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Internationalisation of ICT R&D in Asia vis a vis the world regions

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We analyse the internationalisation of ICT R&D in Asia and compare it with the other world regions. Despite the strong linkages between Japan, the US and the EU, Asia seems to be very attractive as a location for R&D activities. It is also striking how the role of Japan as a partner of other Asian countries decreased mainly in favour of the US. At the aggregate level, there are strong differences in R&D internationalisation across regions. This might indicate that each region follows a different R&D internationalisation path. Alternatively, it might also be a sign of unequal capabilities of "going global". In this respect, the US offers an interesting example of a region which benefit from the process of internationalisation of inventive activity not only through building research collaborations with foreign inventors, but also through successfully capturing innovations developed by foreign researchers.

Keywords: Globalisation, R&D internationalization, R&D location, patent statistics

JEL classification: D8, O32

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Introduction

Over the last few decades, an intensive process of redistribution of production across the world has been observed (Dachs & Pyka, 2010; Fayol-Song, 2011; Meyers, Dachs, & Welfens, 2008; UNESCO, 2010; Van der Zee, 2006). As part of the process, large corporations have begun to seek new knowledge opportunities worldwide (Bartlett & Ghoshal, 1990; Dunning, 1994). This is motivated by rapid innovation and strong market adaptation needs, of which knowledge-intensive sectors, such as the ICT industry, are the most prominent examples.

In spite of the abundance of evidence, very low levels of international inventive collaboration have been observed so far. These rather puzzling results call for an in-depth analysis that take into account the motivations to go global. This paper describes and analyses the internationalisation of ICT R&D from various perspectives. Its main focus is, first, to disentangle the process of innovation into the input and output side and look at them separately. Second, it assesses the level of internationalisation in Asia and to compare it with the remaining major world regions, i.e. the EU, the US, Japan and the rest of the world (RoW).[i] Here, the most relevant question is how a larger number of players creates additional competition for R&D resources and how will the distribution of the R&D resources will look like in the future to come.

The paper proposes a methodology to study R&D internationalisation and uses various types of data allowing for an assessment of the process by looking at it through various perspectives. As a result, it offers a solid picture of the topic and provides a detailed description of the international R&D of all the major world regions

Literature review

The available evidence does not create a coherent picture of the R&D internationalisation (Carlsson, 2006). In one of the pioneer studies on the subject found that the technological activities of multinational firms are concentrated in their home countries (Patel & Pavitt, 1991). More recent studies do not show significant changes with respect to the internationalisation of R&D activity either (Macher, Mowery, & Di Minin, 2007; Picci, 2010).

A partial explanation of this puzzle can be found in the fact that the existing studies are either based on firm level analysis (Boutellier, Gassmann, & Zedtwitz, 2008; Florida, 1997; Gulbrandsen & Godoe, 2008; Kuemmerle, 1999) or provide case study analysis at a country level (Gassler & Nones, 2008; Kumar, 2008; Pittiglio, Sica, & Villa, 2009). Moreover, the available studies focus on developed countries (Niosi, Manseau, & Godin, 2000) and, with some exceptions (Chen, 2007; Kumar, 2008; Lee, Lee, Song, & Kim, 2008; Oh, Kim, & Ahn, 2010; Schmiele, 2011; Simon, 2007), ignore the emergence of the developing countries as a location of inventive activity. Furthermore, studies that take into account a large group of countries and explain technological collaboration activities between them are scarce as well (Belderbos, Fukao, & Iwasa, 2006; Patel & Pavitt, 1991; Picci, 2010). Thus, not surprisingly, only few studies explicitly investigate innovation internationalization empirically at the global level (Bartholomew, 1997; Niosi & Bellon, 1994).

Another impediment of understanding the issue of R&D internationalisation is related to the fact that it is a complex phenomenon. For example, despite the abundance of the literature discussing the importance of knowledge acquisition by tapping onto foreign resources, there is, in fact, little evidence to support the hypothesis that this is really taking place. On the contrary, with respect to the knowledge creation by foreign R&D units, firms tend to focus the work of their foreign technology centers on those domains in which they are strong at home (Patel & Vega, 1999). The aim of this strategy is to adapt products, processes, and materials to suit foreign markets and to provide technical support to offshore manufacturing plants, and not to see for assets. Thus, these at first sight inconsistencies might be a result of various reasons why firms choose certain locations for R&D. As not all R&D activities are taken abroad with a view to delivering new inventions that can then be patented and transferred to other locations, tangible outputs of international inventive collaboration remain scarce. Hence, when dealing with the issue of R&D internationalisation, it is necessary to account for the differences in strategies to "go abroad".

Research questions

We aim at looking at R&D internationalisation from different perspectives that would at least partially reflect various motivations behind decisions to do R&D abroad. Specifically, we divide between the input and output of R&D process and look at the internationalisation levels of each stage. Further, we look at the R&D collaborations between the major world regions. This approach allows us to answer two types of questions:

First, we analyse what is the difference between the internationalisation of input and output of R&D? In practical terms, we are interested in such questions as:

- What is the level of internationalisation of R&D infrastructure, i.e. R&D centres, and product design expenditures?
- What is the level of international co-patenting?

- What is the level of foreign ownership of domestically developed innovations? Or, in reverse logic, how important are inventions developed abroad in a portfolio of inventions owned by domestic firms?

Second type of questions addresses the strength of R&D linkages between regions that emerge as a result of companies R&D internationalisation strategies. Here, specific questions include:

- Where do firms from different regions locate their R&D centres and where do they develop their products?
- What is the composition of ownership of R&D centres in each region?
- What is the level of R&D collaboration between individual regions?

Methodology and data

Disentangling the R&D value chain

To address the complexities related to R&D internationalisation, it is necessary to follow the developments of the global knowledge creation network. To this end, we propose a methodology of disentangling the R&D value chain and divide it into two stages (see Figure 1). The first stage concerns the input-side of the R&D process and the second the output side of R&D activity. Such division reflects some of the complexity of the R&D process and allows accounting for the differences of doing R&D abroad. Thus, following this division, the level of internationalisation of each R&D stage can be analysed separately.

< Insert Figure 1 here>

Data on input and output of ICT R&D

This analysis makes use of unique data in order to build a comprehensive source of information on ICT companies' R&D internationalisation level. On the input side, we use two measures of R&D activity. The first one concerns the location of R&D centres of a number of multinational companies. The second one measures the allocation of semiconductor design expenditures by a sample of companies manufacturing products including semiconductors. Concerning the R&D output side, ICT patent data are used.

Data on R&D centre location and distribution of semiconductor design expenditures

Information on R&D centre location and semiconductor design expenditures originates from the *2011 JRC-IPTS ICT R&D Internationalisation Database*, a company-level dataset dedicated to observing the internationalisation of ICT R&D. It includes 171 multinational ICT companies and provides information on company location, the location and ownership of over 2,800 R&D centres worldwide, geographical allocation of company level semiconductor design expenditures broken down by country where expenditures are carried out. Companies included in the database are considered as major ‘semiconductor design stakeholders'. The firms contained in the dataset represent at least 28% of the full *R&D Scoreboard*.[ii] Also, in 2009, these firms accounted for more than 30% of all patent applications to the USPTO. Consequently, this information allows for a relatively representative illustration of the R&D-related behaviour of large multinational ICT companies. Table 2 includes the list of companies included in the database and Figure 2 shows the distribution of ownership and location of altogether over 2.800 ICT R&D centres across the previously defined regions.

< Insert Figure 2 here>

Semiconductor design expenditures are attributed to various countries that "influence" decisions on parts or vendor selection when Original Equipment Manufacturers (OEM) develop electronic products. This is done based on the knowledge of where engineering teams are and where the decisions concerning systems design and selection take place.

Figure 3 shows the allocation of companies' semiconductor design expenditures across the five regions for the period between 2007 and 2011. In absolute terms, the total value of design expenditures of 173 firms from our sample reached $193.641 Mil. in 2007 and $220.477 Mil. in 2011.

