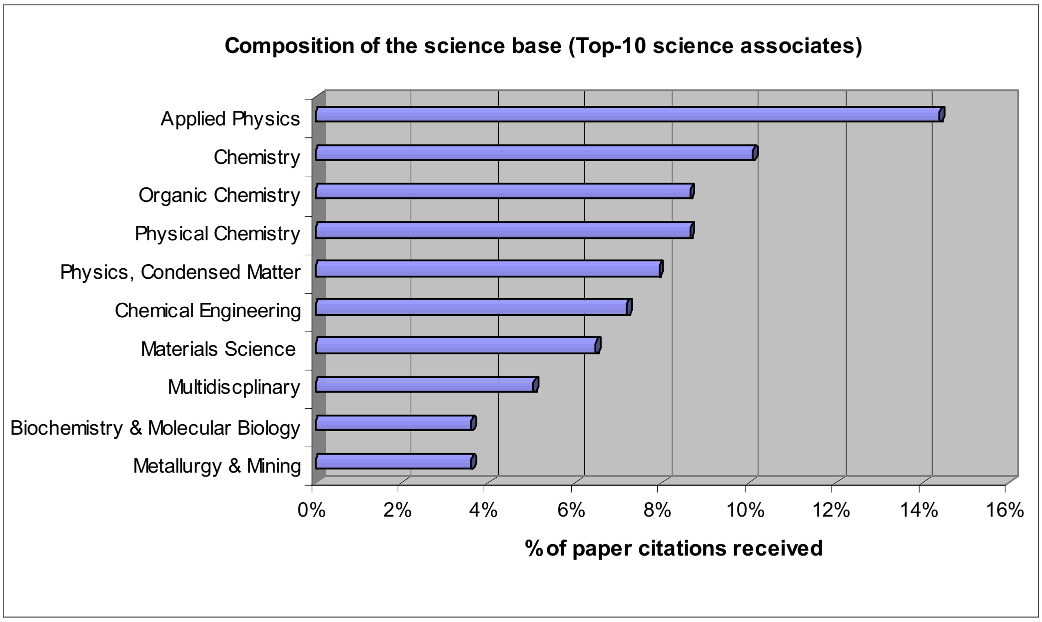


F. Analysis of the S&T interaction in Nanotechnology

F.1. Research areas of importance for Nanotechnology

Through application of the S&T linkage methodology, the science associates of Nanotechnology, i.e. the science areas of importance for the development of the field, have been analysed. In figure 32, the 10 most important science areas related to Nanotechnology are presented according to their importance, i.e. based on the percentage of total science citations received in the period 1992-1996. These 10 domains (Applied Physics, Chemistry, Organic Chemistry, Physical Chemistry, Condensed Matter Physics, Chemical Engineering, Materials Science, Multidisciplinary, Biochemistry & Molecular Biology, Metallurgy & Mining) account for almost 85% of all science interactions, implying that the science interaction in Nanotechnology is rather concentrated. Nevertheless, the total number of interacting science domains is 38. In appendix 1 we present a complete overview of the science associates of Nanotechnology.

Figure 32 – Science associates of 'Nanotechnology'



The most important area of research, measured by the number of science references identified, is Applied Physics that receives about 14% of all paper citations. Research in the area of Chemistry receives 10% of all citations. Organic Chemistry accounts for 9% of all science interactions. Physical Chemistry and Condensed Matter Physics respectively account for 9% and 8% of all paper citations. The research domain of Chemical Engineering accounts for 7% of all science interactions, whereas Materials Science and Multidisciplinary research respectively receive about 7% and 6% of all citations. Biochemistry & Molecular Biology just like Metallurgy & Mining are research areas that receive about 4% of all paper citations in Nanotechnology.

F.2 Regional publication activity in the major 'science associates' of Nanotechnology

In this section, we elaborate on the publication activity of each of the 'Triad' regions in the science domains that are related to the field of Nanotechnology (based upon the EPO data). Keeping in mind that in several cases the number of interacting science fields of a certain component technology exceeds 100, a threshold has been set to analysing all science areas that account for more that 5% of all science interactions of the IPC-class based component technology in examined (read: 5% of journal paper citations). For more background on the 'direct approach' and the importance of the analysis of the publication activity, we refer to section C2 (Part I).

Based on the EPO data, we conclude that the science domains of Applied Physics, Chemistry, Organic Chemistry, Physical Chemistry, Condensed Matter Physics, Chemical Engineering, Materials Science, and Multidisciplinary, each account for more than 5% of all science interactions (the threshold-value).

In regard of the frequency distributions listed in Appendix I, a comparative statistical analysis of the top-10 science domains of the science bases of USPTO-patents versus the EPO-patents has been conducted. The top-10 science domains based on the EPO-data account for 75,5% of all journals cited in EPO-patents. The top-10 science domains based on the USPTO-data account for 83,2% of all journal citations present in USPTO patents. Of the top-10 science domains in both databases, 7 overlap between the databases. A Mann-Whitney U-test performed on the top-10 science domain ranking across both patenting systems reveals no statistically significant difference between the top-10 rankings (Mann-Whitney U-test: z-value=0,83 – p-value=0,41, n.s.).

In view of the assumed importance of the research performed in these science domains to the development of Nanotechnology, the publication performance of each of the 'Triad' regions in these domains is highlighted in the next paragraphs.

Science Domain: Applied Physics (370)

Table 33 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	3134	3708	3381	3663	4254	4243	4917	6138	5388	5375
US	4606	5268	5219	5334	6148	5368	5785	5610	5036	4814
Japan	2377	1998	2510	2392	3451	2676	3369	3506	3135	3490
World	13978	15396	15750	16128	18990	16830	19188	21814	19354	19692

Figure 33 – Evolution in the publication activity of each of the 'Triad' regions

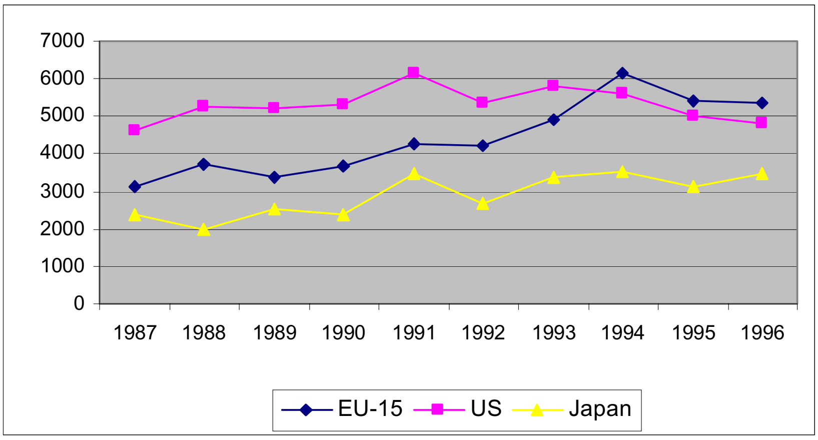
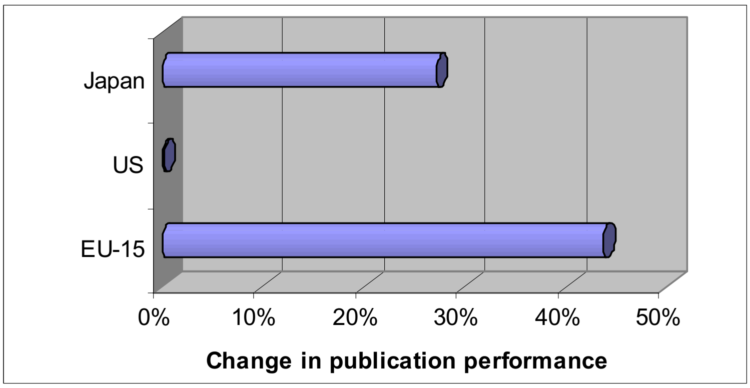


