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Performance of ICT R&D

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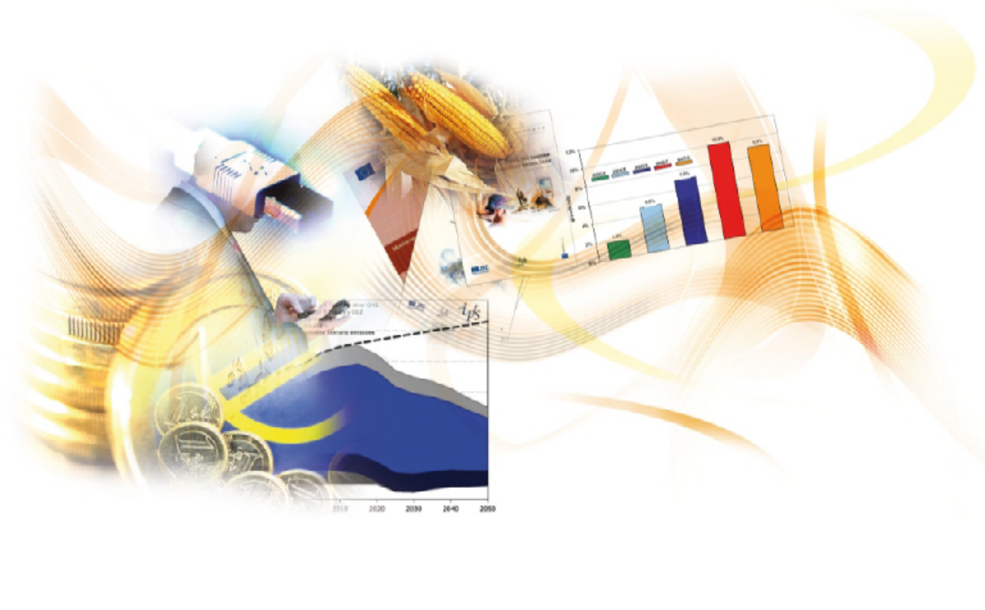

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The mission of the JRC-IPTS is to provide customer-driven support to the EU policy-making process by developing science-based responses to policy challenges that have both a socio-economic as well as a scientific/technological dimension.

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Preface

It is an indisputable fact that the ICT industry and ICT-enabled innovation in non-ICT industries and services make an important contribution to the economic growth of advanced economies. In the EU, and also in the USA and Japan, the ICT sector is by far the largest R&D-investing sector of the economy. The EU ICT sector is therefore a significant contributor to the ambition of achieving the target of investing 3% of GDP in R&D in the EU. But, when comparing ICT expenditures over GDP, the USA, Japan, and also Taiwan and Korea, are investing significantly more in ICT R&D than the EU. These characteristics and observations have provided the rationale for the PREDICT research work (PREDICT stands for 'Prospective insights on ICT R&D '), which aims to gain a deeper understanding of the dynamics of research in the ICT industrial sector. In turn, this can provide important policy insights and options.

The PREDICT research and analysis has been carried out by the Information Society Unit at JRC-IPTS and co-financed by IPTS and the Information Society & Media Directorate General of the European Commission. PREDICT combines in a unique way three complementary perspectives: national statistics, company data, and technology-based indicators such as patent data. It relies on the latest available official statistics delivered by Member States, Eurostat and the OECD. Where this data still contains gaps, rigorous cross-checking and estimating methods have been applied by JRC-IPTS to provide the study with the necessary set of data. PREDICT results have been reported in a series of report published annually since 2008. This multiannual analysis allows us to confirm the consistency of the data over time and offers a privileged view of the major ICT R&D trends across recent years. PREDICT results have been used, among others, in the preparation of EU policy initiatives aimed to support ICT R&D in Europe.

2011 marks the publication of the fourth annual report. For the first time, this year's PREDICT report is complemented by a series of three thematic reports presenting more detailed analyses of some of the themes included in the annual report, namely: R&D investment by top ICT R&D companies worldwide, performance of ICT R&D analysed through ICT patenting, and internationalisation of ICT R&D. This report presents the results of a multiannual analysis of performance of ICT R&D analysed through ICT patenting.

All reports published under the PREDICT project are available at http://is.jrc.ec.europa.eu/pages/ISG/PREDICT.html

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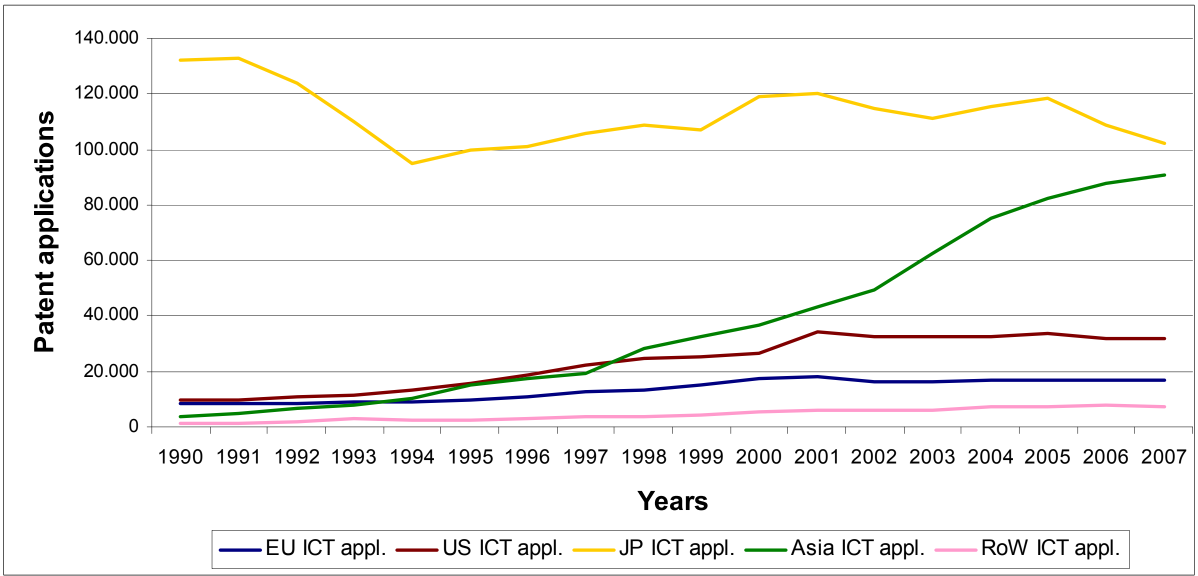
1. Executive Summary

This report analyses ICT R&D by presenting patent statistics as a measure of *output* of the R&D process, and by proposing an economic modelling framework for analysing the *impact* of the R&D processes.

A wide coverage of patent data and a detailed analysis of patent-based indicators allowed for rather detailed comparisons over a long time period of ICT priority patent applications, which were used as proxy measures to investigate the inventive capability at regional and country level.

ICT priority patent applications by EU, US, JP, Asian, and RoW inventors.



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

The annual number of ICT priority patent application by inventors based in the EU has remained stable since the burst of the dot.com bubble in 2001, and a similar pattern can be observed for ICT applications by inventors based in the US (though US absolute values are about twice the EU ones). ICT applications for Japan-based inventors have been slowly decreasing over the last decade, though it was traditionally the geographic area with the highest number of applications for several reasons (from sector specialisation to regulatory framework and policy support).

However, since the early 90's the annual number of ICT priority patent application by inventors based in Asia (excluding Japan) has strongly increased. To give a term of reference, in 2007 about 17 000 ICT priority applications were filed by EU-based inventors, 32 000 were filed by US-based inventors and almost 91 000 (from 3600 in 1990) were filed by Asia-based inventors. Most of this spectacular growth in Asian ICT priority applications can be attributed to two countries: first to South Korea up until 2004, and second to China which had a spectacular increase from 2000, and annual figures that exceeded 40 000 in 2007 - significantly above annual figures for both the EU and US.

When the effect of country size is eliminated by weighting the number of ICT priority applications by number of inhabitants, Japan comes first, followed by the US, with around 100 applications in 2007, the EU with 34 applications, and Asia with 24 applications per million inhabitants.

Within the EU, the countries that file the most patents in ICT are Germany, France and the UK, accounting together for 80% of all ICT priority patent applications by EU-based inventors. Germany-based inventors alone generate half of all ICT applications for the EU. However, when the number of ICT priority patent applications is weighted by number of inhabitants, Finland, Germany and Sweden are the top three performers in the EU.

The second part of this report outlines an economic modelling framework which aims to provide further, in-depth insights into the economic impact of ICT R&D by establishing links between R&D expenditure, invention activities and their impact on the macro economy. The understanding of the processes through which ICT R&D impacts upon growth and employment is a necessary precondition for the development of strategies to stimulate growth and employment through appropriate ICT R&D policies. The explanation must go beyond methods such as growth accounting which is widely used to allocate productivity growth calculations to various related components without, however, giving any insight into causality or motivation of constituent actions.

2. Introduction

This report analyses ICT R&D by presenting patent statistics as a measure of *output* of the R&D process, and by proposing an economic modelling framework for analysing the *impact* of the R&D processes. The chapter builds on previous analyses described in the 2009 Edition of the PREDICT Report (Turlea et al., 2009) (Part 2 – *Thematic Analysis: Output of ICT R&D in the European Union*) and its 2010 edition ((Turlea et al., 2010) (Chapter 7 – *ICT Patents in the European Union*). New developments include wider coverage of patent databases and refined, more detailed analysis of patent statistics described in the first part of this chapter. The second part of this chapter outlines an economic modelling framework with a view to not only modelling the R&D processes, but also establishing a link between R&D expenditure, the invention activities and their impact on the macro economy.

R&D, and particularly ICT R&D, has been prominent in EU policies for more than two decades.[1] As the OECD's Secretary-General Angel Gurría pointed out: "*Investment in science and technology is an investment in the future*".[2] Indeed, ICT R&D expenditure is the money spent on adding to the stock of knowledge and inventing new applications, which ultimately have an impact on living standards.

Measures which are used to proxy the welfare of a society, such as material living standards or GDP per capita, are closely related to productivity levels. Most of the gap in GDP per capita between OECD countries and the US is due to differences in labour productivity levels.[3] As a Nobel Prize winner Paul Krugman put it: "*Productivity is not everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker*".[4] Productivity increase, which is driven by technology and working methods, relies heavily on innovation, human capital and technological change as its main drivers.[5]

The recent economic crisis has also had an impact on R&D spending, which has declined in OECD countries since 2008, with a few exceptions.[6] The increasingly limited resources which can be invested in R&D make *how* those resources are invested even more important. Again, as pointed by Mr Gurría: "*There is also a need to increase the efficiency of this* [R&D] *spending. The right governance structures should be in place if countries are to make the most of the resources devoted to science and technology*"[2]. The more efficient allocation of R&D resources requires not only an understanding of how R&D expenditure turns into invention and innovation, but also how the resulting products and technologies impact on the economy and society.

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1 EU's **Lisbon Agenda** in 2000 with its **mid-term review** in 2005 puts particular accent on ICT R&D; The 2009 Commission's Communication entitled "**A Strategy for ICT R&D and Innovation in Europe: Raising the Game**" proposed a strategy to establish Europe's industrial and technology leadership in ICT. In 2010, the importance of R&D for the EU was clearly reinforced in the Communication from the European Commission "**Europe 2020 – A strategy for smart, sustainable and inclusive growth**" and in two of its Flagship Initiatives: "**Digital Agenda for Europe**" detailing important areas with respect to ICT, and "**Innovation Union**" which clearly expresses the need to "*continue to invest in education, R&D, innovation and ICTs*" but that such investments must be stepped up. It also states that "*reaching 3% of EU GDP on R&D by 2020 could create 3.7 million jobs and increase annual GDP by close to €800 billion by 2025*".

2 (OECD, 2010b).

3 (OECD, 2008).

4 (Krugman, 1997).

5 (OECD, 2008).

6 The countries which increased public spending on R&D were Germany, Korea, Sweden, the USA.

An insight into the nature and the role of technology in the economy[7] allows us not only to appreciate that technological change is one of the sources of economic growth, but also to understand better the sources of technological change and, consequently, how to stimulate it. R&D expenditure and the associated inventive activities play a key role in the development of new technologies and the improvement of existing ones and hence in innovation-based, modern economic growth.[8] ICT, because of their widespread use and large scope for product, process and organizational improvement, constitute a General Purpose Technology,[9] Governments therefore focus their attention on ICT as they have a profound impact on economic growth.

Examples of measures which proxy invention or new knowledge created include the Community Innovation Survey (CIS), and Patent and Trademark statistics. The CIS provides representative data on innovation activities across the EU[10] for product and process innovations for goods and services at the NACE 2-digit level. Patent statistics are particularly informative about inventions specific to ICT. The OECD finds countries with strong specialisation in ICT turning to patents as a prime method of securing rights on new knowledge.[11] Various studies[12] have already addressed the numerous advantages of exploiting patent data as a measure of inventive output. Patent data provide increasingly detailed and wide information on the expected results of research and development efforts and of inventive activity in general. Moreover, the type of information they provide is seen as 'objective', and it offers quantitative results that can be effectively combined with other indicators for cross-validation. Patent data are built up from administrative data compiled by Patent Offices for their internal purposes of managing the patenting process: they can thus provide wide coverage at relatively low cost and also over a long time series.