< Insert Figure 3 here>

Patent-based measures of R&D internationalisation

Regarding the data on the R&D output side, we use patent data. Despite a number of limitations in using patents as a measure of international collaboration (Bergek & Bruzelius, 2010), patent-based indicators have a long-standing tradition in identifying internationalisation patterns (Bas & Sierra, 2002; Patel & Pavitt, 1991; Patel & Vega, 1999). However, while most of the previous studies have considered the patent portfolios of firms, here patents are attributed to countries. This way, our methodology of computing patent statistics follows the most recent approach in literature (de Rassenfosse, Dernis, Guellec, Picci, & van Pottelsberghe de la Potterie, 2011; Turlea et al., 2011). To avoid the problem of double-counting, we use priority patent applications.

Our analysis uses measures of internationalisation that are based on the presence of inventors and/or applicants residing in different regions of the world among the list of people who file a patent application. An international patent application is defined in the analysis presented here as a patent application with people and organizations residing or located in different countries or regions. Using this methodology, we use four concepts of internationalisation of a given patent are used in the analysis:

- **Co-invention**: A patent with at least two inventors residing in different countries or regions. This concept captures international co-inventions and is used to construct a relative measure of *international collaboration between inventors*.

- **Co-ownership of inventions**: A patent with at least two applicants residing in different countries. This concept is used to construct a measure of *international co-ownership of inventions*.

- **Cross-border ownership of inventions**: There are two concepts associated with this type of internationalisation that capture the notion of cross-border ownership of patents: 1) A domestic invention is owned by a foreign applicant. This concept captures foreign ownership of domestic inventions. It is used to construct a relative measure of *foreign ownership of domestic inventions*. 2) A domestic applicant owns a foreign invention. This concept captures domestic ownership of foreign inventions. It is used to construct a relative measure of *domestic ownership of foreign inventions*.

According to Table 1, there were nearly half a million of patent applications submitted to one of the patent offices considered in 1990. This number continued to grow, on average, nearly 4% per year. Regarding the number of international co-inventions there were only 804 applications that included at least two inventors from different countries in 1990. By 2007, this number grew to over 6.200 patent applications. Thus, as a share in total patent applications, the number of international co-inventions is marginal. This confirms the results of the findings concerning the low levels of internationalisation of R&D output (Patel & Pavitt, 1991; Picci, 2010). Nevertheless, this part of innovation activity should not be ignored, considering the increasing orientation of large firms to source their technologies from around the world and to patent the resulting inventions with the aim of exploiting them around the world (Nepelski, De Prato, & Stancik, 2011).

< Insert Table 1 here>

The source of the patent data is the European Patent Office (EPO) Worldwide Patent Statistical Database 2010.[iii] 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 USPTO, the Japan Patent Office as well as the other most active Patent Offices worldwide, including China and India. The time period taken into account covers from January 1990 to December 2007.

Data analysis of ICT R&D internationalisation

Location of ICT R&D centres

Where do ICT companies locate their R&D centres?

Figure 4 shows where companies from different regions tend to locate their R&D centres. Out of 743 R&D centres owned by EU companies, in 2009 51% were located in one of the EU. The other most frequent location choice for R&D activities among the EU firms was the US (18%) and Asia (18%). Only 3% of R&D centres owned by EU companies were located in Japan. 50% of the 1078 R&D centres owned by US companies were located in the US. The other most frequent locations for R&D activities among US firms were the EU and Asia. Only 2% of US-owned R&D centres were located in Japan. Over a half of the Japan-owned R&D centres were located in the Japan and 15% in other Asian countries. The remaining centres were located in either the EU or the US. 69% of the 273 R&D centres owned by Asian companies were located in Asia. As observed before (Van Hoesel, 1998), the other most frequent locations for R&D activities among Asian firms were the US and the EU. Only 3% of R&D centres owned by Asian companies were located in Japan.

The data presented above shows that the pattern of locating R&D activity in the same region as a company's headquarters is very common among all firms, as usually described in the literature. However, there are also some considerable differences between the regions. For example, whereas companies from the EU and the US have around 50% of their R&D centres located in other regions, their Asian counterparts maintain about 70% of their R&D centres in Asia and only 30% outside of Asia.

The data also confirms the existence of strong linkages between the EU and the US. As of 2009, of all the foreign locations, US ICT firms seem to consider the EU countries as most attractive for locating R&D centres outside the US. Very similarly, EU ICT firms seem to consider the US and Asia as the most attractive location for R&D centers. Each of these regions hosts 18% of all EU-owned research centers. Regarding the Asian countries, the analysis clearly shows their importance as a destination of R&D expenditures of foreign companies, particularly US and EU ones. For example, hosting 18% of EU-owned and 16% of US-owned R&D centres, Asian countries are already one of the most attractive foreign locations for EU and US companies for R&D activities.

< Insert Figure 4 here>

Who owns the ICT R&D centres?

Figure 5 shows the ownership structure of ICT R&D centres located in the five world regions. In 2009, 51% of the 749 ICT R&D centres located in the EU are owned by EU companies and 30% of them belong to companies with headquarters in the US. The remaining R&D centres belong to companies headquartered in Japan, Asia, and RoW. Also the largest percentage of ICT R&D centres located in the US is owned by domestic companies and 16% belong to EU firms. Companies based in Japan and Asia own 11% and 4% of R&D centres located in the US. The least internationalised R&D infrastructure is in Japan, where 89% of all R&D centres belong to domestic companies. Regarding the remaining Asian countries, only one third of R&D centres located in Asia belongs to domestic companies. This low share of ownership by domestic companies is exceptional among the analysed regions. Companies from the US and the EU own 29% and 22% of R&D centres located in Asia respectively, while their Japanese counterparts own 17% of the R&D centres located in Asia.

In general, the above analysis shows that domestic companies own the highest share of R&D centres located in each region. However, considerable differences between the ownership patterns exist. For example, whereas about half of the ICT R&D centres located in the EU are foreign owned, only 11% and 35% of the ICT R&D centres located in Japan and the US respectively are owned by foreign companies, and as much as two thirds of the ICT R&D centres located in Asia are foreign owned. Furthermore, although the data indicates the existence of strong linkages between the triadic countries, the role of Asia as one of the major R&D locations is considerable.

< Insert Figure 5 here>

Allocation of semiconductor design expenditures

Where do companies spend their money to make semiconductor designs?

Figure 6 presents the allocation of semiconductor design spending according to their source. In 2008, EU companies spent 70% of their semiconductor design budget within the EU. Among foreign destinations, Asia emerges as the major recipient of the semiconductor design expenditures by EU companies. In 2008, EU companies spent 16% of their semiconductor design budget in Asia, while only 9% was spent in the US. Despite some slight differences, US companies show similar allocation patterns of their semiconductor design expenditures. For US companies Asia seems to be the most attractive foreign location for developing electronic products. In 2008, 12% of the total budget of US companies was spent in Asia, as compared to 4% in the EU and only 1% in Japan. Also Japanese companies spend the majority of their semiconductor design expenditures within their own country. Regarding the amount spent in other regions, Japanese firms, like their counterparts from other regions, appear to favour Asia the most. In 2008, Asian countries received 7% of Japanese companies' semiconductor design budget. The data shows also that Asian companies concentrate their semiconductor design expenditures within their own region, where they spent 90% of their budget in 2008. Among foreign destinations of their semiconductor design expenditures, the US holds the first and the EU the second position.

The analysis of the data on the allocation of semiconductor design expenditures across the world regions reveals the following: First, as for other measures of inventive activity, irrespectively of the region of origin, companies tend to invest the largest share of their semiconductor design budget within the geographical borders of their home country or region. Second, in relative terms, Asia is the largest recipient of semiconductor design expenditures made by ICT firms abroad, regardless of the region of origin, except for firms from the RoW. As indicated in Figure 3, its importance in this respect can be expected to further increase in the very near future.

< Insert Figure 6 here>

What is the source of semiconductor design expenditures in each region?

Figure 7 provides information on the source of semiconductor design expenditures in the five regions in 2008. Concerning the EU, the major source of semiconductor design expenditures are EU companies. In 2008, over 80% of semiconductor design expenditures in the EU were made by domestic companies. Regarding the remaining sources, 8% and 6% came from the US and Japanese companies respectively, the largest foreign semiconductor design spenders in the EU. In the US, domestic companies are the largest semiconductor design investors and, in 2008, their share of semiconductor design expenditures invested in the US amounted to 83%. Among foreign companies, EU firms are the major investors in the US (5%). Firms from the remaining regions contributed equal shares of 4% to the total semiconductor design expenditures invested in the US. Also in Japan, the major investors of semiconductor design in this country are again local companies. In 2008, they contributed 95% of the total expenditures on semiconductor design. Among companies from other regions, only EU and US companies made notable contributions to semiconductor design spending in Japan. Companies from each of these regions accounted for 4% altogether of semiconductor design expenditures in Japan. This makes Japan the country with the lowest share of semiconductor design expenditure made by foreign companies.