Table 34 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	22,42%	24,08%	21,47%	22,71%	22,40%	25,21%	25,63%	28,14%	27,84%	27,30%
US	32,95%	34,22%	33,14%	33,07%	32,37%	31,90%	30,15%	25,72%	26,02%	24,45%
Japan	17,01%	12,98%	15,94%	14,83%	18,17%	15,90%	17,56%	16,07%	16,20%	17,72%

Figure 34 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Chemistry (286)

Table 35 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	4932	4791	4945	4878	5027	5051	5279	5585	5661	5623
US	4309	4106	4570	4438	4748	5007	4976	5029	5034	4994
Japan	2558	2344	2506	2285	2456	2389	2342	2455	2214	2186
World	18982	18331	19444	18966	19308	19887	20192	20832	19905	19294

Figure 35 – Evolution in the publication activity of each of the 'Triad' regions

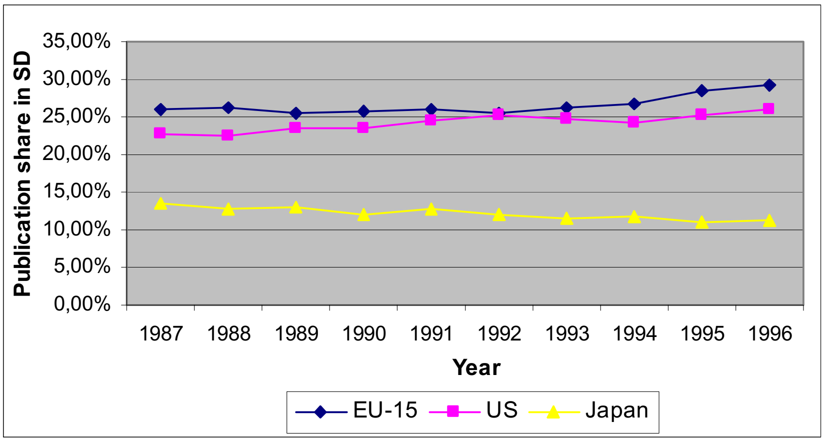
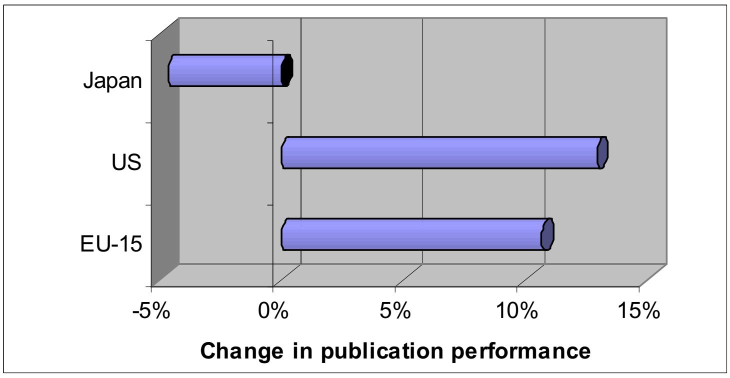


Table 36 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	25,98%	26,14%	25,43%	25,72%	26,04%	25,40%	26,14%	26,81%	28,44%	29,14%
US	22,70%	22,40%	23,50%	23,40%	24,59%	25,18%	24,64%	24,14%	25,29%	25,88%
Japan	13,48%	12,79%	12,89%	12,05%	12,72%	12,01%	11,60%	11,78%	11,12%	11,33%

Figure 36 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Organic Chemistry (289)

Table 37 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	4023	4318	4197	4435	4818	4535	4734	5156	5219	5194
US	2547	2923	2665	2783	2902	2947	3305	3092	3219	2905
Japan	1248	1209	1300	1556	1461	1438	1434	1603	1677	1652
World	11135	11884	11752	12451	12961	12106	12763	13221	13484	12878

Figure 37 – Evolution in the publication activity of each of the 'Triad' regions

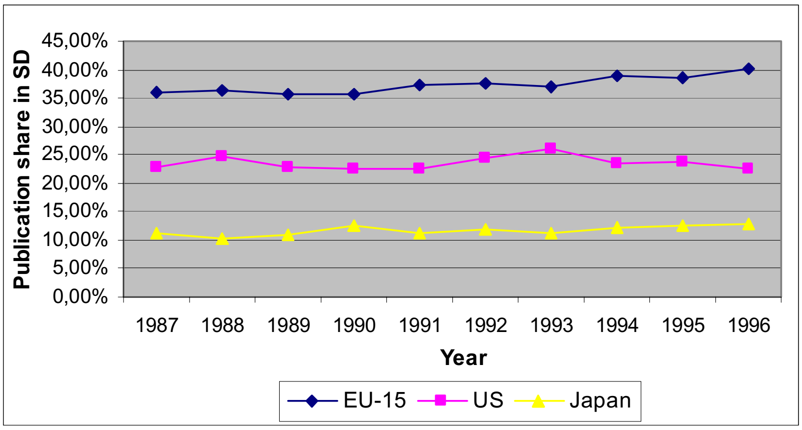
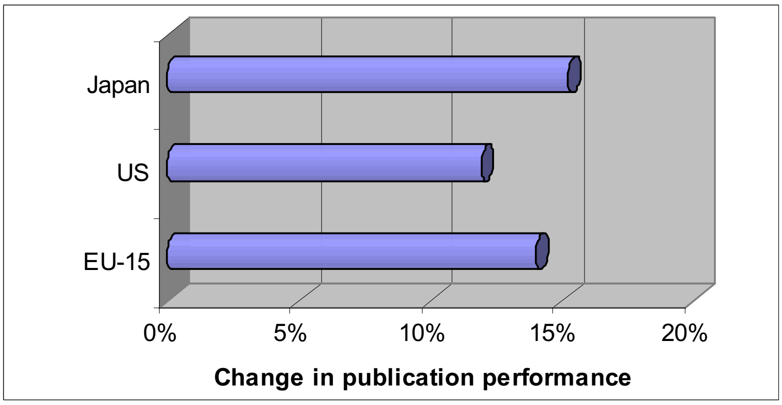


Table 38 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	36,13%	36,33%	35,71%	35,62%	37,17%	37,46%	37,09%	39,00%	38,71%	40,33%
US	22,87%	24,60%	22,68%	22,35%	22,39%	24,34%	25,90%	23,39%	23,87%	22,56%
Japan	11,21%	10,17%	11,06%	12,50%	11,27%	11,88%	11,24%	12,12%	12,44%	12,83%