However, the use of patent data as a proxy of inventive output has several shortcomings as well. On the one hand, not all inventions (and related innovations) are patented, and on the other, not all patented inventions turn into innovations. In fact, some innovations cannot be screened by means of patent data (production process innovation, for example), and firms often opt for different strategies to protect and exploit their inventions (keeping them secret is the most obvious way). Furthermore, the value of patents can be very different, as strategic or defensive patenting is a widely applied strategy to slow down competition in a specific market or to accumulate a patent portfolio to be used as bargaining power. Differences in patenting fees and rules also affect the propensity to patent innovations in different countries.[13] For these reasons, different patent-based indicators are used in order to exploit the available data on patents in the most effective way.

Measures of invention, such as patent statistics, provide quantitative information about the output of R&D processes. However, it is an assessment of their socio-economic impact, together with issues of complementarity and substitutability between public and private R&D investments, that is of central interest for policy makers. An econometric approach to modelling the impact of ICT R&D can provide not only insights into the current situation

7 Mainly Solow (1956), Arrow (1962), Romer (1990).
8 For example: Helpman (1997), Griliches (1992), Coe and Helpman (1995).
9 Helpman (1998) identifies four characteristics of General Purpose Technologies: (i) considerable scope for improvement initially, (ii) varied uses, (iii) applicability across large parts of the economy, and (iv) strong complementarities with other technologies.
10 The latest CIS (2008) was carried out in 27 Member States, candidate countries and Norway.
11 (OECD, 2010a). See also Rassenfosse and Potterie (2009) and Picci (2008) for further empirical analysis.
12 Among many others, Griliches (1990), Smith (2005), Guellec and van Pottelsberg (2007), Picci (2009).
13 See Rassenfosse and Potterie (2009) and Rassenfosse and Pottelsberghe (2010).

regarding the importance of ICT R&D in the economy, but also tools for policy design, scenario analysis and forecasting.

The first part of this report analyses patent statistics as a proxy to measure inventive activity related to ICT R&D in the EU, the US and other regions. The second part of the report introduces econometrics and economic modelling as an approach to gain further, in depth insight into the economic impact of ICT R&D.

3. ICT patents in the European Union

This section provides an analysis of ICT inventive activity in the EU and elsewhere by taking into account patent applications data as a proxy of the output of the inventive activity itself.

3.1 Introduction

3.1.1 Methodology update[14]

The European Patent Office (EPO) develops and updates the EPO Worldwide Patent Statistical Database (known as the PATSTAT database), providing worldwide coverage of patent applications submitted to around 90 patent offices in the world.[15] The present analysis is based on indicators built by extracting and elaborating patent application data from the April 2010 release of the PATSTAT database. The analysis takes into account priority patent applications filed at 59 patent offices: the EPO itself and 58 national patent offices including those of the 27 EU Member States, the US Patent and Trademark Office (USPTO), the Japan Patent Office (JPO) and also OECD countries' patent offices and other patent offices worldwide (those which account for the highest number of patent applications, including China and India).[16] The time period taken into account is 1 January, 1990 to 31 December, 2007.[17] Patent applications data from the PATSTAT database provide information on the country of residence of the inventors and of the applicants who have legal title to the patent. Patents are therefore usually attributed to countries using either the 'inventor criterion' or the 'applicant criterion', depending upon whether the inventive activity or the ownership of inventions is under investigation.[18]

The methodological choice to work on priority applications[19] needs to be clearly assessed. It allows us to take into account, process and analyse a much broader dataset than any other

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14 See also the patent data methodological information in the Annex to this report.

15 PATSTAT updates are released twice per year. PASTAT contains worldwide coverage of information on patent applications. The database is designed and maintained by the EPO (http://www.epo.org), as member of the Patent Statistics Task Force led by the Organisation for Economic Co-operation and Development (OECD). Other members of the Patent Statistics Task Force are the World Intellectual Property Organisation (WIPO), the Japanese Patent Office (JPO), the US Patent and Trademark Office (USPTO), the US National Science Foundation (NSF) and the European Commission (EC), which is represented by Eurostat and by DG Research. Data are mainly extracted from the EPO's master bibliographic database DocDB and cover nearly 90 national Patent Offices, the World Intellectual Property Organisation (WIPO) and, of course, the EPO. The database provides a 'snapshot' of data available in the sources database at a specific point in time, and is updated twice per year. Detailed information on PATSTAT is available online at the EPO website: http://www.epo.org/patents/patent-information/raw-data/test/product-14-24.html (last accessed: 12 December 2010).

16 To the selected patent offices in 2007 were filed 99.7% of the total number of priority patent applications. The complete list of considered Patent Offices includes: EPO, EU27 Member States, USPTO, JPO, Arab Emirates, Australia, Brazil, Canada, Chile, China, Columbia, Croatia, Hong Kong, Iceland, India, Indonesia, Israel, Korea, Malaysia, Mexico, New Zealand, Norway, Pakistan, Philippines, Puerto Rico, Russia, Singapore, South Africa, Switzerland, Taiwan, Thailand, Turkey, Vietnam.

17 The accuracy of data for more recent years could suffer from delays in the collection process and updating procedure of the PATSTAT database (even if the updating of data appears to have remarkably improved in the latest releases of the database).

18 Please refer to the Annex for more detailed information about priority applications and about the 'inventor criterion' and 'applicant criterion'.

19 A patent application for a given invention first filed at any of the patent offices worldwide by an applicant seeking patent protection is assigned a priority date (in case of first filing in the world) and is known as the "priority application". Counting priority applications only, rather than all patent applications, avoids multiple counting of the same inventions and is a better proxy measure of inventive activity. Please refer to the Annex for more detailed information about priority applications.

methodological choice made before in the patent analysis domain (e.g. PCT or triadic patent-based indicators). This choice has the support of a growing body of scientific literature and is generating increasing numbers of relevant results.[20] A secondary analysis is also proposed here: the results will be crosschecked with more classical approaches like the Triadic patents application analysis.[21]

Compared to the patent analysis presented in the two previous editions of the PREDICT report (Turlea et al., 2009; Turlea et al., 2010), the present analysis takes onboard several methodological improvements. Box 3 in the Annex to this report provides an overview of these methodological improvements.

These observations are developed in the following two sections. The first section mainly compares the EU (as a whole) with the US, Japan, and Asia. The second analyses the ICT inventive output of the EU Member States.

3.2 Inventive activity and ICT inventive activity across the world

This section aims to provide a global perspective of inventive activity, by giving a comparative overview of the innovative prowess of the EU, the US, Japan, Asia and the rest of the world (RoW) as proxied by patent application statistics. The analysis is based on priority patent applications and reflects the patenting activity of inventors from different regions. It provides figures regarding: (1) total patent applications (ICT and non ICT), and (2) patent applications in technological categories related to ICT.

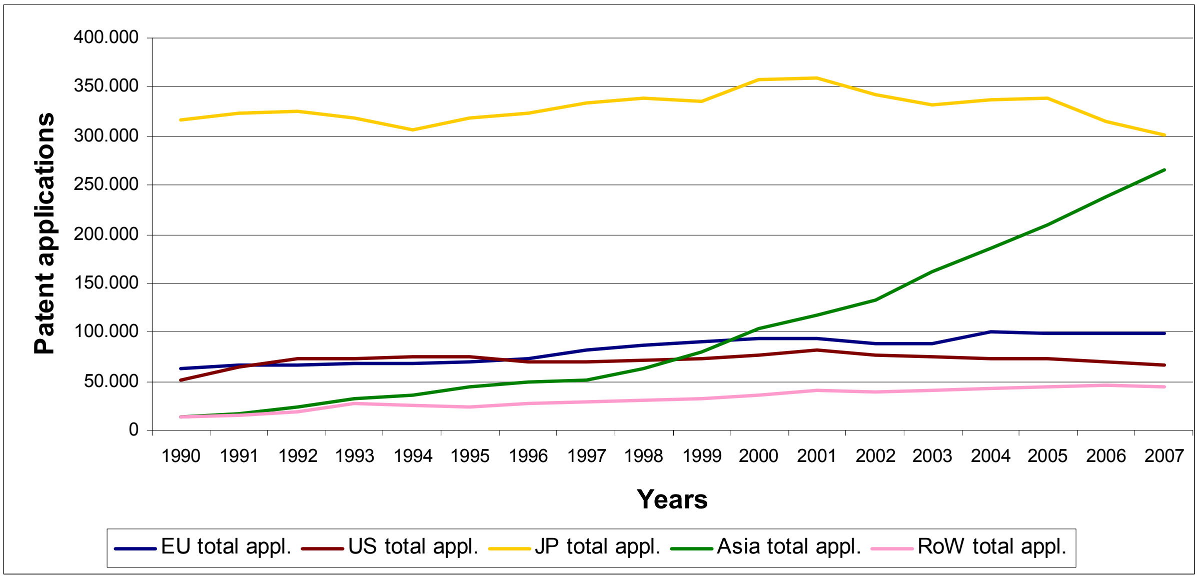
3.2.1 ICT and total patenting activity

Figure 1 presents the total number of priority applications filed by inventors located in the 5 analysed world regions (EU27, the US, Japan, Asia (excluding Japan), and rest of the world (RoW)), between 1990 and 2007, in all technology classes (ICT and non ICT).

20 See for example: Picci L. (2010), Picci (2009), Turlea et al (2010). Important source of information were also the presentations held by participants of the workshop "The Output of R&D activities: Harnessing the Power of Patents Data" held at the Institute for Prospective Technological Studies (JRC, European Commission) in Seville (May 2009, May 2010), and the OECD-EPO conference on patent statistics in Vienna (October 2009).

21 Among the different methodologies proposed by literature in order to build indicators based on patent applications, the consideration of families of "triadic patents" is widely adopted, in particular, among others, by Eurostat and OECD. In this approach the indicator is built by considering 'triadic patents', meaning all patent applications filed at least at the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO). This triple filing to particularly important patent offices is expensive and is meant to guarantee a wide protection to inventions, which are therefore suitable to be considered of high value. On the other hand, the cost of triple filing is expected to prevent smaller firms from accessing it. Moreover, concern about the possibility of strategic patenting has been raised by literature, in consideration of the fact that patenting activity performed at international level could hide strategic marketing purpose of slowing competition by means of the fear of litigation costs, rather than being oriented at protecting the results of inventive activity.

Figure 1: Total priority patent applications by EU, US, JP, Asian, and RoW inventors



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

The figure shows that:

- the output of inventors based in Japan (yellow line) in terms of total patent applications is more than three times bigger than that of EU inventors (blue line) or of US inventors (red line),
- the output of inventors based in Asia (green line) rapidly increased from 1997. It overtook the EU level in 2000, and by 2007 had almost reached that of Japan,
- EU inventors (blue line) have filed more patent applications every year than US inventors (red line) since the mid 90s.

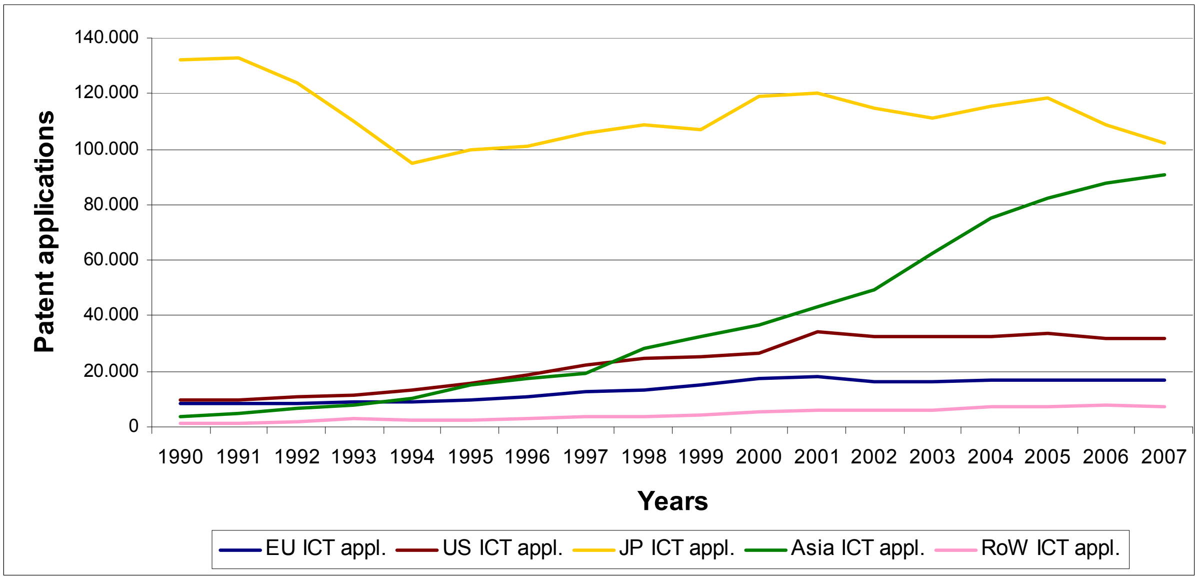
Asian output shares show a CAGR of almost 20% over the considered period: starting from less than 14 000 patent applications in 1990, and rising to 265 000 in 2007.

