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Co-patenting networks in nanotechnology: A comparison of South Korea and Germany

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Abstract

South Korea and Germany are among the nations with highly productive regions in information technology, biotechnology and nanotechnology. While Germany has a long history of government investment in science and technology, South Korea is a late-comer trying to catch-up. Interestingly, nanotechnology is a field in which South Korea seems to have not only caught-up, but 'leap-frogged' over many of the developed countries such as Germany. Among other reasons, this could be because of better public-private collaboration, as according to frameworks such as the Triple Helix model and innovation studies in the national system of innovation stream, collaboration between firms and public universities/universities is crucial for the build-up of capabilities in new science based sectors. The present chapter examines this hypothesis through a study of collective patent applications (i.e. associated with more than one organisation) in nanoscience and nanotechnology within the larger field of materials science and technology. Analysis confirms the crucial role of public laboratories in kick-starting revolutionary new technology paradigms such as nanotechnology in both countries. One of the explanatory factors for the leadership of South Korea seems to lie in the fact that large firms are the gatekeepers of knowledge flows in its innovation system as reflected by the collective patents; while in Germany this role is assumed by the public laboratories.

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Introduction

A number of scholars consider innovations to emerge within a system through interactions between different economic actors such as the state, public agencies, firms, public laboratories, universities, civil society etc. (Freeman, 1987; Lundvall, 1992; and Nelson 1993). Initially, such systems were considered at a national level, but increasing globalisation of innovation processes has replaced the national focus with a more outward, internationalized, outlook, to include regional (Cooke, 1994) and sectoral (Malerba and Orsenigo, 1997) perspectives. In these innovation systems, universities, public research organisations directly sponsored by government and firms are the dominant players engaged in R&D activity. Together, they are instrumental in determining the "rate and direction of inventive activity"[1]. Therefore, collaboration between these actors is deemed particularly important for the build-up of capabilities in new science based sectors like nanotechnology. But what kinds of collaborations are most effective? Are there patterns which are most suitable for a specific context or a target than another? The existing literature is relatively silent on such issues. This leads to the query, since the race to acquire capabilities in nanotechnology is relatively recent, and public-private collaboration is important for the same: can different countries exhibit different patterns of cooperation between public laboratories and private firms? In this chapter we attempt to provide to a partial answer to the above question, by identifying and comparing patterns in collaborative patents in Germany and South Korea.

In standard convention, peer-reviewed publications are considered as an indicator of knowledge generation (De Solla Price, 1963[2)], and patent applications are taken as an indicator of applied scientific R&D outputs (Jaffe, 1989). Publications issue more from public or academic institutions, while patent applications are more accounted for by firms. This is obviously because intellectual property and copyright protection are far more pressing to firms than the sharing of front-line/cutting-edge (theoretical) research.

An organisation can create the knowledge forming the basis of a patent application either through internal R&D or through external strategic alliances. In the latter case, the partners are likely to deposit the patent application together. A patent application, whether individual or joint, signifies an R&D effort already undertaken, even if it is not granted (Grupp 1998). In other words, a joint patent indicates an R&D effort that not only represents a common goal of the actors involved, but also signifies a relationship. Thus, patent application data is an ideal source for studying university-industry collaboration. Moreover, these relationships can be calculated and visualized through network analysis and network graphs in order to draw inferences on the underlying national innovation policies that produced them.

Nanosciences and nanotechnology (Nano S&T) are an offshoot of material sciences and technology (Materials S&T). Material science is a very broad area of research encompassing parts of engineering, math, physics, chemistry, geology and biology. What is specific to materials science is the interest in understanding the properties of materials, and on the basis of these properties to explore the ways of engineering (creating) and re-engineering (transforming) matter so that the examined materials become useful in industrial processes or as a product. Nanotechnology is part of this last quest, where the re-engineering of materials occurs at the molecular, and even atomic level, in order to change the properties of the materials to suit their possible application in an industrial process or product. This inclusion is also apparent if we look at education in nanoscience

[1] See "The Rate and Direction of Inventive Activity", R. Nelson (ed.), NBER, 1962

2 Little Science, Big Science, by D. De Solla Price.(1963) NY: Columbia Univ Press

and technology, where most courses given are positioned within a department or faculty of materials science and engineering.