Asia and the RoW show quite different patterns of semiconductor design expenditure composition from the other regions. In 2008, the Asian company share in the region's semiconductor design expenditures was 65% and for the RoW it was 56%. Both values are the lowest among the analysed regions. EU and US companies are the largest foreign semiconductor design investors in Asia and the RoW. For example, expenditures by EU companies amounted to 12% of the total spending on semiconductor design in Asia. For comparison, American companies contributed 16% to expenditures in the same region. Consequently, companies from these regions are the largest foreign contributors to the spending on semiconductor design in Asia.

The above data confirms that, in general, domestic companies contribute the most to expenditures on the design of electronic systems in each region. However, a detailed investigation reveals that some regions receive a higher share of foreign expenditures than others. For example, whereas only 5% of the semiconductor design expenditures in Japan are invested by foreign companies, the share of semiconductor design expenditures of foreign firms in Asia is 35%.

< Insert Figure 7 here>

Internationalisation of ICT R&D output: patents-based evidence

Following the logic of the R&D value chain as described briefly in Section 7.6, the current section attempts to measure and identify inventions, i.e. the output of R&D activity resulting from international collaboration. First, we compare the levels of internationalisation across the major world regions. Second, we analyses in detail the patterns of internationalisation in each of the five world regions.

Based on Figure 8, we can make a number of observations with respect to the four concepts of internationalisation described in Section 2. Regarding the level of international co-inventions, according to Figure 8a, the highest co-inventive activity occurs between RoW and non-RoW inventors. Lower co-inventive activity is observed for the EU and the US. Both these regions show very similar patterns, peaking at 2%. Japan and Asia are the only two regions with below 1%, a picture consistent with previous findings (Motohashi, 2008). Concerning the co-ownership of ICT inventions depicted in Figure 8b. we can see that although the ranking of regions stays the same as above, the levels of cross-regional collaboration are much lower. Co-ownership for the EU and US regions is again very similar, as it is for Japan and Asia. Figure 8c shows the level of foreign ownership of domestic ICT inventions for each region. It can be seen that between 1990 and 2007, this measure grows for every region except Asia. Furthermore, the level of ownership of EU inventions by foreign applicants is – at 10% – relatively high. US, Japan and Asia record a considerably lower level of inventions owned by foreign entities. Lastly, with respect to domestic ownership of foreign ICT inventions, Figure 8d shows that, in contrast to the previous case, the US report the highest share of ownership of foreign inventions, whereas the EU drops. At the same time, Japanese and Asian applicants do not show an intensive activity with respect to acquiring property rights over inventions developed outside of their home region.

The above allows us to draw the following conclusions. First, there are significant differences between the levels of the four alternative metrics, with the two measures of cross-border ownership of inventions being well above the measures of inventor collaboration and co-ownership of inventions. Second, these data show that, in general, the degree of internationalisation in the production of technology has increased since the early 90s, but it is still rather low. Third, there is a clear, though opposite, gap between the two measures of cross-border ownership of inventions in the case of the EU and the US. As regards the EU, it gives a hint of the importance of the role of foreign firms in EU inventive activity. The fact that the share of EU ICT inventions owned by non-EU applicants (Figure 8c) is higher than the share of non-EU ICT inventions owned by EU applicants (Figure 8d) indicates the relatively high importance of extra-EU applicants in the EU inventive activity. The typical case reflected by these data is a non-EU firm owning a R&D lab in Europe and filing patent applications either in Europe or in the US. Alternatively, as regards the gap in the case of the US, the share of US ICT inventions owned by non-US applicants (Figure 8c) is lower than the share of non-US ICT inventions owned by US applicants (Figure 8d). This highlights the important role of US firms in global inventive activity. The analysis also confirms that, until now, Japan and Asian countries report relatively modest tangible results of international collaboration, as measured by patents.

< Insert Figure 8 here>

The case of Asia

Regarding the remaining Asian countries, Figure 9a reveals that US inventors are the main partners of their Asian counterparts. Asian-US co-inventions account for almost 70% of all international co-inventions in the Asian region. The remaining portion of Asian collaboration is equally split between the EU, Japan and the RoW. Concerning the co-ownership of inventions, as illustrated by Figure 9b, there is a high level of volatility that results from a very low number of inventions co-owned by Asian and non-Asian applicants. Nevertheless, here again we can see a strong dominance of the US and Japanese partners. The former one plays also a key role in owning inventions developed by Asian inventors (see Figure 9c). With 20% of all Asian inventions owned by foreign entities, European applicants hold the second place after the US. The distribution of Asian ownership of foreign inventions is more diversified (see Figure

9d), though US inventions owned by Asian applicants form the largest part of foreign inventions owned by Asian entities. In contrast, although the ownership of Japanese inventions was at the level of the one by the US in 1990, it dropped significantly by 2007. At the same time, the EU has gained on attractiveness as a source of intellectual property for Asian applicants.

Concluding, the US is the most important partner for both Asian inventors and applicants in co-inventing and sharing property rights of intellectual assets. It is also striking how, despite its geographical proximity, the role of Japan as a partner of the remaining Asian countries decreased in terms of joint R&D projects over the last decades in favour of both the US and Europe.

< Insert Figure 9 here>

The case of Japan

Turning to Japan, Figure 10a shows that US inventors are the major partners of Japan in co-inventing. However, here again, we can see that Asian inventors are gaining on importance as co-invention partners. Concerning the co-ownership of inventions, Figure 10b reveals that there is a strong collaboration with the US, although from 2002 onwards, the number of EU and Asian inventions co-owned with Japanese entities increases considerably. A similar situation can be observed with regard to the foreign ownership of Japanese inventions. The main foreign owners of Japanese inventions are US applicants. However, their share has dropped from around 80% at the beginning of '90s to around 52% in 2007. This decrease resulted in an increase of the role of the EU and Asian applicants as holders of property tights over Japanese-developed inventions. This increase is clearly evident when, in 2003, the previous 80% US contribution is split between the EU and Asia, resulting in almost equal share for each of these three regions. Finally, Figure 10d illustrates the opposite relationship, i.e. distribution of international inventions owned by Japanese entities. In this case, there is still a clear dominance of the US as a destination of Japanese firms for sourcing invention outputs. The second most popular destination is the EU. Interestingly, Asian inventions do not play a considerable role in the pool of foreign inventions owned by Japanese applicants.

In summary, the above analysis of the regional composition of Japanese international collaboration indicates that the US plays a dominant role as a partner of Japan in terms of co-invention and co-ownership of inventions. Nevertheless, over the last few years we could witness a growing importance of other regions, in particular Asia and the EU.

< Insert Figure 10 here>

The case of the EU

Figure 11a casts some light on the international collaboration of EU inventors with inventors from other regions. This figure shows that US inventors, followed by their counterparts from the RoW and Asia, are the most important partners. Interestingly, while at the beginning of 90s, Asia played only a minor role, as compared to Japan, the situation has changed over the last two decades and Asian partners have gained a considerable more important role in collaboration with EU inventors, as compared with their Japanese counterparts. Regarding the co-ownership of inventions between EU and non-EU applicants, Figure 11b shows that the US and the RoW hold the leading position. Contributions by Japan and Asia are similarly volatile, but lower in magnitude. Concerning the ownership of EU inventions by foreign entities, Figure 11c reveals that

US applicants are the main foreign owners of EU ICT inventions, with around 70% average contribution, although their share has been decreasing over the last few years. At the same time, the role of Asian applicants is rising even though their contribution is still relatively low. Presenting the reverse relationship, Figure 11d shows the share of foreign inventions owned by EU applicants. The contribution of the US to the inventions portfolio owned by EU applicants is again very important and varies between 41% (in 1994) and 81% (in 2001). In 2007, this contribution is about 50% which means that out of all ICT inventions held by EU applicants, 2.7% are US inventions. The second most-owned foreign inventions are the ones originating from the RoW and Asia.