The trend for EU-based inventors is rather stable, reaching about 100 000 patent applications with a compound annual growth rate (CAGR) from 1990 to 2007 of 3%. A similar trend applies to the US, showing a CAGR of 2% over the same period.

The trend for Japan-based inventors is also relatively stable (CAGR at about -0.3%).

While Figure 1 includes applications in all technology classes (ICT and non ICT), Figure 2 shows the number of ICT priority applications for the same world regions and period.

Figure 2: ICT priority patent applications by EU, US, JP, Asian, and RoW inventors



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

When considering ICT applications, the main observations are:

- The number of ICT applications by Japan-based inventors (yellow line) is consistently higher over the period than that of inventors based in the other regions.
- The number of ICT applications by Asia-based inventors (green line) overtook the number of applications by EU-based inventors in the early 90s, and the number of applications by US-based inventors in the late 90s.
- More ICT applications have been filed every year by US-based inventors (red line) than by EU-based inventors (blue line), contrary to what was observed previously when considering patent applications in both ICT and non-ICT technology classes.

Asian ICT patenting output, along the same lines with what happened with total applications, shows an impressive CAGR of more than 22% over the considered period: starting from less than 3 500 in 1990, Asian ICT patent applications rose to about 94 000 in 2007.

The output of Japanese ICT patenting activity showed signs of certain instability in the early 1990s, with a CAGR between 1990 and 2007 of about -1.5%.

The EU CAGR between 1990 and 2007 was close to 4%, whereas for the US it was higher than 7%.

It should be noted that US-based inventors applied for twice as many ICT patent applications as EU-based researchers.

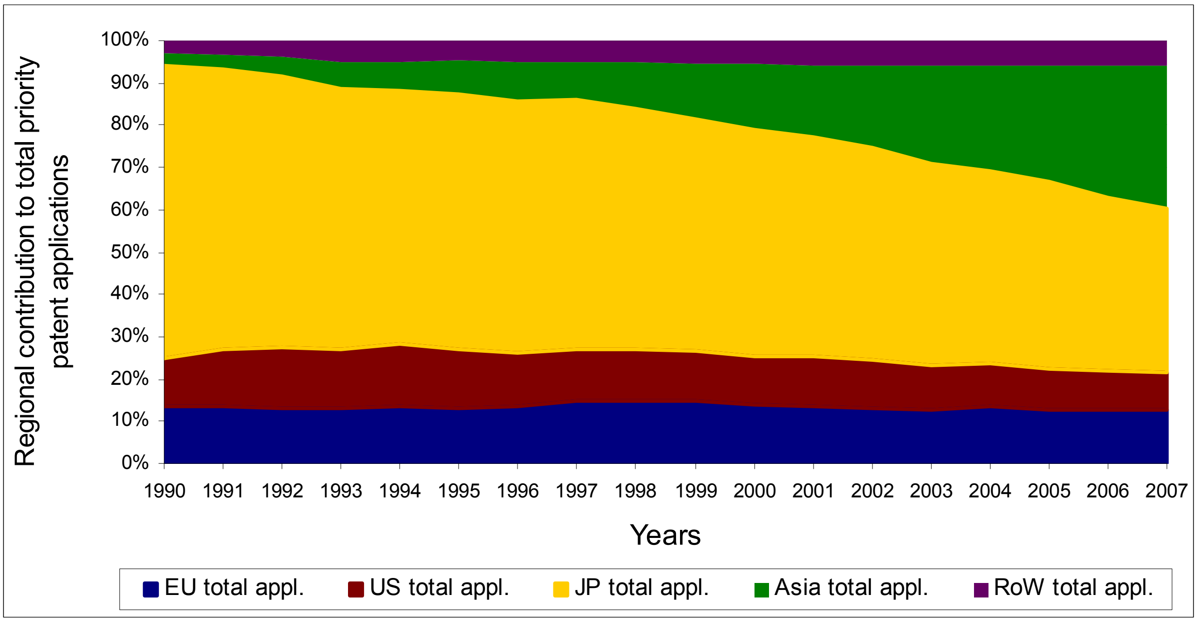
Furthermore, the US share of ICT applications over the total number of applications (ICT and non ICT) largely exceeded the EU share: 48% in 2007 for the US against 17% for the EU (not shown in the figure).

3.2.2 World regions contribution to total and to ICT patenting activity

Figure 3 presents:

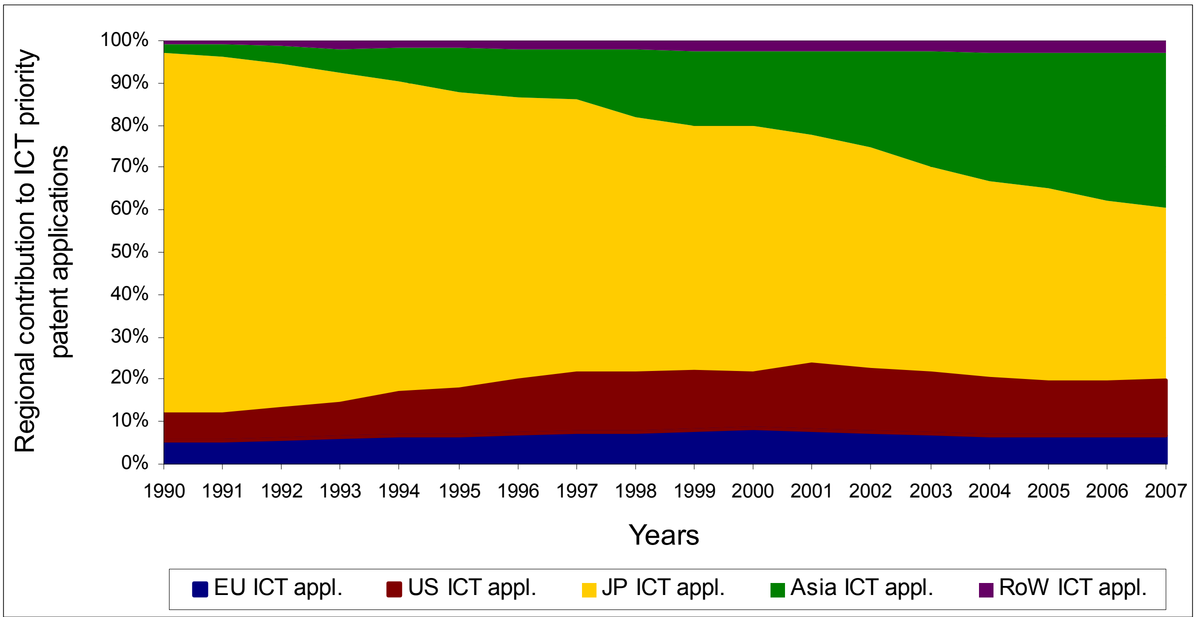
- First, the evolution of the contribution of each world region to total (ICT and non-ICT) patenting activity (in % of the total for all regions),
- Second, the evolution of the contribution of each world region to ICT patenting activity (in % of the total for all regions).

Figure 3: Contribution of world regions to total inventive output, 1990-2007, %



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

Figure 4: Contribution of world regions to ICT inventive output, 1990-2007, %



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

In terms of share of total ICT patent application worldwide in 2007, the EU contributed up to 7% of the total number of ICT patent applications worldwide, and the US 13%. Japan alone contributed almost 41% of the ICT applications worldwide (as well as the 39% of total applications worldwide).

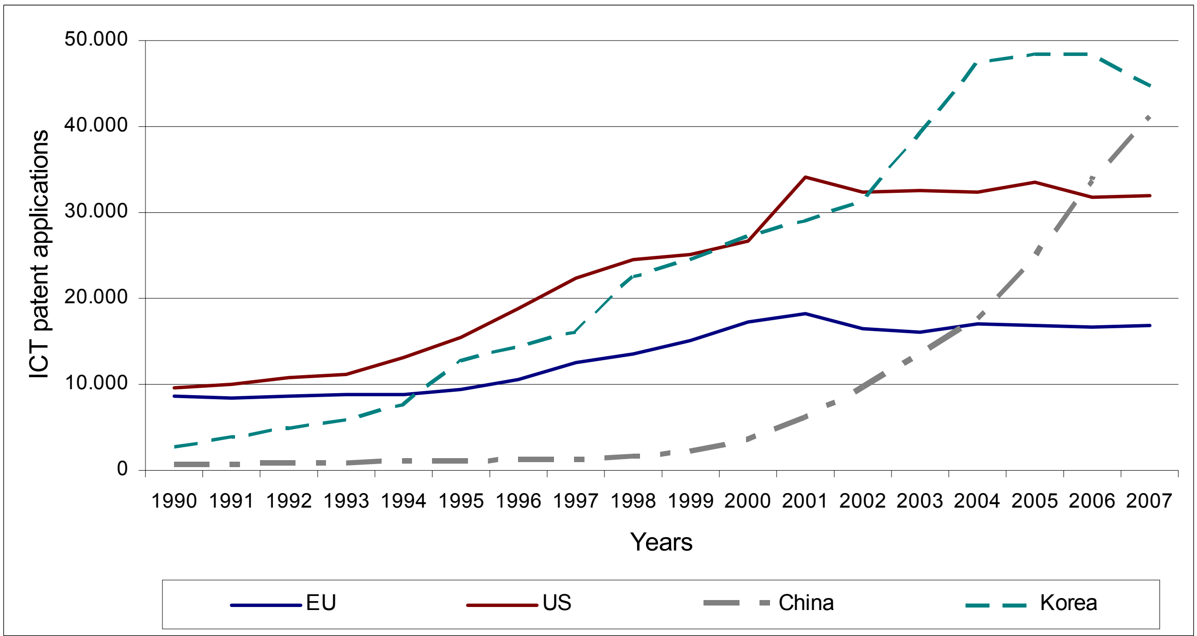
The most relevant aspects illustrated by both figures are:

- the rather stable weight of the EU and the US, and the fact that, in ICT, the US contribution is twice that of the EU;
- the dominant contribution of Japan to patent application activity, rapidly replaced in the last decade by the Asian one;
- the very rapid increase over the last decade in Asia's contribution, with regard to both total and ICT inventive output.

The impressive growth observed for Asia raises the question of which Asian countries contribute most to this growth. The next figure shows that the ICT patent applications filed by China- and Korea-based[22] inventors in 2007 added up to 91% of the total Asian ICT application output, and therefore explain Asia's strong performance.

Figure 5 shows the output of ICT inventive activity in China and Korea as compared with that of the EU, and the US.

Figure 5: ICT priority patent applications of the EU, the US, China and Korea



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

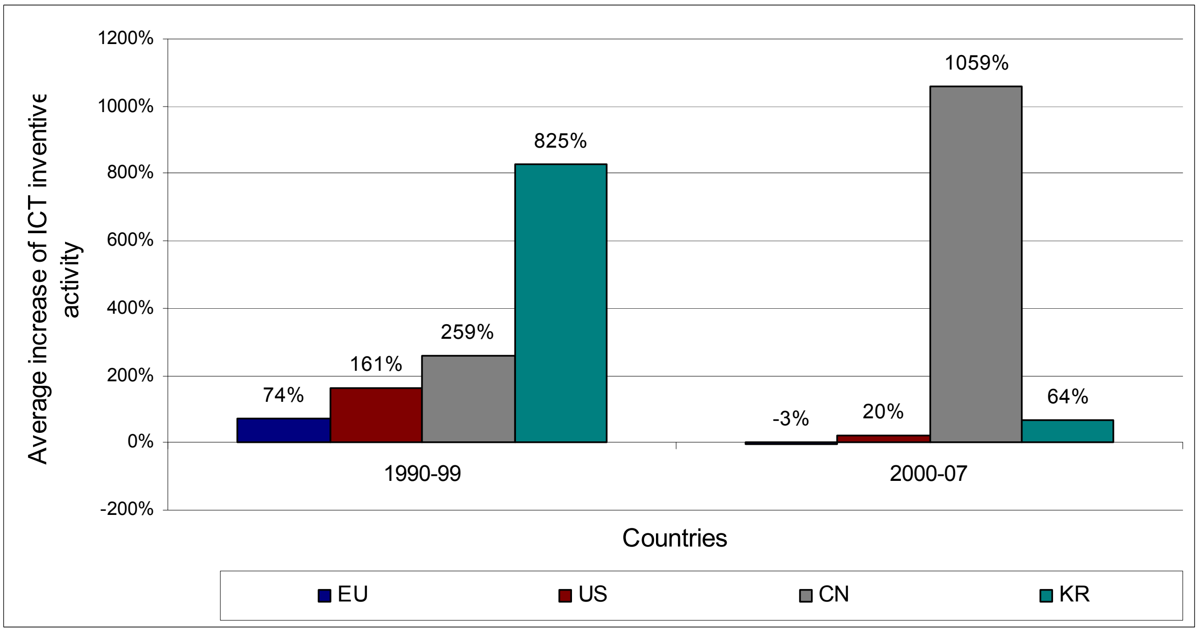
In 2007, South Korea accounted for more than 47% of all Asian ICT patent applications, and China about 44%. The overall CAGR of South Korea in the period 1990-2007 was 19%,

[22] Please refer to Section 3.1.1 and to the Annex for details on the way patents are attributed to countries using either the 'inventor criterion' or the 'applicant criterion'.

while that of China was 21%. China's inventive output has increased impressively since 2000: by the mid-2000s, it had overtaken both EU and US output.