South Korea and Germany are interesting to compare as countries, because of some basic similarities in their national innovation system coupled with their leadership positions in nanotechnology. The industrial focus of both countries is on the medium and high-tech manufacturing sectors. They are both endowed with a large and qualified work force, though shortages of high-skilled labour are envisaged in the near future due to a progressively graying work-force. South Korea and Germany are also among the nations with highly productive regions in information technology, biotechnology and nanotechnology (see graph in figure A1 in appendix). Germany however has a longer history of government investment in science and technology and economic growth fuelled by innovation. By comparison, South Korea is a late-comer which has to catch-up. Interestingly, nanotechnology is a field in which South Korea seems to have not only caught-up but ‘leap-frogged’ over many of the developed countries such as Germany. For instance, in the older area of Material S&T, in 2008, Germany had 11295 patent filings, while South Korea accounted for only 6208 in the European patent office[3]. However, for Nano S&T, the leadership is reversed with 86 patent filings for South Korea as opposed to just 18 for Germany. Even if we take a longer view (1975-2009) South Korea is ahead of Germany with 1507 filings as compared to 517 for Germany. Given that public-private collaboration is important for creating capabilities in new science intensive sectors, in order to examine if this played a role in the leap-frogging feat of Korea, it is pertinent to focus on co-deposited patents issuing from the two countries in Materials S&T and Nano S&T.

The present chapter, while studying public-private cooperation in Materials S&T and Nano S&T using patent statistics, aims to make a contribution to the literature on the triple helix model within the catch-up literature. Knowledge intensive sectors like microelectronics and biotechnology emerged through collaboration between universities, public research institutions and firms with support from the state (Jolly and Ramani, 1996). Scholars referred to this pattern of knowledge creation and utilisation, as the Triple Helix model, or Mode 2, as opposed to the classical Mode 1 (Etzkowitz and Leydesdorff, 2000). In Mode 1, knowledge was generated within types of institutions different from those in which it was later applied. For instance, universities were engaged in pure research; public research identified those that could be transformed into technology and developed the same at a pilot scale, which were then transferred to firms for scaling-up and manufacturing. There was thus both a chronological and an institutional separation, between the locus and time of the processes of knowledge generation and utilisation. Under the triple helix model, this neat separation does not apply any more. Very basic types of new knowledge are extremely rapidly applied, but this gives rise to feedback loops in which industrial applications call forth new types of basic research. Moreover, industrial firms do some basic research while public research institutions are increasingly pushed towards industrial applications. Thus, both the chronological and the institutional separation of the traditional model have become very fuzzy. However, within the Mode 2, Triple Helix model, there has not been a study of variety. It would seem therefore, that patterns of public-private collaboration required for building capabilities in new and emerging sectors like nanotechnology would be more or less the same.

Technology and innovation policies shape the triple helix model at multiple levels; starting from a local district to a national or a regional level; sometimes with a specific technology and industrial focus. They are implemented through government agencies and clusters of public research organizations. Different countries need not only have different policies, but they can also vary in terms of the effectiveness of national agencies propagating the government policies. Hence, the point of departure for our chapter is the assumption that the impact of the national system of

[3] PATSTAT database.

innovation on the triple helix is likely to be noticeable in the networks of the collaborative R&D between public sector organizations and firms at both sectoral and intersectoral[4] levels, and nationally as well as internationally.