In summary, we can conclude that the US region, followed by the RoW, plays the most significant role as a partner for inventive collaboration for EU inventors in the ICT domain. However, the growing role of Asia, which seams to gain on importance at the cost of Japan, cannot be unnoticed.

< Insert Figure 11 here>

The case of the US

Figure 12a presents the role of the various regions as partners of the US in ICT co-inventive activities. It shows that although EU inventors were the major partners for the US at the beginning of 90s, their role has been overtaken by Asian inventors during the last few years. In 2007, Asian inventors' contribution to the US level of co-invention reaches 42%. Asian inventors gain mostly at the expense of Japanese ones. Regarding the level of co-ownership of ICT inventions between US and non-US applicants, Figure 12b shows that the majority of US inventions that are co-owned are co-owned with Japanese applicants. During the 90s, the Japanese contribution to the US level of co-ownership is stable around 70%. EU and Asian applicants then follow with 20% and 10% respectively. The situation, however, changes in 2000, when the contribution of Japan drops down to almost 25%, while the EU reaches more than 50% (2003). Although this change is temporary and lasts only a few years, US-Japanes co-ownership of inventions has never returned to its level from the beginning of '90s and today is much more diversified now. Regarding the levels of foreign ownership of US ICT inventions, Figure 12c shows a significant role of Japan in the 90s, which decreases from 2000, and an increasing role of the EU and Asia. Finally, concerning the ownership of foreign inventions by US applicants, Figure 12d reveals the important and stable role of the EU, the increasing role of Asia and the decreasing role of Japan.

In conclusion, the composition of US collaboration partners is much diversified and there is no single region that would play a dominant role. In contrast to the beginning of the '90s, the EU, Japan and Asia play equally important role, although the picture is changing permanently and very strong dynamics between the US and Asia can be observed.

< Insert Figure 12 here>

Synthesis of eight dimensions of ICT R&D internationalisation

Figure 13 provides a snapshot of the R&D internationalisation levels for each dimension used in this study and each region. First of all, it can be observed that the EU, the US and the RoW regions exhibit higher levels of internationalisation across all measures than Japan and Asia. Furthermore, there are considerable differences in R&D internationalisation strategies adopted by each region and/or gaps in the advancement in the process of internationalising R&D activities. For example, whereas the EU and the

US exhibit similar levels of the internationalisation of R&D input, i.e. R&D centres and semiconductor design expenditures, these regions show very different patterns with respect to cross-border ownership of inventions. In particular, the share of US-owned foreign ICT inventions is significantly higher than the corresponding measure for the EU. Similarly, although Japan and Asia show relatively similar levels of internationalisation of R&D input, they exhibit much lower levels of internationalisation of R&D output, as compared to the RoW, the EU and the US. These observations would seem to indicate that internationalisation of R&D activities depends on both the ICT R&D internationalisation 'path' (and policies) followed by each region and the actual strategies and capabilities of companies from different regions to develop ICT R&D activities on a global level.

< Insert Figure 13 here>

Implications

The paper confirms that the structure of the global R&D system is changing. On the one hand, these changes provide opportunities; on the other hand, managers and policy makers need to be alert to these changes more than before, so that they act on them. To provide a tool-set for reacting to these changes, we formulate some implications relevant in the process of innovation strategies at firm and country level. First of all, the internationalisation of innovation is a result of the international division of innovation processes in. Consequently, while designing R&D and innovation strategies, it is necessary to give them a multinational dimension. This requires a departure from the notion of competition for innovation recourses and focusing on the creation of a mutually beneficial system of collaboration between locations. Second, one of the major reasons behind the internationalisation of R&D is the increasing complexity of technologies. This requires both firms and countries to specialize. It means that innovation strategy of a country or a firm should assess its strengths in the global context and define mechanisms towards their enhancement. Third, the expansion of the global R&D system is driven the entry of developing countries. Thus, on the one hand, by linking up with more advanced countries they reach global technology standards more quickly and at lower cost than through independent expansion. On the other hand, by forming R&D ties with newcomers, developed economies gain access to new resource and develop them further in the process of mutual collaboration and expansion. Summing up, the new landscape of R&D challenges the way of national innovation policy making, defined by the notion of competition. If this collaborative and mutually-dependent way of organising economic and innovation activity becomes dominant in the future, the viability of the system will depend on the ability of countries to develop collaboration mechanisms that will support both mutual co-dependencies and rent sharing between them.

Conclusions

The conclusions of this work can be summarised as follows: First, regarding the level of internationalisation of R&D input most the firms tend to locate most of their R&D centres in their home country or region. Similarly, ICT companies tend to invest the largest share of their semiconductor design expenditures within their home region. However, there are some differences between firms from the five regions. For example, companies from Asia have the least, whereas EU, US and Japanese firms have the most internationalised R&D centre infrastructure. Furthermore, although it has been confirmed that there are very strong linkages between the triadic countries, i.e. Japan, the US and the EU, Asia seems to be very attractive as a location for R&D centres and also as a destination for expenditures in semiconductor design (Cho, Lim, Kwon, &

Sung, 2008). Second, concerning the internationalisation of ICT R&D output, the current analysis reveals some interesting patterns. For example, although, the levels of inventor and applicant collaboration in the US and in the EU have been very similar, there is an important difference with respect to the level of ownership of foreign inventions. US firms own significantly more patents including foreign inventors than EU firms do and, at the same time, more EU inventors file patent applications with foreign firms than US inventors do. In other words, although the degree of inventor collaboration and co-ownership of inventions in both regions are nearly identical, the share of US-owned foreign inventions is significantly higher than the corresponding measure for the EU. It can be interpreted that the US may better benefit from the process of internationalisation of inventive twofold. First, by capturing inventions developed overseas and, second, by having higher levels of collaboration with foreign researchers. The example of the collaboration between the US and Asia clearly support this point.

The preceding analysis suffers from a number of limitations, which mainly concern the data used. Moreover, we leave a number of questions that we can not answer with the available data. For example, at the firm level, it is unclear how the geographical expansion of R&D activities affects a firm's performance and its inventive capabilities. Similarly, at the country or regional level, there is the question of what is the overall effect of ICT R&D activity migration on local production and inventive capacities. These issues deserve further examination and create a challenge for the students of the internationalisation process.