Figure 6 provides the average increase in ICT patenting activity of the EU and of the same selection of country (US, CN, KR), for the period 1990-1999 and the period 2000-2007.

Figure 6: Increase of ICT inventive activity the EU, the US, China and Korea



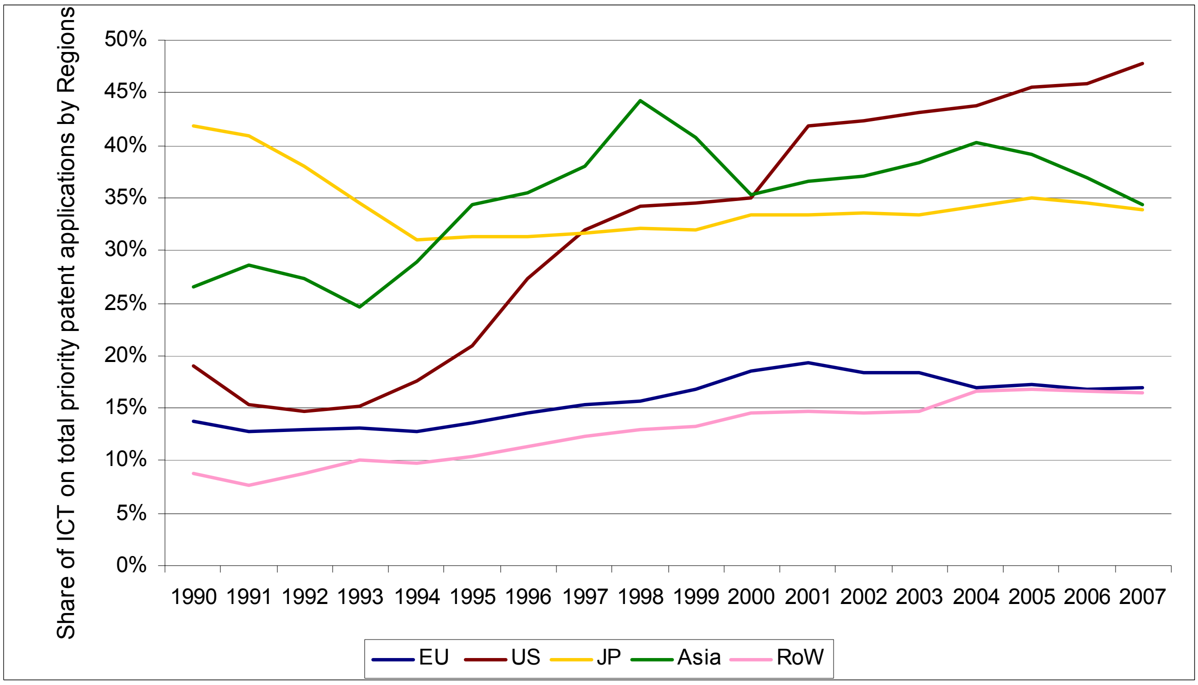
Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

There are two distinct phases in the growth of the contribution made by Asian countries: an earlier phase up until 2000 clearly dominated by the rise of South Korea, and a second one, from 2000 on, which has been marked by the impressive emergence of China in ICT patenting activity.

The figure also shows an overall slowdown (with the exception of China) in ICT inventive activity between the first and the second period.

Figure 7 shows the shares of ICT applications in total priority patent applications by region, over the period 1990-2007 (vertical scale maximum = 50%).

Figure 7: Share of ICT inventive activity in total inventive activity by region, 1990-2007



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

The analysis of the shares of ICT applications in the total number of priority patent applications (ICT and non ICT) by region, over the period 1990-2007, indicates that the EU share has remained stable (17% in 2007, versus18% in 2000 and 2001) while the US share has increased much faster. In 2007, the EU share was the lowest of the five regions' shares and the US share was the highest (it reached 48% in 2007).

The ICT share of patenting activity in Japan stabilised from 2000 on at around 35%, after shrinking in the early 90s. In Asia, this share reached 39% in 1998, then reduced and went back up again to 38% in 2004. In the RoW, it showed a slow but steady increase from the lowest level of 8% in the 90s to 19% in 2006, when it overtook the EU share.[23]

In 2007, the EU share of ICT applications over the total number of applications (ICT and non ICT) was therefore the lowest of all five regions. The US share was the highest and is still increasing.

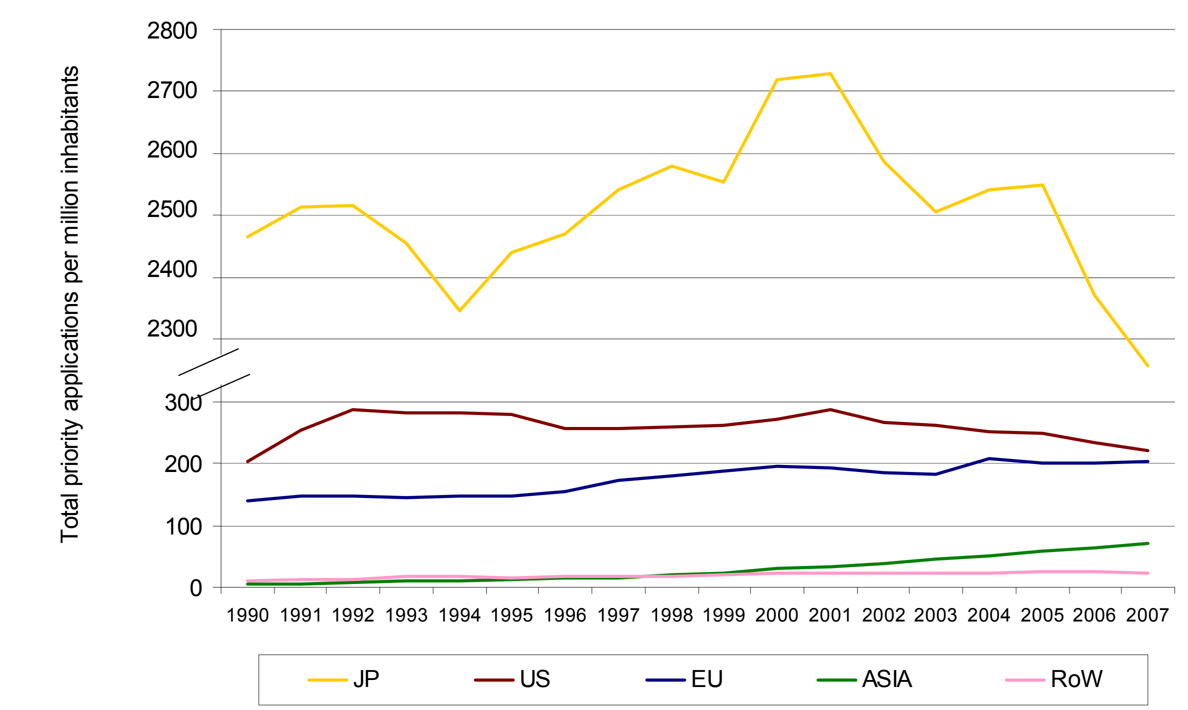
3.2.3 ICT and total patenting activity per capita in EU and in the other world regions

Figure 8 and Figure 9 allow comparisons between the analysed regions by taking into account both the total number of applications per million inhabitants and the total number of ICT

[23] In the RoW group, the top 5 ICT patenting countries were responsible in 2007 for about 93% of ICT patent application s by inventor. They were, in order of decreasing contribution, Russia, Canada, Australia, Brazil and Switzerland.

applications, also per million inhabitants. Please note that the two figures have a discontinuity on the vertical axis.

Figure 8: Total priority patent applications per million inhabitants, by region



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release) and on IMF data on population. Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

Weighting the output of inventive activity by the size of population makes Japan stand out even more than it does in the previous figures. Japan has a smaller population than the US and the EU (around 128 million inhabitants in 2007, against 300 million in the US and 493 million in the EU), and it reached a maximum of more than 2 800 total patent applications (ICT and non ICT) per million inhabitants in 2001. This figure started to decrease slowly afterwards.

Box 1: Japan's outstanding performance in patenting

Japan is a world super-power in patenting. In 2009, the JPO was reported to have issued almost 348 600 patents, the majority with domestic origins.[24] As a result of this patenting prowess, Japanese patent applications represented almost 50% of the global total from 2000 to 2004, according to the Derwent World Patents Index. Japanese patenting predominance lies in three major industry sectors: Chemicals & Materials, Electrical & Electronic, and Engineering.[25] The effects of this huge patenting activity are reflected abroad, as the same source reports that, in the first semester of 2005, approximately 16 000 patents granted in the US presented a priority application filed in Japan.

Patent data available in the PATSTAT database used in this report confirms these trends, and shows that the JPO received in 2007 about 339 000 applications against the almost 305 000

[24] http://www.japan-patents.com/japan_patent_application.html

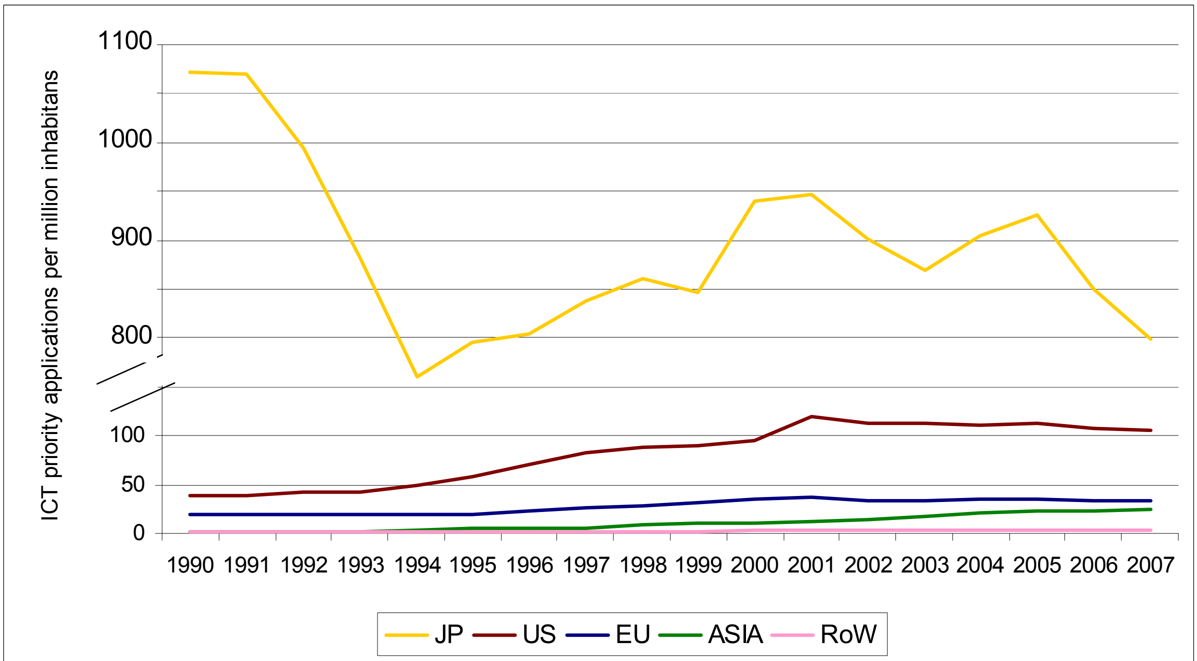
[25] Jeremy Rosie, Thomson Scientific, October 2005, available online at: http://science.thomsonreuters.com/news/2005-10/8292452/

received by the USPTO (irrespective of the country provenance of inventors and applications); with regard to priority patent applications, more than 298 000 were filed at the JPO in 2007, 85 000 were filed at the USPTO, and 19 000 were filed at the EPO.

The high performance in terms of patent applications already present in the 1990s can be explained, according to the literature (Motohashi, 2003; Motohashi, 2006; Kiyokawa, 2006; Goto, 2001) by several factors: i.e. firms' strategic behaviour, the gradual expansion of technology fields covered by patent protection (especially with regard to ICT and pharmaceutical patents), and also the fast increase in R&D expenditure in the 1990s and the changes in the regulatory framework towards stronger support to intellectual property. This last aspect can be identified in several revisions of the Japanese Patent Law since its enforcement in 1953 (the Strategic Framework for Intellectual Property policy was published in June 2003), supporting pro-patent policies for firms' innovations (Motohashi, 2003).

The EU reached 200 total applications per million inhabitants in 2004; this figure then remained stable. In 2007, the US reached about 220 total applications per million inhabitants and Asia 70. The figures for Asia are obviously affected by the size of the population of this region (more than 3 900 million inhabitants in 2007).

Figure 9: ICT priority patent applications per million inhabitants, by region



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release) and on IMF data on population. Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

The picture is clearly dominated by Japan: EU ICT applications per million inhabitants in 2007 were about 4% that of Japan, while US reached 13%. Both the EU and the US show a continuing increase until 2001, i.e., just after the burst of the Internet bubble (38 and 120 ICT applications respectively per million inhabitants in 2001). Then they both stabilised at relatively lower values (about 35 for the EU and 110 for the US in 2007). Asia, however, continued to increase slowly, and reached about 34 ICT applications per million inhabitants in 2007.