Figure 38 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Physical Chemistry (290)

Table 39 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	5376	5612	5778	6112	7321	7205	8810	8619	9137	8343
US	3124	3352	3541	3690	4381	4284	4614	4659	4523	4432
Japan	1192	1116	1308	1212	1542	1637	2049	1804	2286	1964
World	14229	15215	16145	16488	19400	18842	21959	21449	23102	20981

Figure 39 – Evolution in the publication activity of each of the 'Triad' regions

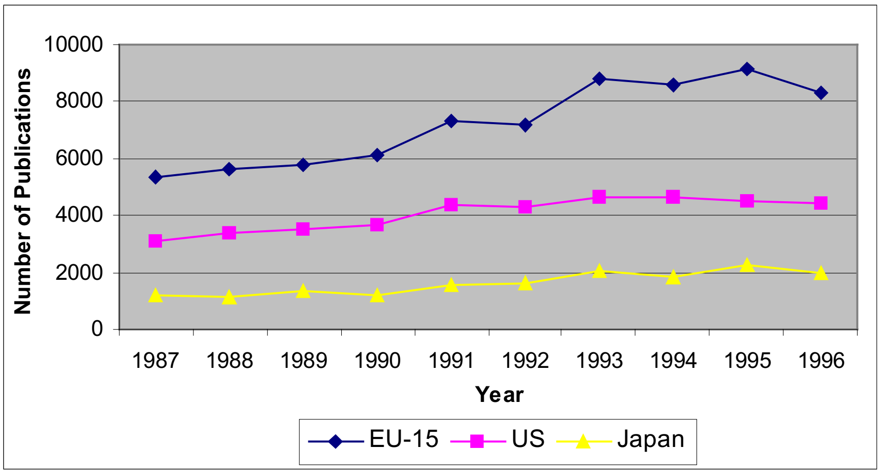
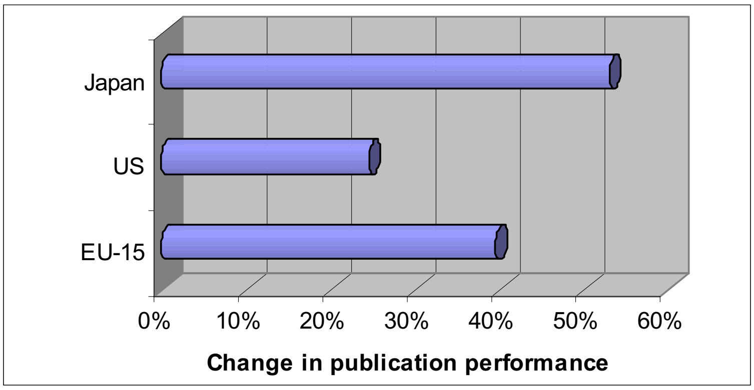


Table 40 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	37,78%	36,88%	35,79%	37,07%	37,74%	38,24%	40,12%	40,18%	39,55%	39,76%
US	21,96%	22,03%	21,93%	22,38%	22,58%	22,74%	21,01%	21,72%	19,58%	21,12%
Japan	8,38%	7,33%	8,10%	7,35%	7,95%	8,69%	9,33%	8,41%	9,90%	9,36%

Figure 40 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Condensed Matter Physics (372)

Table 41 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	3564	4401	5449	5311	5117	6183	6148	7193	6391	6344
US	2522	3061	3214	3052	3083	3325	3423	3664	3143	2688
Japan	588	785	1155	1245	943	1280	1531	1637	1516	1780
World	10902	13215	15127	15519	14430	16426	16964	19144	17205	16617

Figure 41 – Evolution in the publication activity of each of the 'Triad' regions

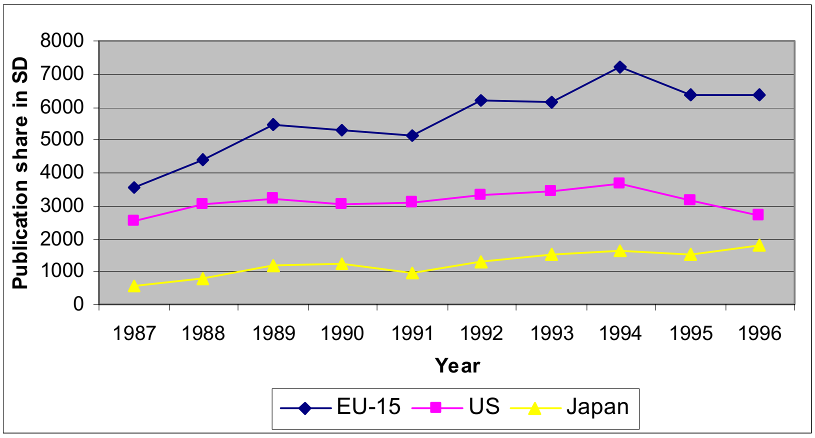
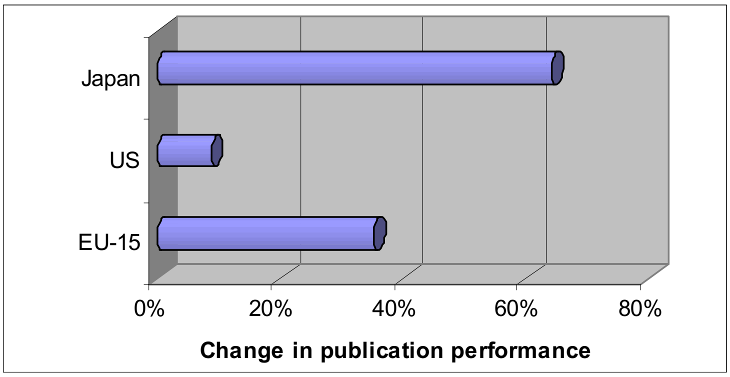


Table 42 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	32,69%	33,30%	36,02%	34,22%	35,46%	37,64%	36,24%	37,57%	37,15%	38,18%
US	23,13%	23,16%	21,25%	19,67%	21,37%	20,24%	20,18%	19,14%	18,27%	16,18%
Japan	5,39%	5,94%	7,64%	8,02%	6,53%	7,79%	9,02%	8,55%	8,81%	10,71%

Figure 42 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Chemical Engineering (310)

Table 43 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	1541	1367	1540	1474	1760	2011	2174	1926	2345	2677
US	2186	1956	1817	1760	1838	1895	1811	1796	1833	1944
Japan	502	615	613	550	590	690	626	798	687	995
World	5862	5631	5685	5605	6191	6601	6672	6692	7121	7898