Annex

Figures

Figure 1: Methodology to study R&D internationalisation

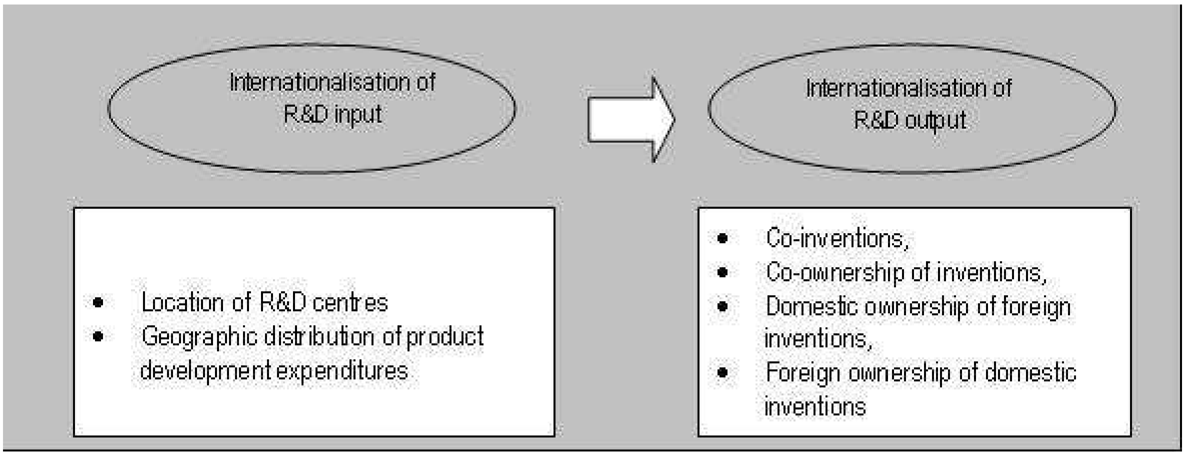


Figure 2: ICT R&D centres by region of ownership and location, 2009, in %

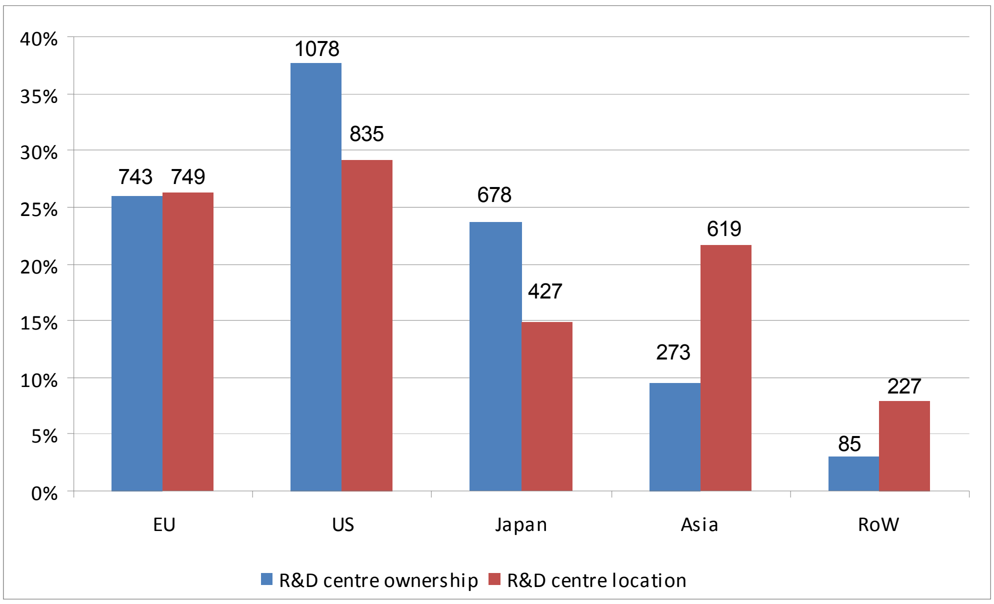


Figure 3: Allocation of semiconductor design expenditures, 2007-2011, in %

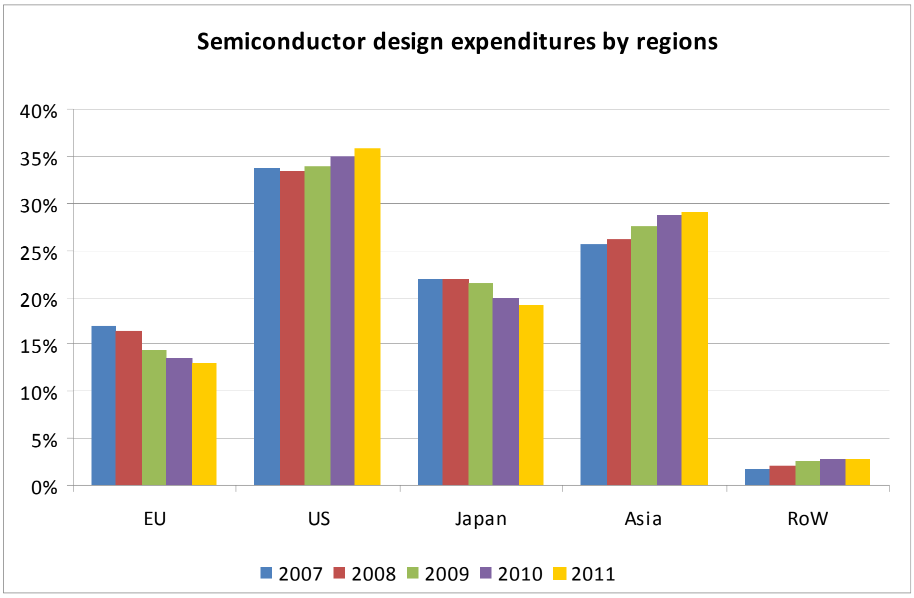


Figure 4: Location of ICT R&D centres by region of ownership, 2009, in %

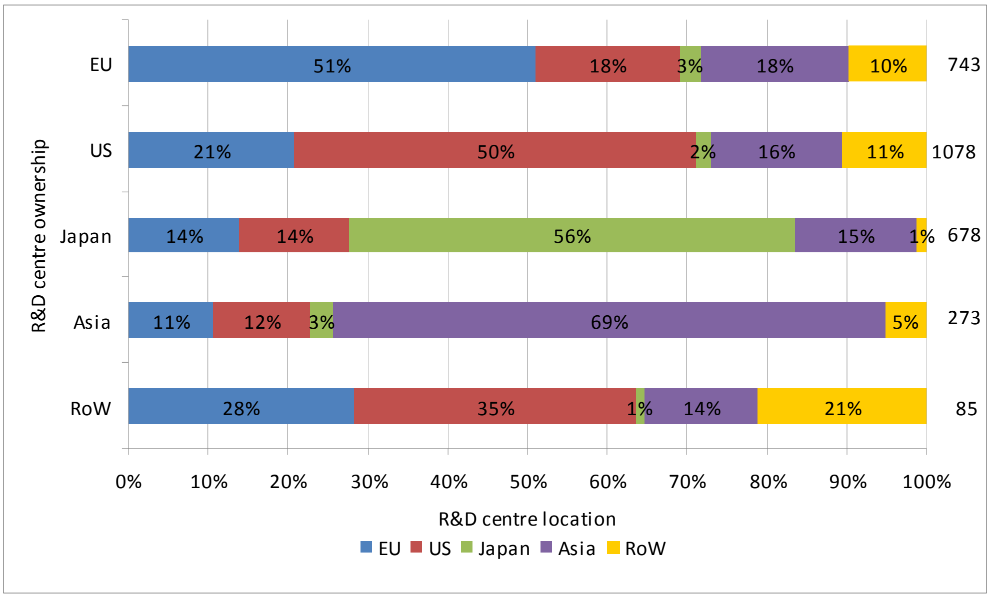


Figure 5: Ownership of ICT R&D centres by regions of locations, 2009, in %

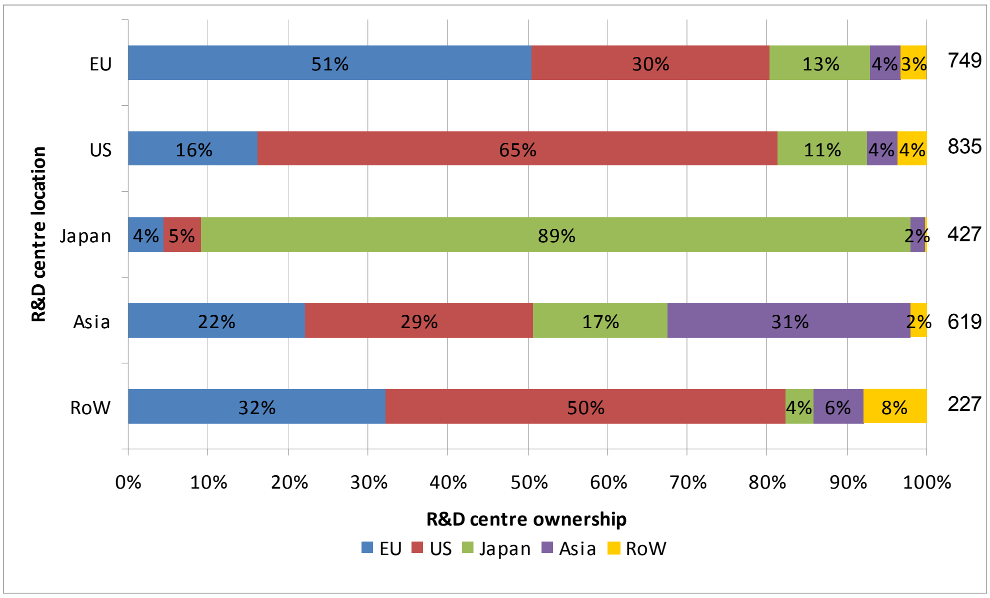


Figure 6: Destination of semiconductor design expenditures by source, 2008, in % and € million