3.3 Inventive activity and ICT inventing activity by EU Member State inventors

This section provides a comparative view of the ICT innovative output of the different EU Member States, from 1990 to 2007, proxied by the patent application activity.

3.3.1 Overview of ICT patenting activity of Member States

Analysis of ICT patent applications filed in 2007 to **the 59 patents offices covered by this analysis**[26] is shown in Table 1.

Table 1: ICT priority patent applications by EU Member State, 2000 and 2007

ICT patent Applications		ICT patent Applications		CAGR, ICT Patent Applications		ICT Patent Applications /milllion inhab.		ICT Patent Applications/GDP (billion euro)	
2007		2000		2000-2007		2007		2007	
DE	7971	DE	8098	EE	35.7%	FI	136	FI	4.03
FR	3030	FR	2888	PT	26.1%	DE	97	DE	3.28
UK	1809	UK	1821	BG	22.4%	SE	62	SE	1.69
FI	723	IT	942	GR	13.6%	AT	52	FR	1.60
SE	571	FI	833	CZ	10.7%	FR	49	AT	1.58
NL	497	SE	721	AT	9.0%	IE	36	BG	1.35
AT	430	NL	458	LT	7.8%	NL	30	SI	1.06
IT	350	PL	305	SI	7.6%	UK	30	CZ	0.91
ES	318	ES	273	CY	6.5%	DK	29	EE	0.89
BE	236	AT	235	BE	5.3%	BE	22	UK	0.88
DK	156	BE	165	SK	4.8%	SI	18	NL	0.87
IE	155	IE	139	DK	4.0%	LU	17	IE	0.82
CZ	116	DK	118	ES	2.2%	CZ	11	HU	0.77
HU	78	HU	91	IE	1.6%	EE	11	BE	0.71
GR	72	CZ	57	LU	1.2%	HU	8	DK	0.69
PT	54	RO	43	NL	1.2%	ES	7	SK	0.59
BG	42	GR	29	FR	0.7%	GR	6	MT	0.36
SI	37	SK	23	UK	-0.1%	SK	6	LT	0.32
RO	36	SI	22	DE	-0.2%	IT	6	GR	0.32
SK	32	LV	11	FI	-2.0%	BG	6	PT	0.32
PL	23	PT	11	HU	-2.1%	PT	5	ES	0.30
EE	14	BG	10	MT	-2.6%	MT	5	RO	0.29
LT	9	LU	7	RO	-2.7%	CY	3	IT	0.23
LU	8	LT	5	SE	-3.3%	LT	3	LU	0.22
LV	5	MT	2	LV	-11.9%	LV	2	LV	0.21
CY	3	CY	2	IT	-13.2%	RO	2	CY	0.16
MT	2	EE	2	PL	-31.0%	PL	1	PL	0.07
EU	16776	EU	17312	EU	-0.4%	EU	34	EU	1.35

This analysis confirms that, in absolute terms, the leading EU countries in ICT patenting are the three largest EU economies: Germany, France and the UK. The number of applications in ICT by Germany-based inventors (8 000 applications in 2007) is more than 2.5 times that of France-based inventors (3 000 applications) and 4.4 times that of the UK (1 800 applications).

[26] See Section 3.1.1 and the Annex on methodology.

Finland, with 720 ICT applications in 2007, is next, followed by Sweden, the Netherlands, Austria, Italy, Spain and Belgium, with between 200 and 600 applications each.

Inventors based in the ten best performing countries filed 95% of all EU ICT patent applications (and almost the same share of total patent applications – ICT and non-ICT-). Inventors based in Germany alone contributed almost half the EU total and ICT inventive activity.

When considering the ratio of ICT patent applications on gross domestic product (GDP) at national level,[27] Table 1 (last column) shows that Finland (with a ratio of 4 ICT applications per billion euro of GDP) is first, followed by Germany (with 3.3), Sweden (1.7), France and Austria (1.6). The European average is 1.35 ICT applications per billion euro of GDP. Bulgaria, Slovenia, the Czech Republic and Estonia then follow (below the European average), followed by the UK, 10th in the list.

In the following sections, two maps will present an overall overview per EU Member State of:

(i) the number of ICT priority patent applications in 2007, divided by the country population (Figure 10),

(ii) the compound annual growth rate (CAGR) of the number of ICT priority patent applications between 2000 and 2007[28] (in Figure 12).

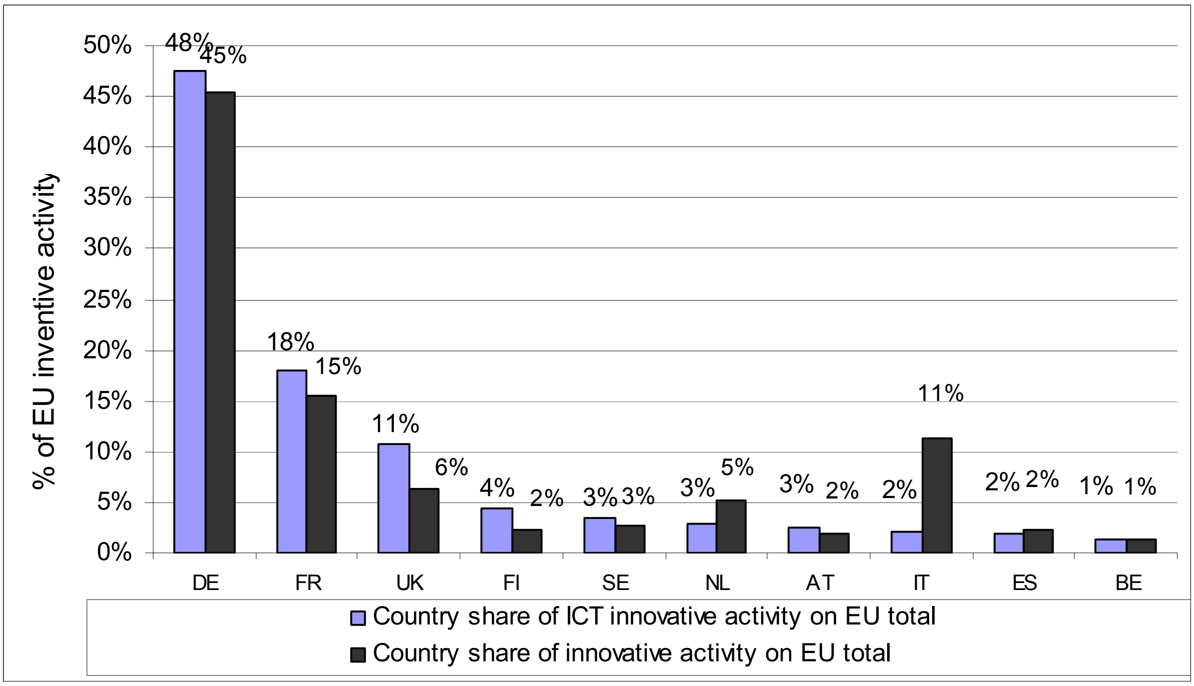
3.3.2 Contribution of Member States to EU total and ICT inventive activity output

As already pointed out, the contribution to total and ICT inventive activity in terms of patent applications is concentrated in a small number of EU Member States. In 2007, the ten 'most patenting' countries contributed up to 95% of total EU patent applications. These countries are, in decreasing order of contribution to the EU total number of ICT priority patent applications: Germany, France, the UK, Finland, Sweden, the Netherlands, Austria, Italy, Spain, Belgium (see Figure 10 and Table 1, first column). When total patent applications are considered, the picture is similar, with 10 countries contributing 95% of the EU output (with Denmark substituting Belgium and Italy ranked 3rd, before the UK).

[27] Eurostat data on gross domestic product at market prices; in millions of euro from 01.01.1999 and millions of ECU up to 31.12.1998.

[28] Please note that, in order to take into account significant values, for Estonia, Latvia, Lithuania and Malta it is proposed the CAGR between 1992 and 2007, for Slovenia between 1991 and 2007.

Figure 10: Contribution (%) to total ICT EU priority patent applications by the ten most IC T patenting EU Member States– inventor criterion



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices and the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

Figure 10 shows that in general those countries responsible for high shares of ICT patenting activity in Europe also contribute more to total patenting activity. Moreover, inventors based in Germany alone contribute almost half the EU total and ICT inventive activity.

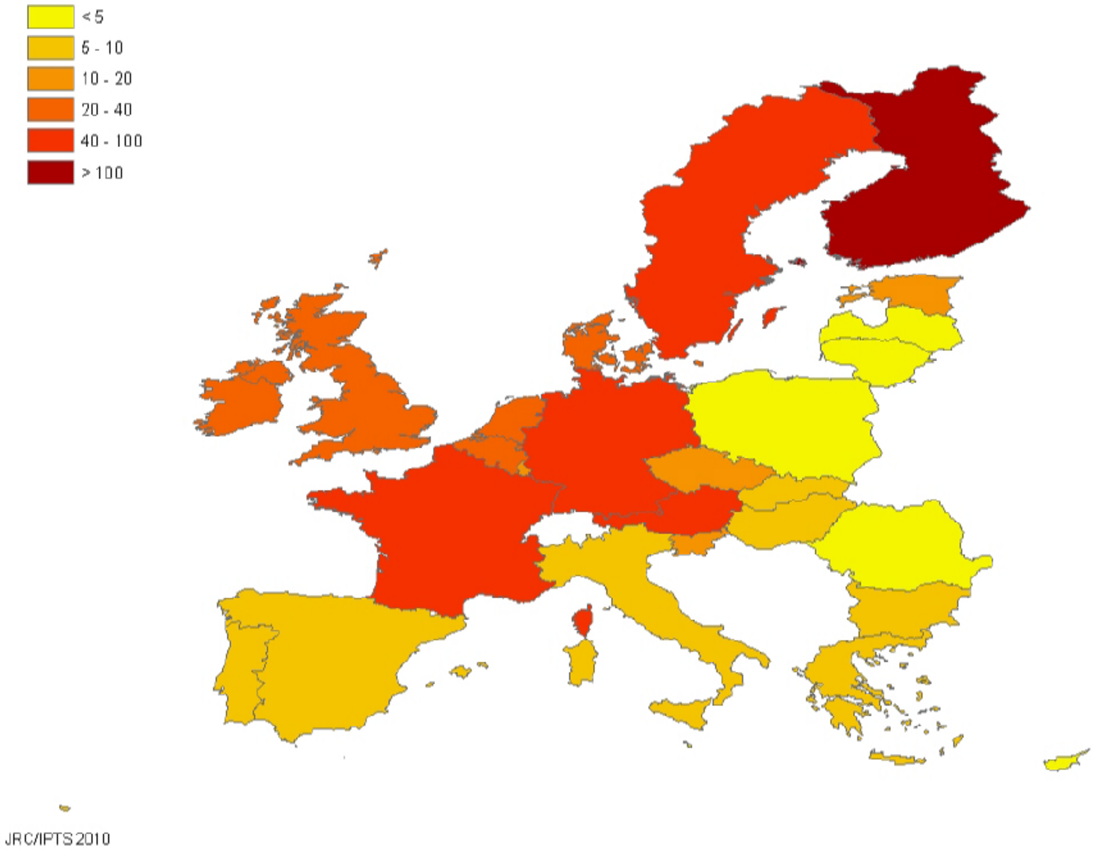
3.3.3 ICT and total patenting activity per million inhabitant in the EU Member States

In order to better understand the prowess of individual Member States in the production of ICT inventions, it is relevant to weight the number of ICT patent applications by the country size measure, either by GDP or population.

Figure 11 shows a grouping of EU Member States by number of ICT priority patent applications in 2007 for each EU Member State, divided by their population (darker colours show the higher values).[29]

[29] See also the last column of Table 1.