Figure 43 – Evolution in the publication activity of each of the 'Triad' regions

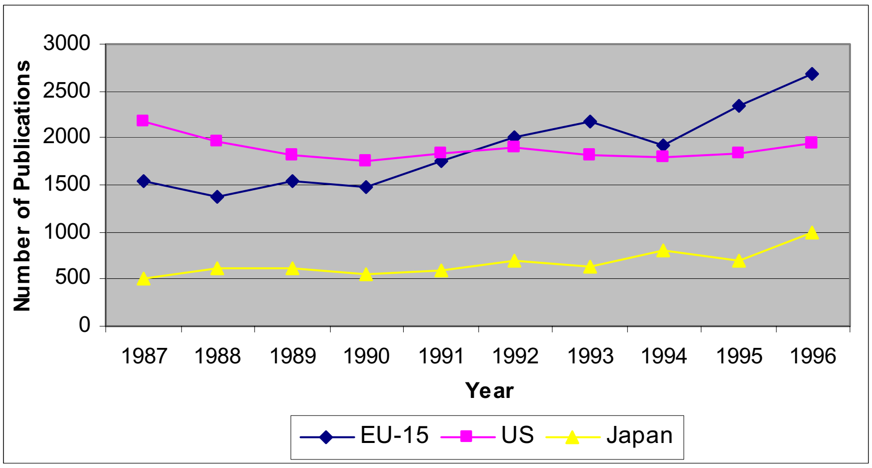
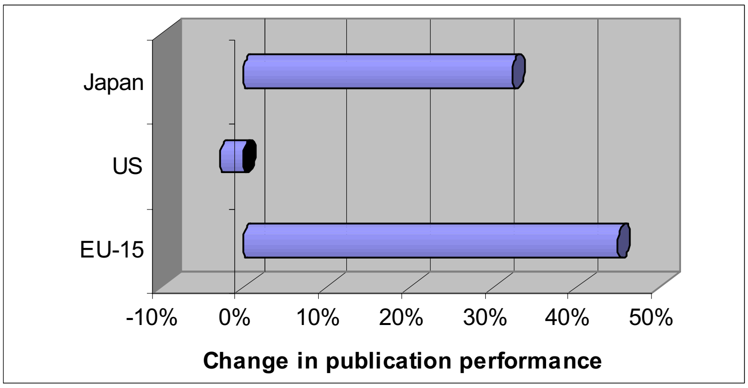


Table 44 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	26,29%	24,28%	27,09%	26,30%	28,43%	30,47%	32,58%	28,78%	32,93%	33,89%
US	37,29%	34,74%	31,96%	31,40%	29,69%	28,71%	27,14%	26,84%	25,74%	24,61%
Japan	8,56%	10,92%	10,78%	9,81%	9,53%	10,45%	9,38%	11,92%	9,65%	12,60%

Figure 44 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Materials Science (334)

Table 45 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	1911	2054	2292	2300	3474	4763	4603	4878	5595	4975
US	1513	1610	1722	2299	2752	3383	3224	3382	3705	2957
Japan	633	704	753	1005	1044	1500	1621	1661	1802	1751
World	5908	6423	6748	8091	10451	13661	13620	14514	16677	14476

Figure 45 – Evolution in the publication activity of each of the 'Triad' regions

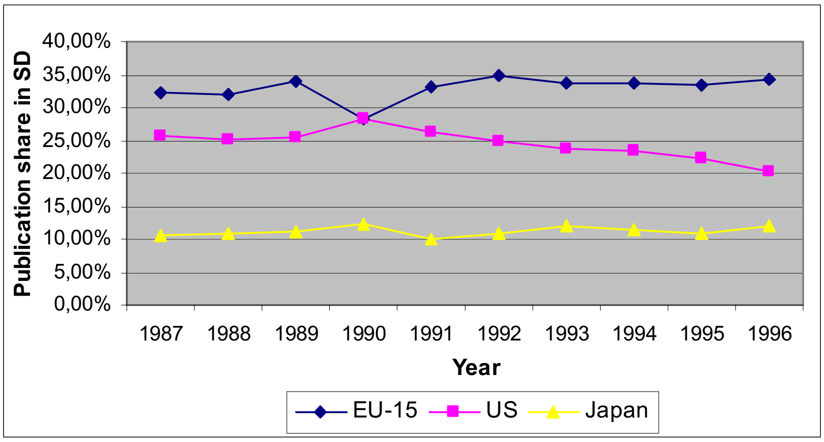
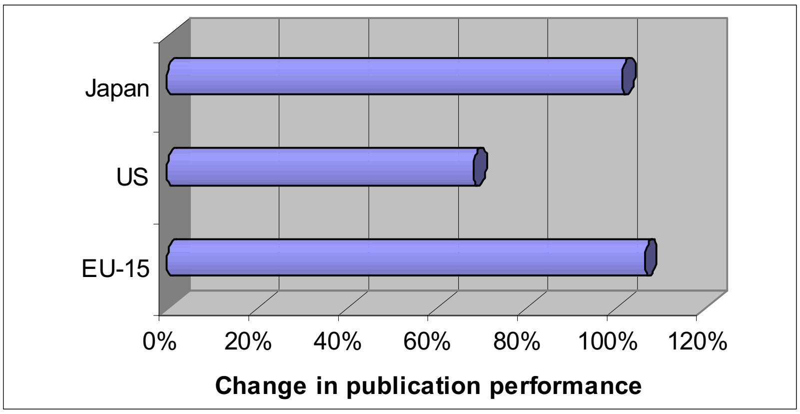


Table 46 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	32,35%	31,98%	33,97%	28,43%	33,24%	34,87%	33,80%	33,61%	33,55%	34,37%
US	25,61%	25,07%	25,52%	28,41%	26,33%	24,76%	23,67%	23,30%	22,22%	20,43%
Japan	10,71%	10,96%	11,16%	12,42%	9,99%	10,98%	11,90%	11,44%	10,81%	12,10%

Figure 46 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



Science Domain: Multidisciplinary (350)

Table 47 – 'Triad' comparison of the publication performance (absolute figures)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	4473	4516	4011	4043	4145	4138	4108	4182	3799	3429
US	6851	6522	6422	6731	6768	6724	6864	6779	6614	6228
Japan	410	350	407	515	432	477	557	442	519	395
World	18726	17857	17008	17296	16421	15664	15397	15398	14908	12975

Figure 47 – Evolution in the publication activity of each of the 'Triad' regions

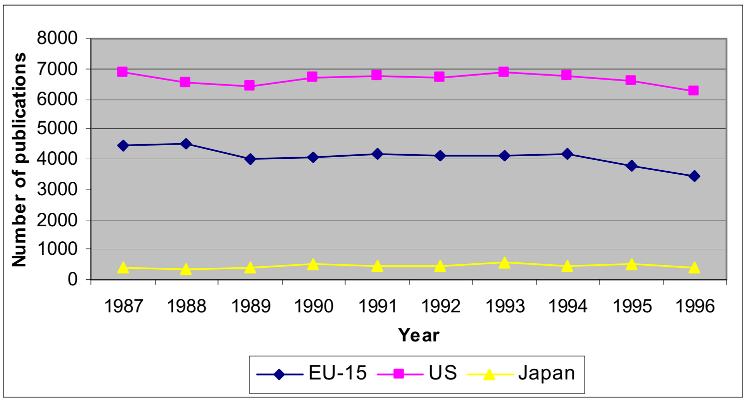
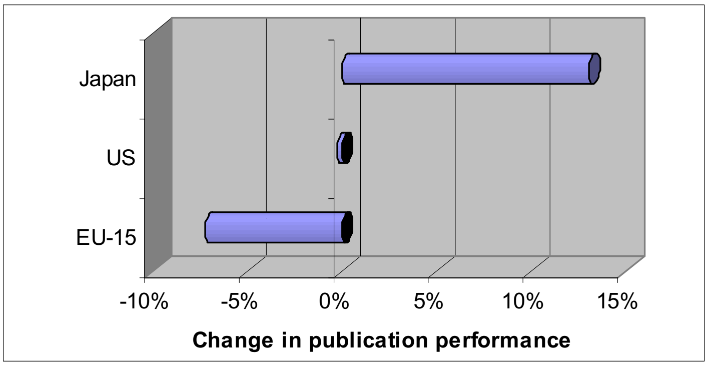