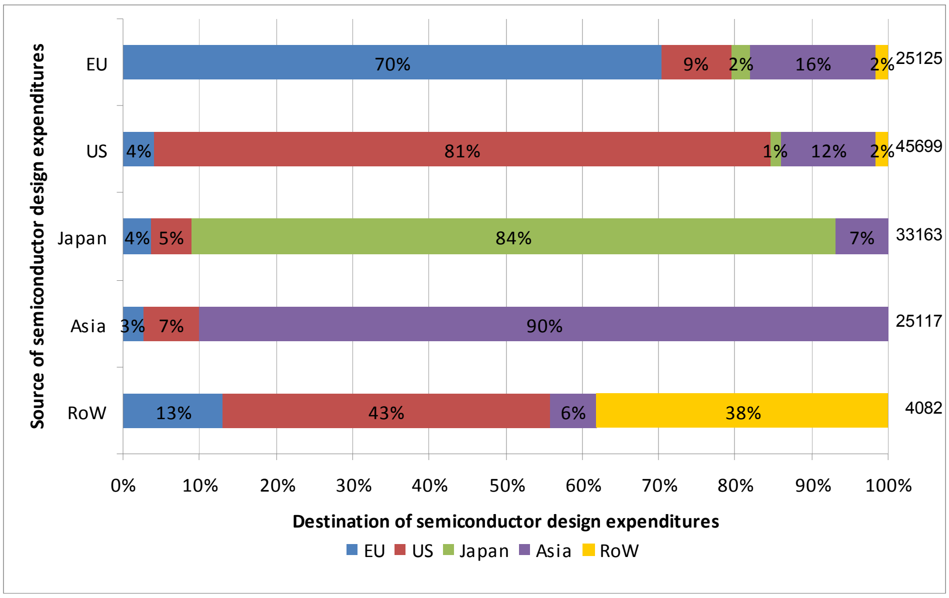


Figure 7: Source of semiconductor design expenditures by region, 2008, in % and € million

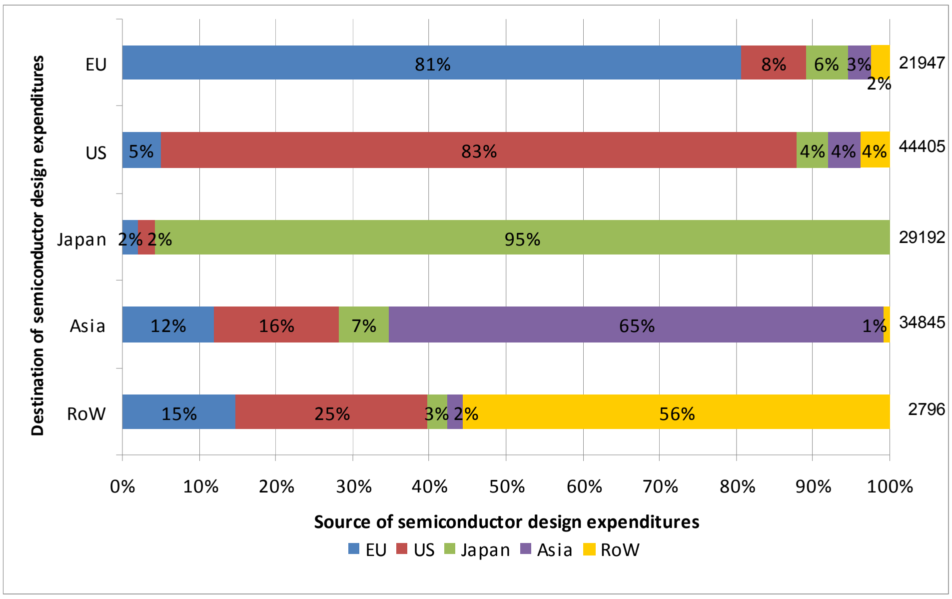


Figure 8: Shares of co-invention, co-ownership and cross-border ownership of inventions in the total number of ICT inventions