Figure 11: Map I – Ratio of ICT priority patent applications on million inhabitants, by EU Member State, 2007

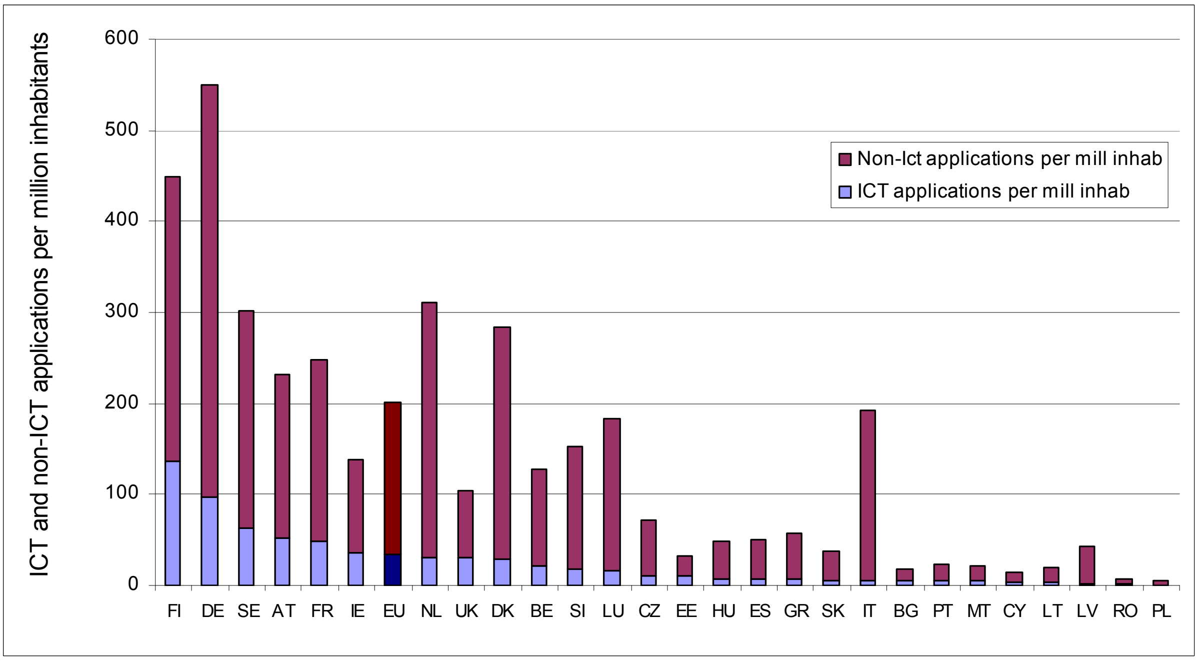


Source: JRC-IPTS calculations based on IMF data on population, and on the PATSTAT database (April 2010 release). Inventor criterion.

When weighting the number of ICT applications by the country population, Finland-based inventors take the EU lead, with almost 140 ICT patent applications per million inhabitants, as can be seen in Table 1. Germany comes next with about 100 ICT applications per million inhabitants, and Sweden and Austria follow with numbers above 50 ICT applications per million inhabitants. Then, above the European average of 34 ICT applications per million inhabitants, come France and Ireland. They are followed by the Netherlands, UK, Denmark and Belgium immediately below the EU average.

Figure 12 shows the ratio of ICT and non-ICT applications per million inhabitants for the 27 EU countries in terms of ICT priority patent applications in 2007. Countries are ranked according to how many ICT applications they have per million inhabitants.

Figure 12: Number of ICT and non-ICT patent applications per million inhabitants, by EU Member State, 2007



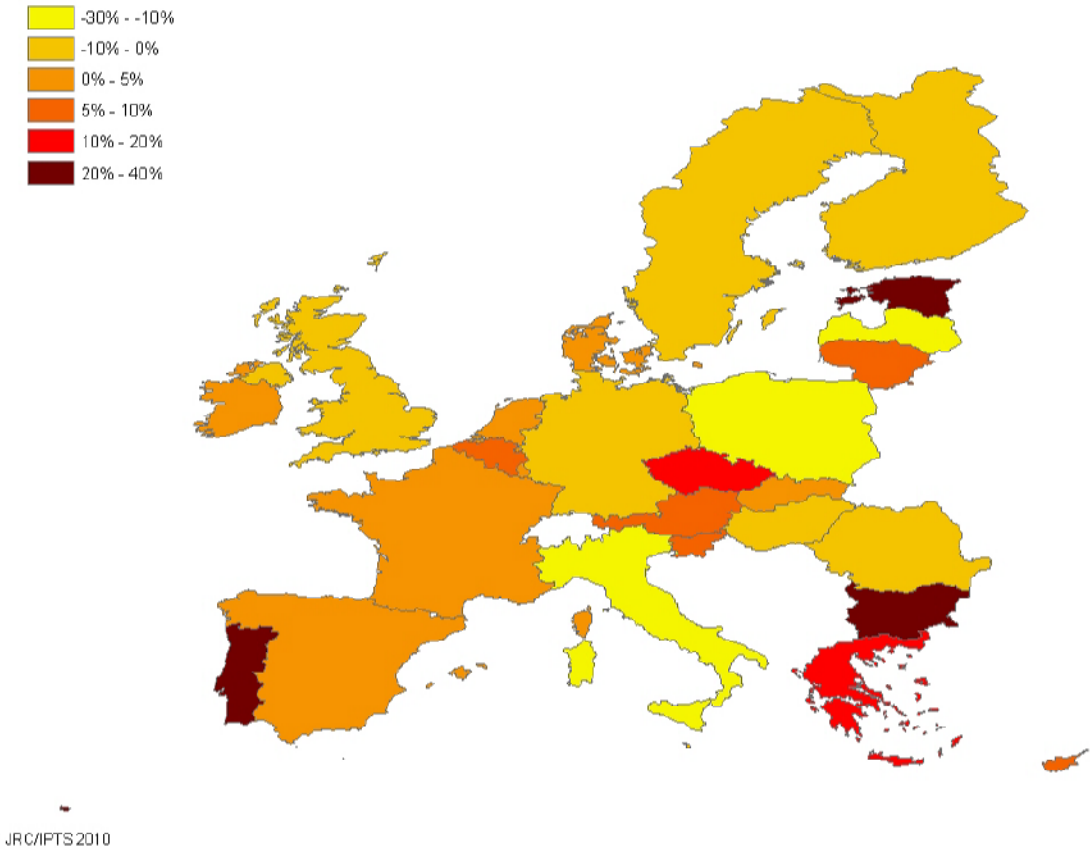
Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices, the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

Figure 12 allows us to compare ICT inventive effort in 2007 to non-ICT inventive activity, and those countries, in which the number of ICT applications per million inhabitants is low even if the output of inventive activity in general is high. Countries with a significantly higher ratio of ICT-related applications per million inhabitants than the EU average consist of Finland first, and Germany second (but first for the total number of applications, both ICT and non-ICT). Austria's position confirms its good performance in ICT inventive activity.

The Netherlands and Denmark have good overall patenting performance but lower intensity in ICT patenting activity and a total number of applications per million inhabitants comparable to that of Sweden. Luxembourg and Italy come next in terms of general applications per million inhabitants, while they are ranked 12th and 19th respectively as regards ICT priority applications over population.

3.3.4 Compound annual growth rate of ICT patenting activity in the EU Member States

Figure 13: Map II – Growth in Output of ICT inventive activity, CAGR 2000-2007 by EU Member State



Source: JRC-IPTS calculations based on the PATSTAT database (April 2010 release). Inventor criterion.

Figure 13 shows a grouping of EU Member States by compound annual growth rate (CAGR) between 2000 and 2007 of ICT patent applications (darker colours show higher values), as indicated in Table 1.

This map shows that, in terms of CAGR, Estonia, Portugal, Bulgaria and Greece grew in the given period at compound rates higher than 10%, and they all recovered from the very low values reached in the previous decade. Leading countries with growth rates higher than 5% are the Czech Republic, Austria, and Slovenia. This group of countries is characterised by the fact that they all started from low figures and rapidly increased their output in terms of ICT priority patent applications. The number of ICT patent applications grew for the Czech Republic from 57 in 2000 to 116 in 2007.

France with 0.7% stands immediately above the UK, Germany and Finland, which occupy positions between 17th and 20th, floating below 0%. The European average is also negative over the considered period (-0.45%).

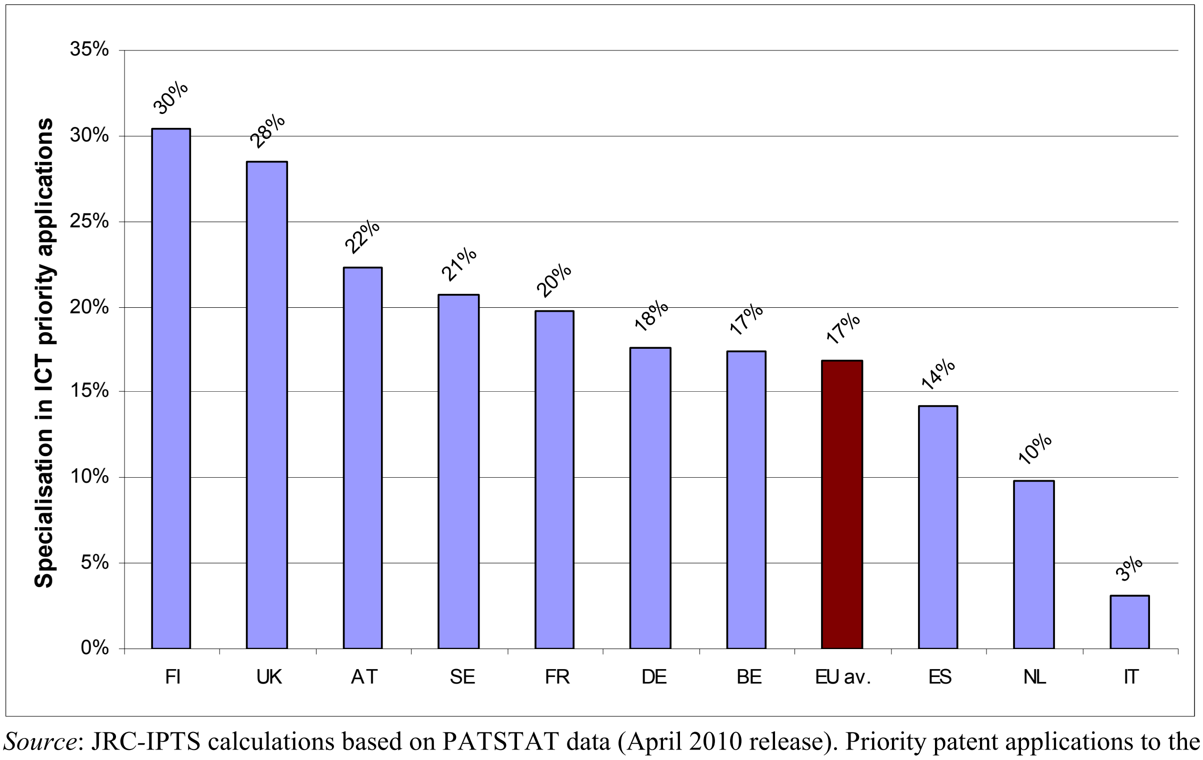
This second group shows lower growth rates when compared with the previous one, but it must remembered that inventors from these Member States already had a rather high number of ICT patent applications in the early 90s. In this period, for example, the output of Germany-based inventors with respect to the number of ICT patent applications was almost stable - around 8 000 in both 2000 and 2007.

3.3.5 Specialisation in ICT priority applications in the EU Member States

Figure 12 shows that countries responsible for a high share of the ICT patenting activity in Europe in general also make a high contribution to total patenting activity. Figure 14, by showing the percentage of specialisation of the EU Member States in ICT patenting activity, can help us understand some of the exceptions. The figure ranks EU Member States, showing the share of ICT patent applications in the total number of patent applications for each country.

Finland has the highest specialisation and also high volumes of ICT applications, but comes third in the complete ranking with a specialisation rate of 30%. Estonia with 33% and Bulgaria with 31% are the most specialised countries, but the overall size of their output in terms of ICT patent applications is small. UK and Ireland follow with 28% and 26%, while France (20%) and Germany (18%) were respectively 12th and 13th, as they had relatively lower specialisation and justified their contribution to the overall EU ICT patenting activity in terms of high number of applications.

Figure 14: Specialisation in ICT priority applications (%) on total priority patent applications by the ten most ICT patenting EU Member States– inventor criterion



Source: JRC-IPTS calculations based on PATSTAT data (April 2010 release). Priority patent applications to the EPO, the 27 Member States' National Patent Offices and the USPTO, the JPO, and 29 further Patent Offices. Inventor criterion.

3.4 Summary of main findings and conclusions

In this section, inventive capability at regional and country levels is investigated, using priority patent applications as proxy measures.

Though the underlying methodology is rather similar to the one applied in previous analyses (described in the past editions of the PREDICT report), the present report proposes a wider analysis and introduces Asian countries and the rest of the world into the country comparisons with the EU and the US. This year's analysis is based on a much wider set of data than in previous years, taking into account 59 National Patent Offices worldwide.

The following main observations can be made, based on the data and on the analysis presented in this report:

- While the annual number of ICT priority patent applications by inventors based in the EU steadily increased in the period from the early 90s until 2001, it has remained stable since the burst of the dot.com bubble.
- A similar pattern can be observed for ICT applications by inventors based in the US, but with US absolute values about twice the EU ones. For example in 2007, EU-based inventors applied for about 17 000 ICT patents while US-based researchers applied for 32 000 ICT patents.
- For many reasons ranging from sector specialisation to regulatory framework and policy support, annual numbers of ICT priority patent applications by inventors based in the Japan have traditionally been the highest of all geographic areas, with figures five times bigger than those of the EU.
- Since the early 90s, the annual number of ICT priority patent applications by inventors based in Asia (excluding Japan) strongly increased, reaching close to 91 000 in 2007 (from 3 600 in 1990). Most of this spectacular growth can be attributed to two countries: first, South Korea where annual figures reached almost 50 000 in 2004 and then stayed at this level and second, China where a spectacular increase started in 2000, and exceeded 40 000 in 2007, thereby putting China's annual figures significantly above those of both the EU and the US.
- When the number of ICT priority patent applications is weighted by number of inhabitants, Japan reinforces its outlying position (with about 800 applications per million inhabitants in 2007). Next comes the US, with around 100 applications, followed by the EU with 34 applications, and Asia with 24 applications per million inhabitants.
- Within the EU, the most patenting countries in ICT are Germany, France and the UK. Together, they account for 80% of all ICT priority patent applications by EU-based inventors, with Germany-based inventors alone generating half the total ICT applications for the EU.
- When the annual number of ICT priority patent applications is weighted by number of inhabitants, Finland, Germany and Sweden were the top performers in the EU with respectively 136, 97 and 62 applications per million inhabitants in 2007. They were followed by Austria, France and Ireland with respectively 52, 49, and 36 applications per million inhabitants, above the EU average of 34 applications per million inhabitants.
- Among the 'old' EU Member States, the ICT patenting performance of Portugal, Italy, Greece and Spain remains low, with less than 10 applications by million inhabitants in 2007, although absolute values for Portugal, Greece and Spain has risen since 2000.
- Among the 'new' EU Member States, performance is mixed, with figures rising (compared to 2000) particularly in Estonia, Bulgaria, the Czech Republic, and Slovenia, and decreasing in Hungary, Romania, Latvia and particularly Poland.