Table 48 – 'Triad' comparison of the publication shares

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
EU-15	23,89%	25,29%	23,58%	23,38%	25,24%	26,42%	26,68%	27,16%	25,48%	26,43%
US	36,59%	36,52%	37,76%	38,92%	41,22%	42,93%	44,58%	44,03%	44,37%	48,00%
Japan	2,19%	1,96%	2,39%	2,98%	2,63%	3,05%	3,62%	2,87%	3,48%	3,04%

Figure 48 – Change in the publication performance of each of the 'Triad' between 1987-1991 and 1992-1996



F.3. Science linkage intensity at the country level

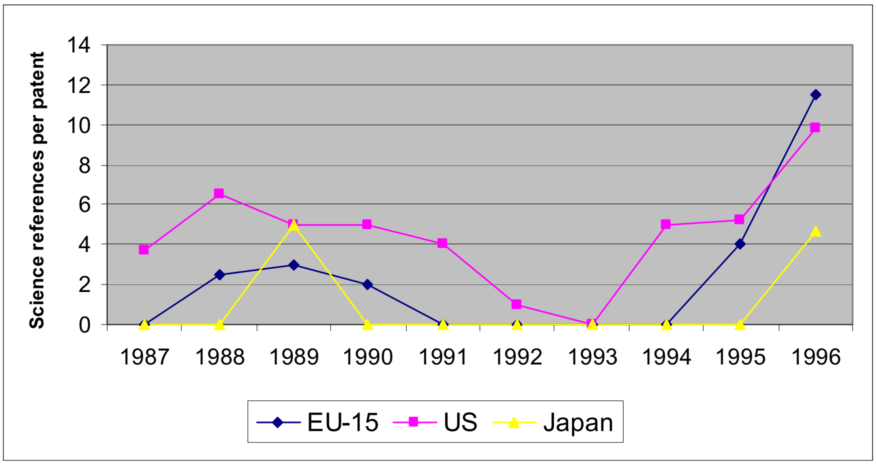
In the remainder of this report, the discussion will focus on the citations to scientific publications. As already mentioned, the NPR-intensity can be seen as a stable indicator of the degree of science dependency. The citations to scientific publications, however, are more directly connected to the intensity of the science interaction, as these publications are the main medium of disclosure of scientific findings within the scientific community. In table 49 we present the science linkage intensity, i.e. the average number of scientific papers cited in patents (also 'propensity-to-cite') of respectively EU-15, US, and Japan-originated patents. The period of analysis is 1987-1996.

Table 49 – Propensity-to-cite on a country level

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*
B	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
D	0,00	2,50	0,00	0,00	0,00	0,00	0,00	0,00	4,00	11,50
F	0,00	0,00	3,00	2,00	0,00	0,00	0,00	0,00	0,00	0,00
FIN	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
L	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
NL	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
S	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
UK	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
EU-15	0,00	2,50	3,00	2,00	0,00	0,00	0,00	0,00	4,00	11,50
US	3,67	6,50	5,00	5,00	4,00	1,00	0,00	5,00	5,25	9,83
JP	0,00	0,00	5,00	0,00	0,00	0,00	0,00	0,00	0,00	4,67

The highest and most stable propensity-to-cite science ratio (average number of paper citations per patents) is present in US-inventor patents. In the case of European inventor patents, we observe a turbulent development in the science intensity over the years studied in this analysis. Over the years 1991-1994, no science interaction could be identified by the direct linkage approach. In 1996 however, we observe a high propensity-to-cite (11,5 paper citations per patent), fully attributable to the German patents related to Nanotechnology (Germany also plays a major role in terms of numbers of patents). In the case of Japan, we also observe a rather limited science interaction. Within Europe, the presence of science interaction is also highly varied and unstable. Figure 49 displays the evolution in the science domain interaction intensity for each of the 'Triad' regions.

Figure 49 – Propensity-to-cite science: comparison of the number of paper citations per patent among the 'Triad' regions



F.4. Research orientation of Nanotechnology (basic vs. applied)

As to the EPO-based research orientation of Nanotechnology (cf. C.4), we find that basic scientific research takes a prominent position. In the first place it has to be pointed out that the absolute number of journal citations present in European Patents is lower that in the USPTO-patents. As a consequence, the interpretation of the findings has to take this into consideration. Nevertheless, by observing the research-type composition for the period 1992-1996 (see table 51), it is clear that more than 65% of the science interaction concerns basic scientific research. In 17% of all science interactions, applied research-targeted basic research, i.e. basic research with an applied focus, is cited. In almost 4% of all interactions applied research is cited in Nano-related patent documents. Finally, engineering science-technological science is the type of research disclosed and cited in about 14% of all interactions.

Benchmarking these findings with the distribution of the type of research cited in the period 1987-1991 (table 50) leads to a rather different pattern. During that period, basic science accounts for only 31% of all interactions, applied research for 0%, targeted basic research for almost 52%, and finally, engineering science-technological science is cited in 17% of all science interactions. In comparison to the first period, we find that during the second period, the importance of basic scientific research in relation to Nanotechnology has increased sharply, whereas the importance of applied research-targeted basic research increased by almost 34%. Engineering science-technological science remained quite stable in comparison to the evolutions in basic and basic targeted research. Applied research started to play a role in the second period, a phase in which also the number of patents in Nanotechnology strongly increased.

Table 50 - Characterisation of the science interaction of patents in Nanotechnology (1987-1991)

Type of research cited	*1987*	*1988*	*1989*	*1990*	*1991*	*Total*
Applied research-targeted basic research	51,72%	50,00%	22,22%	0,00%	42,86%	51,72%
Applied technology	0,00%	0,00%	22,22%	50,00%	7,14%	0,00%
Basic scientific research	31,03%	42,86%	11,11%	50,00%	32,14%	31,03%
Engineering science-technological science	17,24%	7,14%	44,44%	0,00%	17,86%	17,24%

Table 51 - Characterisation of the science interaction of patents in Nanotechnology (1992-1996)

Type of research cited	*1992*	*1993*	*1994*	*1995*	*1996*	*Total*
Applied research-targeted basic research	100,00%	0,00%	0,00%	11,76%	18,75%	17,31%
Applied technology	0,00%	0,00%	0,00%	0,00%	6,25%	3,85%
Basic scientific research	0,00%	0,00%	0,00%	88,24%	59,38%	65,38%
Engineering science-technological science	0,00%	0,00%	100,00%	0,00%	15,63%	13,46%

F.5. Cross-national citation behaviour (geographical distribution of the knowledge spill-over)

A highly interesting feature of the science and technology interaction is to analyse the relation between individual countries in terms of knowledge ‘providers’ and knowledge ‘users’. Knowledge ‘user’ is defined as the country of origin of the inventor of the patent involved in a certain technology area. Knowledge ‘provider’ is defined as the country of origin of the scientific publications cited in the patent documents, at present operationalised via the country of the institutional affiliation of the author(s) on the journal publication(s). This type of analysis again illustrates the knowledge flows and science-technology spill-over between countries.