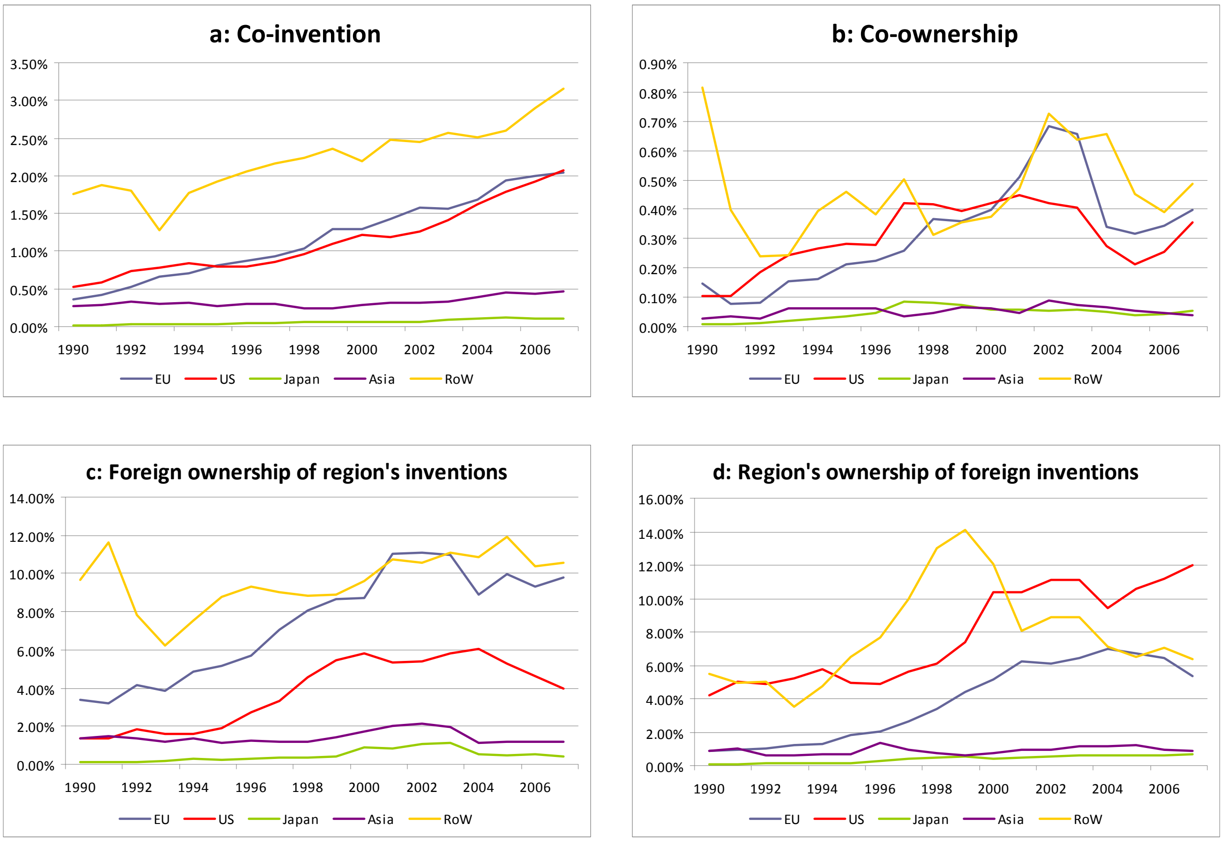


Figure 9: Asian ICT R&D collaborations

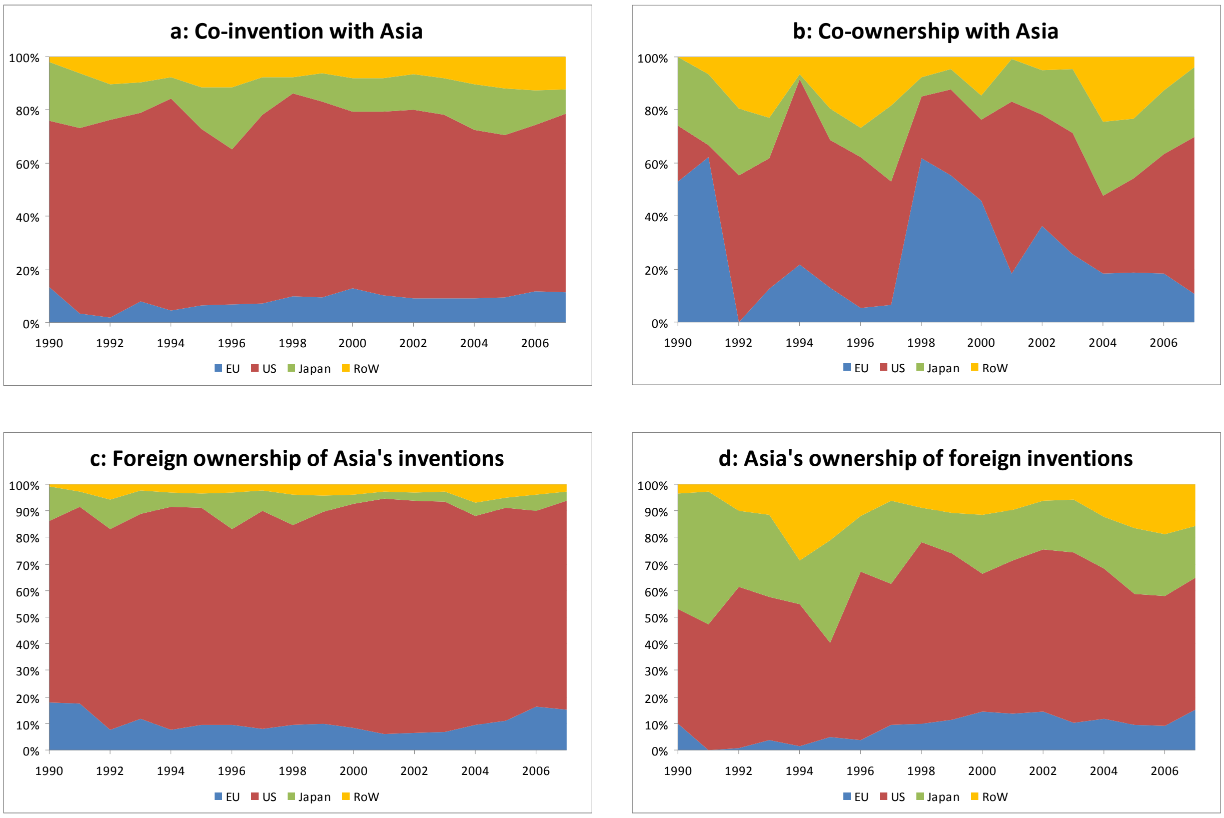


Figure 10: Japanese ICT R&D collaborations

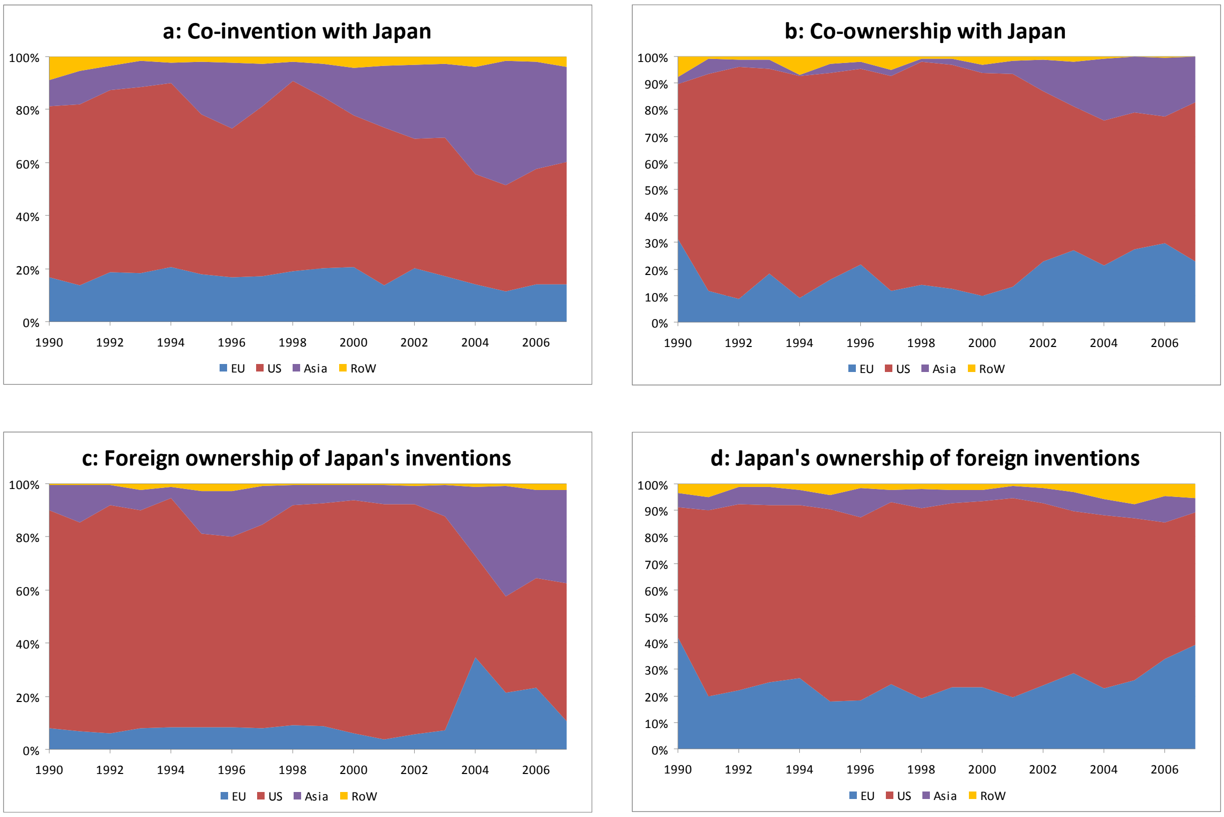


Figure 11: EU ICT R&D collaborations

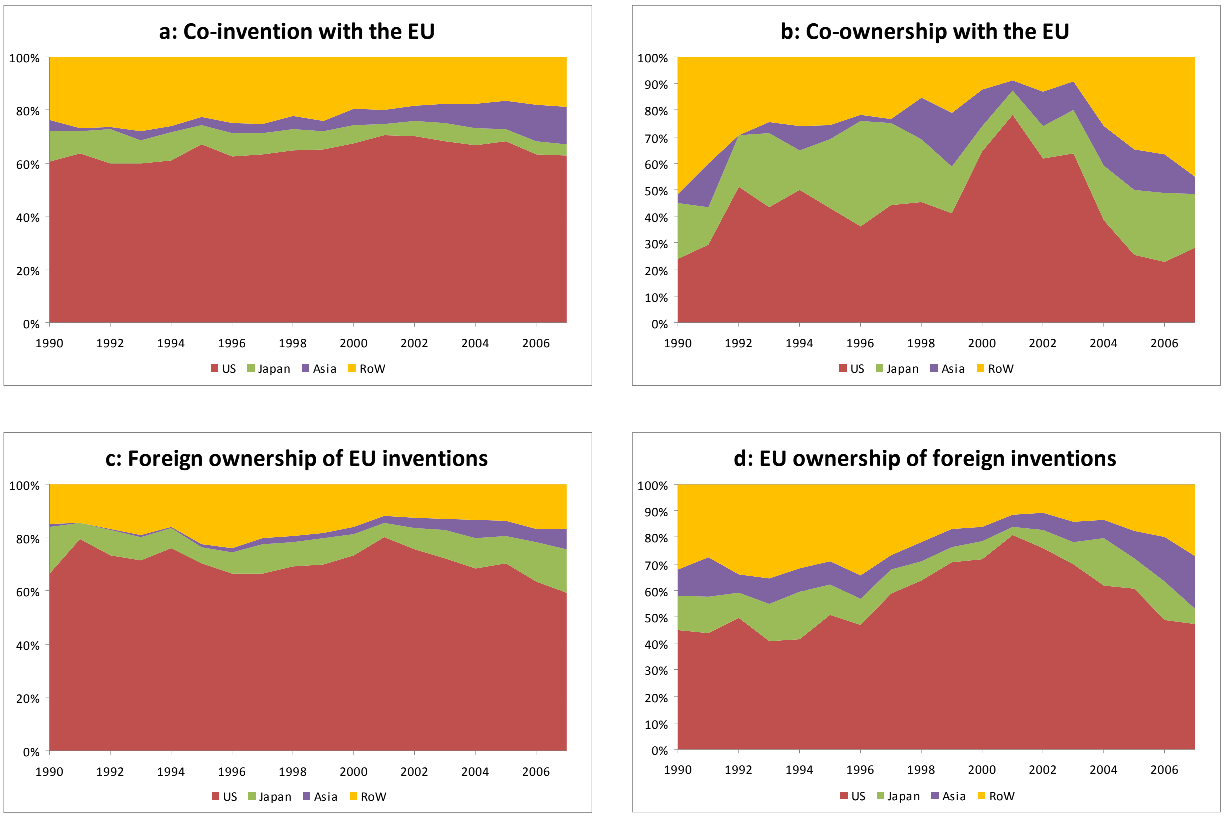


Figure 12: US ICT R&D collaborations

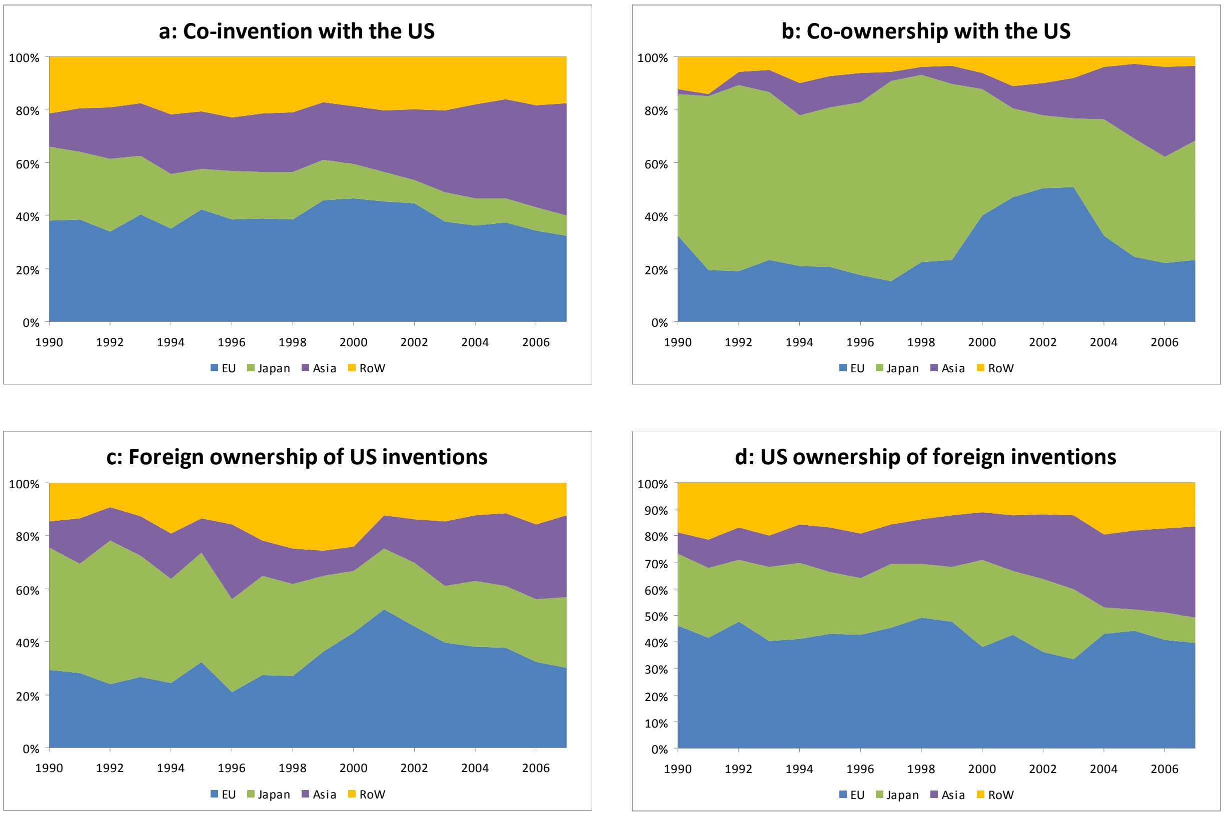
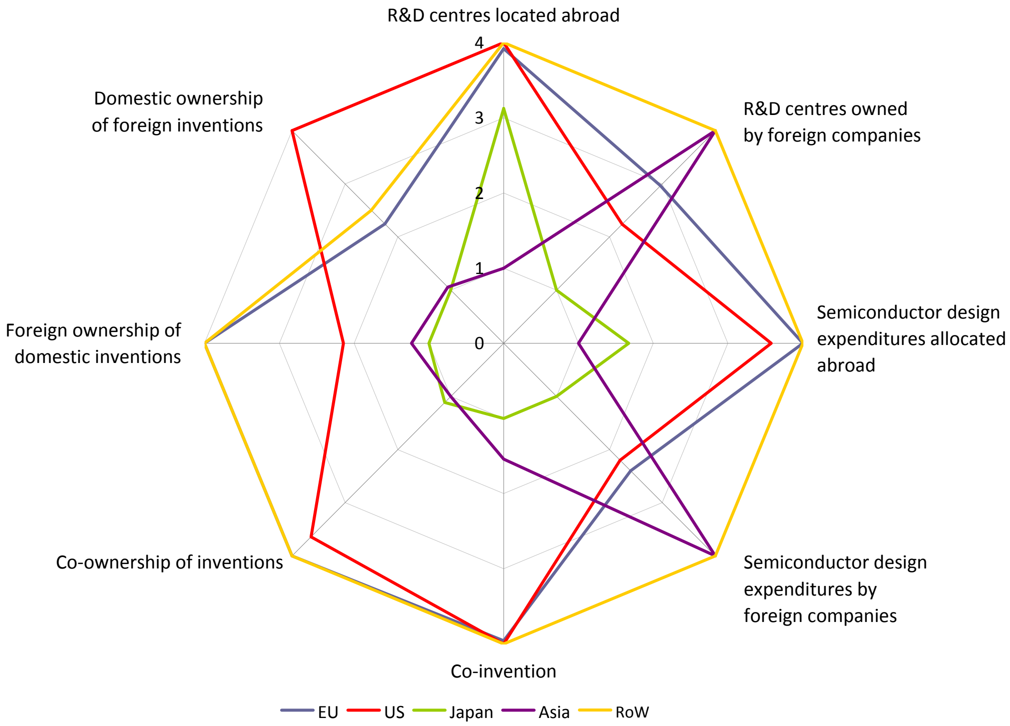


Figure 13: Eight dimensions of ICT R&D internationalization



Note: Values are normalized on a scale from 0 to 4.

Tables

Table 1. Number of patent and international patent applications

	1990	1995	2000	2005	2007
Total number of patent applications	456.425	530.448	666.936	765.175	777.551
Total number of international co-inventions	804	2.195	3.912	5.852	6.229
% of international patent applications in total	0,18	0,41	0,59	0,76	0,80

Source: Own calculations

Table 2: Distribution of companies' activities

ICB sector	% of total	Nr of centres	% of total
Computer Hardware	14,62	327	10,07
Electronic Equipment	11,11	336	10,35
Telecommunications Equipment	10,53	356	10,96
Automobiles & Parts	9,36	425	13,09
Leisure Goods	8,77	266	8,19
Aerospace & Defence	8,19	418	12,87
Electrical Components & Equipment	5,26	232	7,15
Consumer Electronics	4,68	59	1,82
Diversified Industrials	2,92	61	1,88
Electronic Office Equipment	2,92	70	2,16