Though it should be remembered that patent applications are only a *proxy* for inventive activities, the power of patent-based indicators is confirmed by their wide coverage and availability, the increasing accuracy of large amounts of data over a period of 18 years, and the possibility of considering a number of countries.

In-depth analysis of country specificities and dynamics can be carried out, to investigate countries behaviour and to provide better explanations of resulting trends. Useful comparisons can be also carried out at country level, by exploiting the detailed information that patent data provide.

4 Economic performance of ICT R&D

This section reflects current research initiated with the 2009 PREDICT report.[30] Chapter 7 of the 2009 report – *From inputs to outputs in R&D activities* - outlined an analytical framework for R&D performance in which (i) the R&D expenditure leads to an invention (through a knowledge production function); (ii) then the invention, if marketed and adopted successfully, leads to new or improved products and processes; (iii) hence impacting on the economic performance of the firm. The analytical framework of the present report calls upon the CDM model proposed by Crepon *et al*. (1998).

This research framework is extended here in terms of scope and depth. The extended framework expands the analysis of the innovation process beyond the performance of firms and connects it to the macro economy at country and regional levels. It also proposes more detailed micro-macro modelling of R&D processes and their impact on the economy. This line of research, in response to the new EU strategy,[31] is needed to better understand the impact of R&D not only on creating new knowledge, but primarily on employment and economic growth. As emphasised by Máire Geoghegan-Quinn, EC Commissioner for research, innovation and science: "*A sea change in Europe's innovation performance is the only way to create lasting and well-paid jobs* […]".[32] All policy initiatives of this kind call, more and more, for economic impact assessment. They also contain an increasingly explicit shift in their final objectives: ICT R&D is expected to go beyond technological progress and contribute to wealth creation, growth and competitiveness.

The understanding of the processes through which ICT R&D impacts upon growth and employment is a necessary precondition for the development of strategies which aim to stimulate growth and employment through appropriate ICT R&D policies. The *explanation* must go beyond *accounting*, such as growth accounting which is a widely used method to allocate productivity growth calculations to various related components without, however, giving any insight into causality or motivation of constituent actions. As Zvi Griliches, a modern master of empirical economics, points out: [growth] "accounting is not explanation. Real explanations will come from understanding the sources of scientific and technological advances and from identifying the incentives and circumstances that brought them about and that facilitated their implementation and diffusion. Explanation must come from comprehending the historical detail from finding ways of generalizing (modelling?) the patterns that may be discernible in the welter in it."[33]

This report presents and justifies a long-term research plan to comprehensively analyse the role and impact of ICT R&D in the economy. The analytical framework for this line of research has been extended beyond analysing data to constructing economic models capable of performing scenario analysis and forecasting with respect to ICT R&D.

Although there is a considerable body of literature on research on R&D impact in general, there are no economic studies which address ICT-specific R&D in a comprehensive and

[30] Turlea et al., 2009.
[31] Mainly Europe2020 and Digital Agenda, both emphasising the importance and need for an increase in R&D and ICT R&D expenditures.
[32] Press release, 06 October 2010, available at: http://ec.europa.eu/commission_2010-2014/geoghegan-quinn/headlines/press-releases/2010/20101006_innovation_union_en.htm
[33] (Griliches, 2000).

exhaustive manner. Economic modelling of ICT R&D is a worthwhile undertaking for a number of reasons.

The importance of ICT R&D activities in the EU must be emphasised. ICT R&D makes up a large share of overall R&D activities. Even though the ICT sector represents only 4.8% of EU GDP (2007), it accounts for 25% of overall business expenditure in R&D and employs over 32% of all business sector researchers.[34] Also, due to their ubiquitousness in the economy,[35] ICT underpin many of the recent organisational changes and productivity improvements observed in almost every business process across the economy. This ongoing process is propelled by new ICT innovations. Understanding the dynamics of ICT innovations and their past, present and future impact on the economy is central to fully utilising their potential.

The value (added) of this research project is three-fold: (i) although there are studies which provide insights into the economics of R&D, there is no research focused on ICT R&D.[36] As pointed out before, due to differences in impact of ICT R&D compared to other R&D domains, ICT R&D requires a specific approach; (ii) the research project needs in a unique way to bridge micro- and macro-economic perspectives, as this will provide insights into how different firms react to the same policy with respect to their R&D decisions; (iii) the project aims to construct an economic model[37] which reflects the behaviour of the economy (including the roles played by ICT R&D) as accurately as possible.

This tool will allow us to assess the impact of various policies on the economy at a level of complexity which would not be feasible to achieve with qualitative methods. The economy today is increasingly integrated and interconnected, and it is becoming impossible to envisage all the possible ways a single intervention could impact upon the economy without the use of relevant tools, particularly when the effects are considered over time. Some examples of questions that can be investigated with such a tool are provided in Box 2.

Box 2: Example of questions to answer with economic modelling

An R&D tax credit to encourage R&D activities in the private sector might result in the intensification of inventive activities and improved performance of R&D-performing firms. It is more difficult to determine, for example, how much the firms will expand given a certain tax credit magnitude; how firms of different characteristics (e.g. size) will benefit from the same policy; how labour will move between firms/sectors; how firms which do not perform any official R&D will be affected; how national product will change as a result of the policy; how the additional income will be spent – which sectors will benefit from growth; and how the policy will impact on regional and national competitiveness. It is also important to determine the cost of a policy – e.g. the forgone tax revenue due to tax credits –as this will have implications for public spending and, subsequently, for the economy. Finally, it is important to know how all these dynamics will be distributed in the time following policy implementation. These questions are impossible to answer satisfactorily without modern economic tools such as a modelling framework.

[34] 2010 PREDICT report (Turlea et al., 2010).

[35] See, for example the report on ICT embedded systems by Juliussen and Robinson (2010). Available at: http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=3780

[36] It is important to distinguish different ways the ICT can impact on economy. For example, the EU KLEMS project provides valuable information on ICT capital which has implications for productivity change, but does not account for R&D in the growth accounting calculations. There is a dataset 'linked' to the EU KLEMS which provides selected data on R&D stocks, the data however is not used in productivity calculations. The project here is unique in having specific ICT R&D perspective.

[37] There is no need to construct the model from the scratch; the work describe here will rather involve modification of existing models to reflect the economics of ICT R&D.

Although the model will be developed primarily for the evaluation of R&D policies, it can also provide insights into how policies which do not directly focus on R&D affect ICT R&D performance. For example, a trade agreement which results in growing demand for motor vehicles would increase the demand for ICT intermediate inputs and would probably stimulate spending on related ICT R&D. In order to evaluate all these effects in a concise, scientific and explainable way, a dedicated (ICT) R&D-oriented economic model must be developed.

In spite of the fact that there is consensus in the literature about the positive impact of R&D activities on competitiveness and economic growth,[38] the underlying mechanisms remain elusive. The link between R&D activities and performance is neither direct nor straightforward. The areas which require particular attention are:

- Innovation measure: the central (and most difficult to measure) component of this process is innovation. An innovation is the desired output of the R&D process and serves as an input into a production activity which provides a firm with competitive advantage. Patent statistics or Community Innovation Surveys provide measures which can proxy the quantity of innovation; however, they also carry a degree of uncertainty.[39]

- Variations in performance of firms with different characteristics: the propensity to innovate and the ability to turn R&D resources into marketable innovation vary between firms with respect to their size, organisational structure or location.[40] This information is important for the impact analysis of R&D-related policies, in order to understand which type of innovating firms might benefit most from such a policy.

- Placement of innovating firms within the broader, macroeconomic environment: factors which impact upon a firm's performance include not only those internal to the firm, such as R&D decisions, but also those which reflect the constraints of the economic environment within which the firm operates. Because a firm operates as a part of the economy, it faces limited resources for which it competes with other firms. These resources consist of factors of production and intermediate inputs on the one hand, and on the other, the limited absorption capacity of a market which can consume only so many new products. These aspects need to be reflected in the macroeconomic analysis and its modelling.

- Technology diffusion: The diffusion of innovation across economies applies to all technologies, and the case of ICT is particularly powerful as they are considered to be a General Purpose Technology (GPT),[41] due to their ubiquitous presence throughout economy.[42] An ICT innovation is likely to spread to other ICT-using sectors and

[38] See for example: Griliches, 1995; Helpman, 2004; Romer, 1990).

[39] In patent statistics analysis, a single patent is considered a unit measure of invention hence all of the patents are treated equally in terms of innovation cost and potential market value, whereas in reality the cost and impact of patented inventions are likely to vary. Similarly, in the case of CIS statistics, firms declare themselves whether they have innovated or not and on the importance of the innovation. Such self-assessment is subject to strong subjectivity bias.

[40] Examples: impact of a firm size (Acs and Audretsch, 1988), firm location (Freeman and Soete, 1997), or firm size (Bartelsman *et al.*, 2005).

[41] (Helpman, 1998).

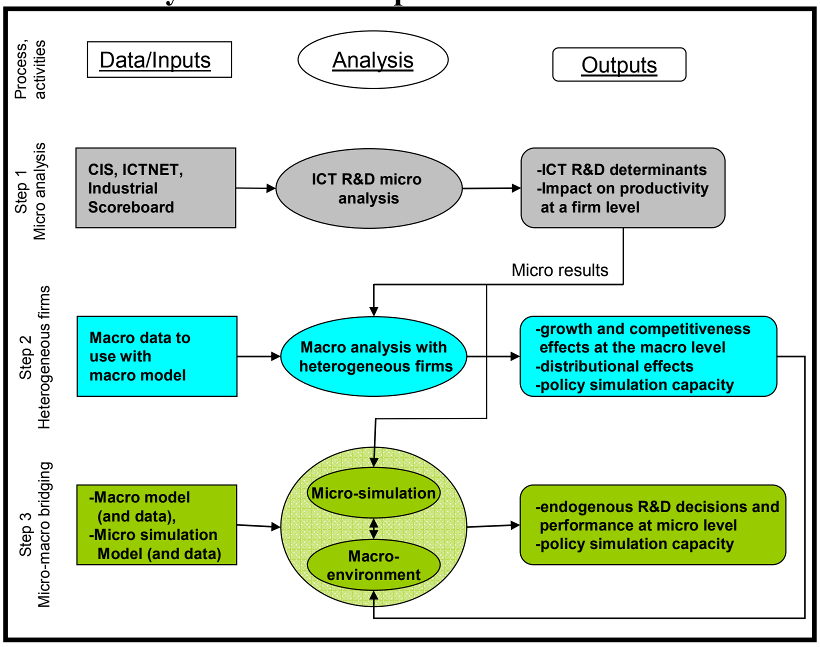
[42] See for example Helpman (1998).

impact upon their performance. This type of inter-sectoral or international technological spillover can be an important source of technology-based growth.[43]

The analytical framework

The rest of this section describes a framework for the analysis of economic dynamics and the impact of ICT R&D on growth and competitiveness. The analysis to be undertaken consists of numerous activities which should follow a logical sequential order. We divide the activities into three groups, each of which constitutes a separate step with its own deliverables. The simplified process and grouping of research activities is presented on Figure 15.

Figure 15: Schematic representation of the activities and work flow of analysis of economic performance of ICT R&D



The representation of the analysis of ICT R&D economic impacts in Figure 15 is organized in three main steps, each of which distinguishes the inputs to be used, the analysis to be performed and the expected outcomes. We briefly discuss each of the steps below:

- Step 1 involves the analysis of firm-level data on ICT R&D expenditure, innovation and productivity. The approach here models firms' decisions whether to engage in R&D activities or not and, if they decide to do so, what share of their resources they will allocate to R&D activities. This analytical framework allows us to identify the most important determinants of engagement in ICT R&D with respect to various firm characteristics. It also provides quantitative insights into the impact of ICT R&D spending on the economic performance of firms. The analysis, once completed, would also show the quantitative impact of government support and/or the impact of additional public R&D spending on a firm's productivity and growth.[44] The output of this step will provide quantitative information on factors which firms take into account when making ICT R&D decisions, pointing at early obstacles to ICT R&D and

[43] (Coe and Helpman, 1995; Madsen, 2007; Marshall, 1890).