Unfortunately, due to the limited available data it has proved necessary to integrate the two analytical periods (1987-1991 and 1992-1996) into one period (1987-1996) for which the cross-national citation analysis has subsequently been performed. Using this approach, a higher number of cross-citations became available to analyse. The results are presented in table 52.

The percentages are based on the total number of science interactions a country accounts for (the row total). Please note the 'EU'-country group is aggregated in the tables. Furthermore, on the 'provider' side (measured via the country of the inventor of the patent) only the EU-15 countries have been positioned, as we are interested in the further characteristics of the EU-15 science base (see figure 50 for a 'Triad' comparison). German inventors (row: D) cite EU-originated publications in 60% (EU 25% and D 35%) of all paper citations, implying that for technological development in the area of Nanotechnology, Germany is to a large extent EU-oriented (1987-1991), and moreover, focused on the utilisation of it's own science base. The results are expected to be biased by the limited number of identified paper citations present in EU-15 patents.

Table 24 – Overview of the cross citation practice between EU-15 countries, US and Japan (1987-1996)

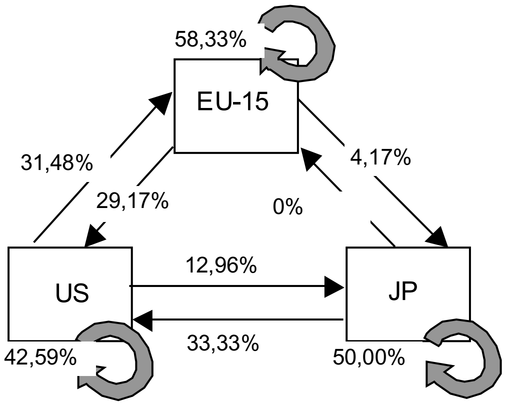
From : inventor country (technology origin)[1]
To : author institutional affiliation country (science origin)

	D	EU	F	JP	US
D	35,00%	25,00%	0,00%	5,00%	35,00%
F	0,00%	25,00%	25,00%	0,00%	0,00%

1. *The absence of the other European countries implies that no science interactions have been identified for these countries*
2. *Due to the sparsely available data the two periods (1987-1991 and 1992-1996) have been combined to one (1987-1996)*

In figure 50, we have summarized the knowledge spillovers between the 'Triad' regions for the period 1992-1996.

Figure 50 - 'Triad' comparison of knowledge 'providers' and 'users' in % for the period 1987-1996



Whereas European invented EPO-patents cite US-originated research in 29,17% of all their science citations (i.e. EPO-patents citing the scientific literature), the reverse is the case in 31,48% of all science citations present in the US-inventor EPO-patents. This implies that the importance of European science for US technological development in Nanotechnology is substantial, a finding that coincides with the publication performance of the EU-15 countries in the science associated of Nanotechnology (cf. C.2), as well as with the findings that resulted from the analysis of USPTO nano-patents. US-originated research is of major importance for Japanese technological development (33,33%). There were no cases identified in which Japanese inventors cite EU-15 originated research. Japanese research, in turn, is only marginally cited by US- and European inventors (respectively 12,96% and 4,17%). Almost 43% of all relevant knowledge deployed in US-technological development (measured via EPO-patents) is also from US-origin. European inventors in EPO-patents 'utilize' European research in more than 58% of all their science citations, which supports the assumption that European research in Nanotechnology is of high significance for European technological development. Japanese inventors utilize their own research in half of all paper citations present patent documents.

F.6. Type of research cited by the 'Triad' regions

Whereas the previous sections focused on the origin of the cited papers and patents in order to obtain a first analysis of the relationships between individual countries and regions (in the sense of relevant knowledge 'providers' and 'users' for technological development), the next sections will further analyze the specific type of research exchange between the 'Triad' regions. The majority of the papers cited in Nanotechnology concern basic research. Figures 51 to 53 illustrate (in more detail), the type of research cited by each of the major regions.

Figure 51 - Evolution in the type of research cited by European inventors (EU-15)