Semiconductors	2,92	73	2,25
Computer Services	2,34	109	3,36
General Industrials	2,34	172	5,30
Health Care Equipment & Services	2,34	57	1,76
Household Goods & Home Construction	2,34	109	3,36
Durable Household Products	1,75	23	0,71
Pharmaceuticals	1,75	66	2,03
Technology Hardware & Equipment	1,75	10	0,31
Software	1,17	31	0,95
Construction & Materials	0,58	8	0,25
Industrial Machinery	0,58	15	0,46
Media	0,58	10	0,31
Medical Equipment	0,58	11	0,34
Support Services	0,58	3	0,09
	100	3247	100

Table 3: Distribution of companies by region

Region	Number of companies
Asia	31
EU	35
Japan	32
US	66
RoW	14
Total	178

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[i] Asia includes India, China, South Korea, Taiwan, Singapore; and the RoW covers Australia, Canada, Switzerland, Turkey, Russia, and Norway, the other countries in South and Central America, the other countries in Asia including the Middle-East, and Africa.

[ii] See ICT Scoreboard, Nepelski D., Stancik J. (2011). 'The top world R&D-investing companies from the ICT sector – a company-level analysis'. JRC Scientific and Technical Report IPTS, JRC, http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=4379

[iii] To identify ICT patent applications, the taxonomy of the IPC technology classes proposed by the OECD is adopted (OECD, 2008)