[44] An example of analytical framework to suit the needs is the CDM model (Crepon *et al.*, 1998) with numerous subsequent applications. The CDM model is usually used in conjunction with Community Innovation Survey (CIS) type of data, which is available from Eurostat.

offering ways for policy to eliminate the impediments and also to encourage larger R&D investment. The effects will be analysed for firms of different sizes, locations, and other characteristics.

- In Step 2, the micro results from Step 1 will be used to replace a single 'representative' firm in the macroeconomic model with a representation of heterogeneous firms in order to account for distributional effects of policies between various firms. Macro models, such as Computable General Equilibrium (CGE) models,[45] usually use a concept of a representative agent – a single firm which represents the production of an entire sector or industry. Though this specification delivers valid macro results, it provides no insights into distributional effects between the firms which form the 'representative agent'. The single representative firm will be extended into numerous heterogeneous firms differentiated with respect to various characteristics, such as size, organizational structure, age or location – characteristics which affect firms' R&D decisions and performance - to eventually form a specification with a more accurate resemblance to the characteristics of the economy.[46] Once the model has been constructed and calibrated to address the above issue, it will not only allow policy and scenario analyses related to ICT R&D at a macro level, but also provide insights into the micro distribution and welfare effects of policy impact. The output of Step 2 will be a working macro-economic model with a representation of heterogeneous firms suitable for policy scenario analysis and also, if implemented in a dynamic version, for forecasting.

- Finally, Step 3 develops a micro simulation model that reflects the behaviour of firms performing ICT R&D, and integrates the micro model within a macro framework. The value added of micro simulation specification over the heterogeneous firms approach is a better representation of firms' behaviour. The micro simulation model can simulate the behaviour of individual firms over time and account for new entries and exits.[47] Furthermore, in combination with a macro model (e.g. CGE) it can provide reliable forecasts and can deal with the microeconomic effects of macroeconomic policies, i.e. it can determine how different firms from the same sector react to the same policy in terms of R&D decisions, R&D intensity and what the impact will be on their productivity.

IPTS intends to develop the modelling framework presented above as part of the PREDICT project. The results will be published in reports and academic publications, and on the PREDICT web site (http://is.jrc.ec.europa.eu/pages/ISG/PREDICT.html.

45 The Computable General Equilibrium (CGE) class of models is based on Input-Output (IO) tables analysis. The OECD (2008) describes the use of the CGE (Monash) model not only for assessing impact of single R&D policies but also for undertaking assessment of entire research programs at the national level.

46 The concept and rationale for heterogeneous firms in a macro model was produced by Melitz (2003); see also Zhai (2008) for application for a global CGE trade model.

47 The micro simulation modelling is believed to have flourished after seminal work of Guy Orcutt (1957). For reviews of a growing literature about importance of linking macro, meso and micro models, see for example: Davies (2009) and Ahmed and Donoghue (2007).

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Annex – Methodology for patent data

A brief description of the PATSTAT database

The results presented in Chapters 6 and 7 are based on analysis performed on a subset of the PATSTAT database. The PATSTAT database is the European Patent Office (EPO) Worldwide Patent Statistical Database; it provides a snapshot of the data available in the EPO's 'master bibliographic database DocDB' at a specific point in time, and it is updated twice per year. Data extracted from the source database cover nearly 90 national Patent Offices, the World Intellectual Property Organisation (WIPO) and the EPO.

A brief description of main methodological aspects follows. For a more complete and detailed description of the methodology followed, please refer to Chapter 8 of the 2009 Report (Turlea et al., 2009), to Annex 8 of the 2010 Report (Turlea et al., 2010), and to Picci (2009).

Priority applications

A number of steps have to be taken in the process of patenting an invention. When the application is first filed at a patent office by an applicant seeking patent protection it is assigned a priority date (in case of first filing in the world) and a filing date. The filed application could become a granted patent, being then assigned a grant date, if no reasons for refusing the application have been raised during the process of analysis of the subject, novelty, non-obviousness and industrial applicability of the invention.

The indicators proposed in this report are intended to provide the best measure of the inventive capability of countries, rather than of the productivity of patent offices. To achieve this objective, patent applications are taken into account, rather than granted patents. The reasons behind this choice are manifold and documented in the scientific literature on patent statistics. In the present report, therefore, references made to 'patents' always mean 'patent applications'. Moreover, the considered subset of data includes only 'priority patent applications'; this means that only the first filing of an invention is considered and all the possible successive filings of the same invention to different patent offices are not counted again. An invention is therefore counted only once. 'Priority patent applications' are considered a more suitable proxy measure of inventing capability, even if a number of shortcomings have been pointed out by the literature (OECD, 2009d; de Rassenfosse et al., 2009).

Data set considered: patent offices and years covered

The analysis proposed in the present report is based upon the April 2010 release of the PATSTAT database. The considered subset of data included all priority applications filed in any of the Patent Offices taken into account: the EPO, USPTO, JPO; national patent offices of the 27 EU Member States; national patent offices of Arab Emirates, Australia, Brazil, Canada, Chile, China, Columbia, Croatia, Hong Kong (Hong Kong SAR), Iceland, India, Indonesia, Israel, Korea, Malaysia, Mexico, New Zealand, Norway, Pakistan, Philippines, Puerto Rico, Russia, Singapore, South Africa, Switzerland, Taiwan (Taiwan Province of China), Thailand, Turkey, and Vietnam. To avoid taking into account data affected by delays in the updating procedure of the database, the analysis considers only the period between 1990 and 2007, even if more recent data would be available.

Box 3 - Methodological improvements compared to the analysis in the 2010 PREDICT Report (Turlea et al., 2010)

The present analysis encompasses several methodological improvements in comparison with the one proposed in the 2010 PREDICT Report (Turlea et al., 2010). Those improvements can be grouped in four main areas:

(i) **The consideration of 59 patent offices** -versus 29 in the 2010 report- constitutes a major improvement in the coverage, allowing for a more valid comparison when using patent applications as a *proxy* for the inventive prowess of countries, that otherwise would be affected by a serious 'home country bias'.[48] The importance of the Japan Patent Office (JPO), the Patent Offices of China, India and Brazil among others is clear, not only when considering the related countries, but also in the comparative global analysis of performance and internationalisation.

(ii) **The coverage of analysed countries** in which inventors are based is also much larger. In addition to EU and the US, the present analysis also includes Japan, and the following groups of countries: Asia and Rest of the World (RoW).

(iii) **The methodology applied to attribute the patent applications to the above countries** by using the country of residence of the inventors or of the applicants who have legal title to the patent has been improved as well, following the most recent literature.[49] This represents an important step as the increase in the number of Patent Offices taken into account brought several additional criticalities[50] in the data, and the need to deal with a much larger amount of missing information.[51]

(iv) The adoption of **a different software tool for query, extraction and organisation of data** from the PATSTAT database allowed for extending the coverage and the flexibility of the analysis.

Finally, taking into account the April 2010 release of the PATSTAT database not only allows to include **more recent data (up to year 2007), but also provides updated data for previous years**.

The reader should note that, due to the above mentioned improvements, data presented in the present report are not fully comparable with those published in the 2010 report.

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48 The propensity of applicants to first submit applications to the patent office in their home country (or, in the case of a European Country, to the EPO) is at the root of what is referred to in the literature as 'home country bias'. See Picci (2009).

49 The methodology is the one detailed in Picci (2009) and in de Rassenfosse et al. (2011).

50 Criticalities are coming from the different quality of data provided by some of the patent Offices taken into account, in spite of the effort by EPO to improve data completeness and congruence to a reasonable level.

51 The issue of "missing" information is a relevant one, to the extent of this analysis, in particular when information about the country of residence of the inventors (and / or applicants) is missing. Literature progressively agreed on procedures to be applied in order to be able to collect such an information from other sources (e.g. from subsequent filings of the same applications when available, or from other parts of the applications records). In some cases, the information about the country of residence of inventors (and / or applicants) is proxied with that of the country where the application has been filed. This is done in cases known to be affected by this lack of information for procedural reasons, for example, in the case of the JPO.

Assigning patents to countries (or regions): inventors vs. applicants

The literature commonly refers to the possibility of adopting two alternative criteria in order to assign patents to countries: it is possible to refer to, either the declared country of residence of the inventor(s) ('inventor criterion') of a patent, or to that of the applicant(s) ('applicant criterion').[52] According to patenting rules, the applicant is "the holder of the legal rights and obligations on a patent application", i.e. the patent owner (see OECD 2009). The applicant is in many cases a company or a university, but it could also be an individual.

Several applicants could hold rights on a patent application, and they have legal title to be owners of the patent once (and if) it is granted. In the same way, several inventors could have taken part in the development process of the invention, and be listed in the patent application. A *fractional count* is applied in order to assign patents to countries in cases in which more inventors (or applicants) with different countries of residence have to be considered for the same application.

In the present report the adoption of the inventor criterion has been chosen; in general, the choice of the criterion depends on the perspective by which the innovative capability has to be investigated.

As mentioned above, the dataset includes all priority applications filed at selected 59 Patent Offices **It must however be made clear that**, in the cases in which the inventor criterion is used, we call 'EU applications', those applications in which **EU-based inventors** are involved, and **not all applications to EU patent offices** (which can involve EU-based or non-EU-based inventors). In the same way **'US applications' are those involving US-based inventors rather than those filed to USPTO** (which can involve US-based or non-US-based inventors). Moreover, the application of the fractional count implies that, in case of an application holding more inventors with different countries of residence, for that specific application a value lower than a unit will be assigned to each of the respective countries. The use of fractional count of patent applications, by assigning 'fractions' of a patent application to different countries depending on the country of residence of each of the inventors (or applicants), produces, as a consequence, decimal figures in the number of patent applications per country.

52 "EU-based" inventors are inventors (persons or companies, as declared in the patent applications) whose country of residence (or that of registration for companies) is one of the 27 EU Member States. Please note that, notwithstanding the effort by EPO for a constant and effective improvement of the quality and coverage of data provided, only 50% of country codes are present in the database (EPO, 2010). The missing countries of residence are attributed by means of several procedures, continuously updated and discussed in literature (OECD, 2009; Picci, 2010; de Rassenfosse et al., 2011).This fact stands as one of the main reasons behind some differences in figures in the time series of each annual report (other reasons have to be found in the constant updating and refining of data provided by Patent Offices to EPO and in turn by EPO by means of PATSTAT, and in the minor intrinsic effect of applying a different software tool). EPO works on reducing the amount of missing country information (by filling the missing codes with the country of publication in the next editions), but at present time the attribution of country codes by means of a set of subsequent procedural steps is the only alternative commonly adopted worldwide. It must be noticed that the lack of information about the country of inventors (and applicants) has noticeable consequences in the case of Japan, as EPO does not receive this information on Japanese data and therefore for Japanese documents PATSTAT does not explicitly indicate the country (EPO, 2010), which is then assigned in all possible cases by means of procedures. Thus, the huge number of Japan-based inventors could hide a share of inventors resident in countries different from Japan, but which it is not possible presently to identify. Finally, the country does not necessarily hold a reference to the "nationality" of inventor or applicant (EPO, 2010).

Technology classes

With regard to the identification of ICT patent application technology classes, the same approach as in the 2010 edition of the report has been followed, considering the taxonomy of the International Patent Classification (IPC) technology classes proposed by the OECD (OECD, 2008a). The mentioned taxonomy links four categories of ICTs to groups of technology classes. The four categories, and the corresponding IPC classes, are the following:

- **Telecommunications**: IPC codes G01S, G08C, G09C, H01P, H01Q, H01S3/ (025, 043, 063, 067, 085, 0933, 0941, 103, 133, 18, 19, 25), H1S5, H03B, H03C, H03D, H03H, H03M, H04B, H04J, H04K, H04L, H04M, H04Q;
- **Consumer electronics**: IPC codes G11B, H03F, H03G, H03J, H04H, H04N, H04R, H04S;
- **Computers and office machinery**: IPC codes B07C, B41J, B41K, G02F, G03G, G05F, G06, G07, G09G, G10L, G11C, H03K, H03L;
- **Other ICT**: IPC codes G01B, G01C, G01D, G01F, G01G, G01H, G01J, G01K, G01L, G01M, G01N, G01P, G01R, G01V, G01W, G02B6, G05B, G08G, G09B, H01B11, H01J (11/, 13/, 15/, 17/, 19/, 21/, 23/, 25/, 27/, 29/, 31/, 33/, 40/, 41/, 43/, 45/), H01L.

As a consequence, the distinction between ICT and non-ICT technologies is neither related to the ISIC classification of economic activity nor to NACE codes.

The *fractional counts* approach has also been applied in case of applications referring to more than one technology class.

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Abstract

This report provides evidence on the inventive output of ICT R&D activity in the EU, the US and other regions and proposes an economic modelling framework for analysing the impact of the R&D processes. It uses patent statistics as a measure of output of the R&D process. According to the presented evidence, the annual number of ICT priority patent applications steadily increased in the period from the early 90s until 2001, and, since the burst of the dot.com bubble, it has remained stable. This pattern can be observed for both the EU and the US, though the US absolute values are about twice the EU ones. Since the early 90s, the annual number of Asian (excluding Japan) ICT priority patent applications strongly increased due to two countries: South Korea and China.

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