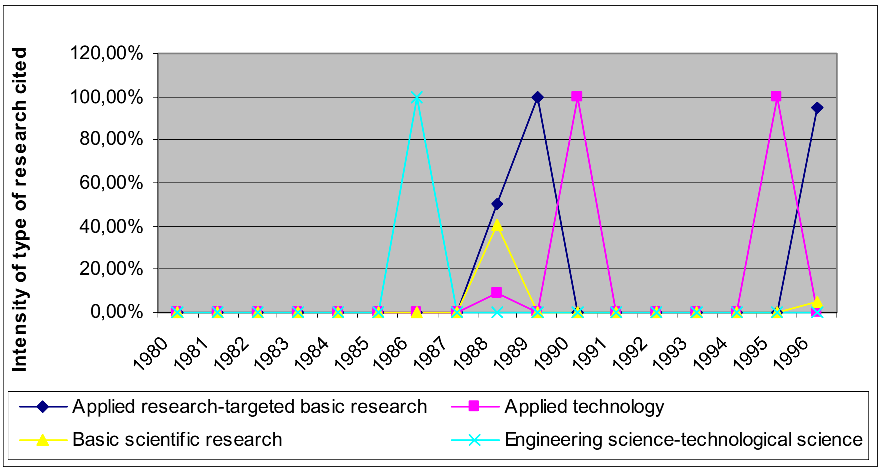


Figure 52 - Evolution in the type of research cited by US-inventors

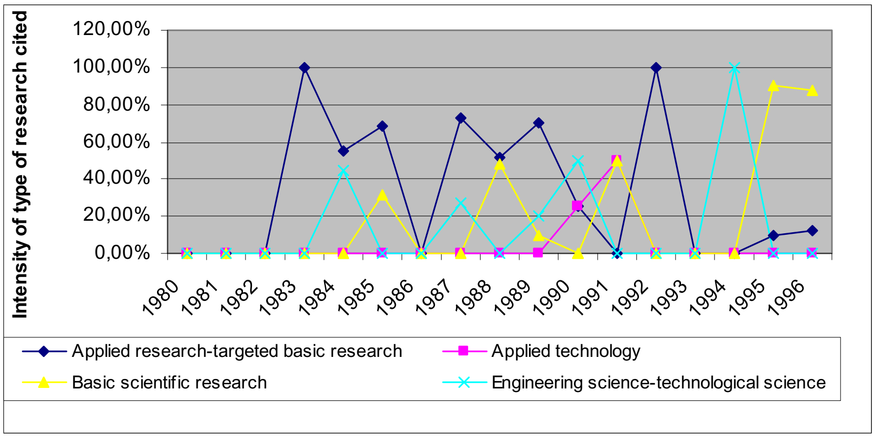
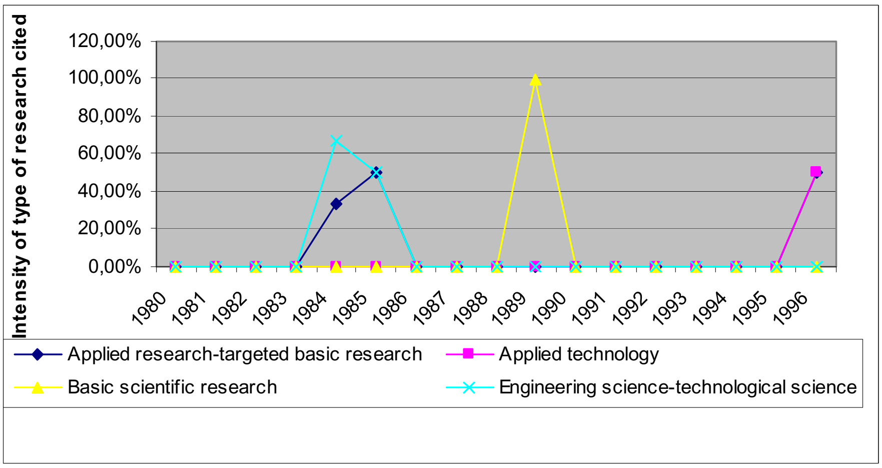


Figure 53 - Evolution in the type of research cited by Japanese inventors



Again, one should keep in mind the limited available data as one of the possible causes of the turbulent development in the type of research cited.

F.7. Type of research and local citation spill-over between the 'Triad' regions

In section F5, we discussed the intensity with which EU inventors cite US and Japan originated research. Looking at the patenting performance presented in table 29a and 29b, we see that Europe performs well, even better than the US and Japan. At the same time, we see that the EU-15 also perform well in terms of scientific publications in the fields related to Nanotechnology. Based on the 'direct' linkage approach however, a clear and direct picture of the interrelation cannot be obtained, as discussed previously given the emerging character of nanotechnology. Nevertheless, in this section, the characteristics of the knowledge exchange between the 'Triad' regions is further analysed and refined in terms of the type of research that is utilized and produced by the respective regions. In other words, the relationship between 'providers' and 'users' of specific types of research along the continuum 'basic' to 'applied' is examined. In figures 54 to 57, we present the origin of the type of research constituting the science base for each of the 'Triad' regions. Note that the lack of data in a specific type of research in the graphs implies that for the regions examined no citations to that specific type of research have been observed.

Figure 29 – Origin of the research-type composition of the EU-15 science base in Nanotechnology (1992-1996)

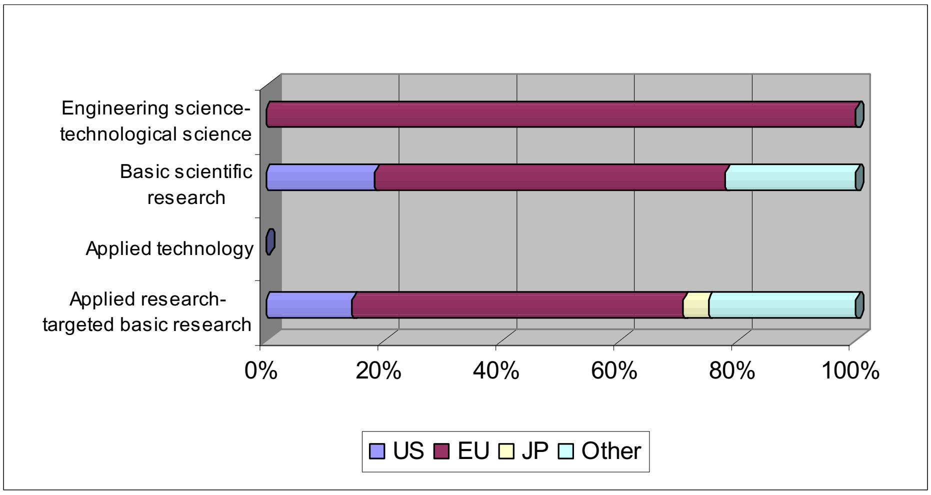


Figure 30 – Origin of the research-type composition of the US science base in Nanotechnology (1992-1996)

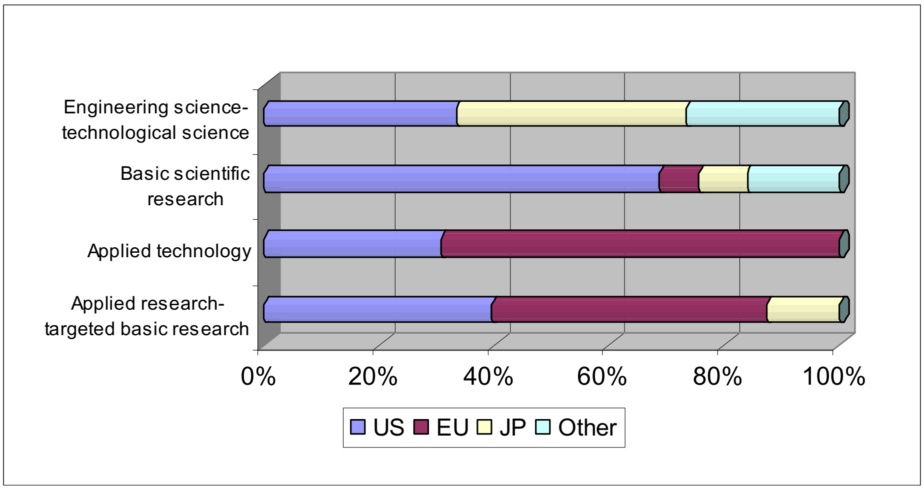
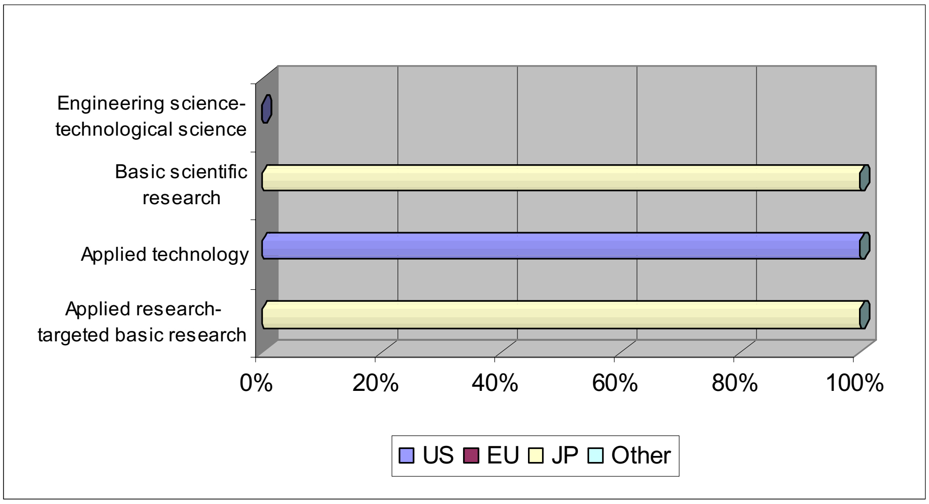


Figure 31 – Origin of the research-type composition of the Japanese science base in Nanotechnology (1992-1996)



As we can see in the graphs presented above, Europe succeeds in 'providing' in the necessary research relevant for EU-technological development in Nanotechnology. In the US-science base we can observe that Europe contributes to the presence of applied and applied research-targeted basic research.

5. CONCLUSIONS

Based on the USPTO and EPO patent data, a steep increase in the number of nanotechnology patents and their non-patent references (applications and grants) is observable during the early 1990s. As from 1992, the EU-15 have been catching up and even managed to incorporate a higher science interaction in the following years. At a EU-member state level, we see that in the Nanotechnology field Germany, France and the UK hold the highest number of NPRs, just as they hold the highest number of patents. Summarizing the numbers, the US holds the highest number of Nano-patents, followed by EU-15 and the Developed Asian countries. Focusing on the EPO-data however, the difference in granting performance is small. The patenting success ratio of the EU-15 amounts to 1:3,11 vs. 1:3,66 for the NAFTA (1 patent granted per 3,11 applications). The EFTA countries seem also highly effective in that regard by obtaining 1 successful patent for every 1,5 application. As far as the propensity-to-NPR is concerned (avg. number of NPRs per patent), the EU-15 and US patents interchangeably show the highest propensity. In 1995 (based on EPO data), EU-15 patents show a propensity of 2,96, whereas US patents and Japanese patents respectively display a propensity of 2,42 and 1,79 (cf. B3 and E3).

The science base of Nanotechnology, i.e. the research bases of great importance to the development the field, consists of Chemistry, Physics, Materials Science, Multidisciplinary (in view of the still developing field of Nanotechnology during which development the research input is still coming from different backgrounds and disciplines), and Instruments & Instrumentation. The composition differs slightly depending on the source (EPO or USPTO) data (cf. C1 and F1), although no statistically significant differences can be observed. The patenting performance in Nanotechnology has been contrasted with the publication performance in the science base.

In quite some of those science domains, we see that EU-15 perform very well, in several instances it outperforms the US and/or Japan. As such, in terms of scientific performance, the EU-15 excels (cf. C2 and F2). This is also reflected in the Triad relationship when looking at the importance of EU research for the Triad partners (cross citation; cf. C5 and F5). Between 30%-to-35% of all paper citations present in US-invented patents (both in the USPTO- and the EPO-system) and Japanese-invented patents (in the USPTO-system) concern EU-originated research. Thus, the utilisation of EU-research seems widespread, thereby keeping in mind that EU-inventors also utilize EU-research over 40% of all their science interactions (both in the USPTO- and the EPO-system). Finally, in terms of type of research cited, a high diversity occurs across all inventor regions, both in the USPTO- and the EPO-systems.

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APPENDIX I – OVERVIEW OF THE SCIENCE ASSOCIATES OF NANOTECHNOLOGY (BASED ON USPTO)

Science Domain	% Citations received	Cumulative
CHEMISTRY PHYSICAL	20,81%	20,81%
MULTIDISCIPLINARY	16,15%	36,96%
PHYSICS, APPLIED	16,15%	53,11%
ENGINEERING, CHEMICAL	7,76%	60,87%
PHYSICS, CONDENSED MATTER	5,90%	66,77%
PHYSICS GENERAL	4,66%	71,43%
CHEMISTRY	4,04%	75,47%
MATERIALS SCIENCE	3,73%	79,19%
POLYMER SCIENCE	2,17%	81,37%
INSTRUMENTS & INSTRUMENTATION	1,86%	83,23%
PHARMACOLOGY & PHARMACY	1,55%	84,78%
CHEMISTRY ORGANIC	0,93%	85,71%
ENGINEERING, ELECTRICAL & ELECTRONIC	0,93%	86,65%
MEDICINE GENERAL & INTERNAL	0,93%	87,58%
MEDICINE, RESEARCH & EXPERIMENTAL	0,93%	88,51%
MICROBIOLOGY	0,93%	89,44%
MINERALOGY	0,93%	90,37%
ACOUSTICS	0,62%	90,99%
CHEMISTRY, INORGANIC & NUCLEAR	0,62%	91,61%
COMPUTER APPLICATIONS & CYBERNETICS	0,62%	92,24%
ELECTROCHEMISTRY	0,62%	92,86%
ENERGY & FUELS	0,62%	93,48%
ENGINEERING	0,62%	94,10%
ENVIRONMENTAL SCIENCES	0,62%	94,72%
IMMUNOLOGY	0,62%	95,34%
MATERIALS SCIENCE CERAMICS	0,62%	95,96%
PHOTOGRAPHIC TECHNOLOGY	0,62%	96,58%
BIOCHEMISTRY & MOLECULAR BIOLOGY	0,31%	96,89%
BIOPHYSICS	0,31%	97,20%
CANCER	0,31%	97,52%
CHEMISTRY ANALYTICAL	0,31%	97,83%
CYTOLOGY & HISTOLOGY	0,31%	98,14%
ENDOCRINOLOGY & METABOLISM	0,31%	98,45%
ENGINEERING BIOMEDICAL	0,31%	98,76%
METALLURGY & MINING	0,31%	99,07%
OPTICS	0,31%	99,38%
PEDIATRICS	0,31%	99,69%
PHYSICS, GENERAL	0,31%	100,00%

APPENDIX II – OVERVIEW OF THE SCIENCE ASSOCIATES OF NANOTECHNOLOGY (BASED ON EPO)

Science Domain	**% Citations received**	**Cumulative**
PHYSICS, APPLIED	14,39%	14,39%
CHEMISTRY	10,07%	24,46%
CHEMISTRY ORGANIC	8,63%	33,09%
CHEMISTRY PHYSICAL	8,63%	41,73%
PHYSICS, CONDENSED MATTER	7,91%	49,64%
ENGINEERING, CHEMICAL	7,19%	56,83%
MATERIALS SCIENCE	6,47%	63,31%
MULTIDISCIPLINARY	5,04%	68,35%
BIOCHEMISTRY & MOLECULAR BIOLOGY	3,60%	71,94%
METALLURGY & MINING	3,60%	75,54%
PHARMACOLOGY & PHARMACY	3,60%	79,14%
MATERIALS SCIENCE CERAMICS	2,88%	82,01%
PHYSICS, ATOMIC, MOLECULAR & CHEMICAL	2,88%	84,89%
CANCER	1,44%	86,33%
CHEMISTRY ANALYTICAL	1,44%	87,77%
COMPUTER APPLICATIONS & CYBERNETICS	1,44%	89,21%
ENTOMOLOGY	1,44%	90,65%
IMMUNOLOGY	1,44%	92,09%
MINERALOGY	1,44%	93,53%
OPTICS	1,44%	94,96%
SURGERY	1,44%	96,40%
CRYSTALLOGRAPHY	0,72%	97,12%
ELECTROCHEMISTRY	0,72%	97,84%
ENGINEERING, ELECTRICAL & ELECTRONIC	0,72%	98,56%
PHYSICS GENERAL	0,72%	99,28%
POLYMER SCIENCE	0,72%	100,00%