Our assumption is founded on the fact that that 'knowledge stocks' , 'knowledge flows' and the 'distances between actors' matter for the innovation performance of a region. The stocks of knowledge accumulated in a country matters as Lundvall (1992, p. 1) points out in the first chapter of his seminal work: "the most fundamental resource in the modern economy is knowledge". This in turn depends on the capacity of the national education and training system to facilitate an "education led growth" (Nelson, 1993, p. 511). The competitive position of countries in "high tech" industries "depends on the availability of university-trained people" (Nelson, 1993, p. 511). For instance, strong firms emerged in the electronics industry in Japan and Taiwan through support by useful research in universities or public laboratories (Nelson, 1993, p. 513).

The growth of knowledge stocks depends on the circulation of knowledge within the country and with international partners. This point is driven home by Nelson (1993, p. 511) who points out that in the US and Germany, skills and knowledge flows within the country were crucial for innovation performance, because the university systems of these countries were "more responsive to the training needs of (the science-based) industry". When universities and public research organizations actively support (national) firms, there are direct interactions and strong linkages between them with circulation of knowledge and skills. Local knowledge networks are highly important, and in addition, inter-regional or international knowledge exchanges within and between clusters have been recognized as complementing the local knowledge networks (Bathelt, Malmberg and Maskell, 2004). Especially in high tech environments, knowledge spillovers are not always achievable locally, forcing firms and also public educational and research institutions, to access knowledge bases further afield.

Among other factors, the geographical concentration of organizations also crucially determines the circulation of knowledge, including both tacit and codified knowledge (Breschi and Malerba, 2001). The presence of clusters is of even greater importance to tacit knowledge exchange than for codified knowledge exchange (Maskell and Malmberg, 1999). For front-line technologies, geographical distance, is not so much an influencing parameter, as "cognitive distance" (Dolfsma and Van der Panne, 2003) between collaborating entities.

The use of social network analysis to study the impact of innovation studies has been explored by scholars in a variety of social sciences. For instance, sociologists like Granovetter (1973), and Wasserman and Faust (1994), have highlighted that the roles of different actors in decision-making networks are not the same. Researchers in economic geography saw the value of social network analysis as a methodology bridging the economics of location and geography, and the (social) relationships of the actors concentrated in certain geographical locations (Boschma and Lambooy, 2002). These methods were quickly picked up by evolutionary economists who likewise saw the extension of these ideas into their domain (Breschi and Lissoni, 2001). The combination of spatial agglomeration (Powell et al, 2002) in economic geography, and cluster theory and innovation systems thinking in economics are perfectly combined using social network analysis (Verspagen and Schoenmakers, 2004, Cowan, Jonard and Ozman, 2004).

However, the locational influences on innovative activity were largely ignored by the authors working on innovation systems in the eighties and early nineties of the previous century. This was rectified only after the realization that outside of "hard" economic factors there are also some less obvious factors influencing these innovation systems, among which 'learning' and 'knowledge spillovers' are most important.

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[4] See "Intersectoral innovation flows and national technological systems: network analysis for comparing Italy and Germany" by R. Leoncini, M. Maggioni, and S. Montresor.

Early research led to the belief that proximity was nearly everything for knowledge transfer in the early stages of an industry life cycle (Audretsch and Feldman, 1996). However, more recent research points to different and more international dynamics playing a role, especially for mature industries (Ter Wal, 2008). Front-line or high tech R&D still confirms to a certain extent, the advantages of proximity rendered by technology clusters (Nachum and Keeble, 2003). This in turn implies that when and where governments fund education, R&D and industry matters crucially (Powel et al, 2002).

All the above arguments confirm that an examination of the collaborative networks involved in patent applications would help us to understand the nature of the functioning of the country-specific triple helix of Germany and South Korea. It would identify key-players on an organizational plane and differences in the public-private linkages in different countries. It will also provide some insight on how the patterns of the linkages corroborate the national innovation systems and the technology and innovation policies currently in place.

The remainder of this chapter is organized as follows. Section 2 presents the main concepts of network analysis that will be used to examine the Nano and Materials S&T patent applications of Germany and South Korea. Section 3 contains the main results. Section 4 attempts to explain the patterns of network collaboration as a function of the country specific triple helix functioning in the two national systems of innovation. Finally, section 5 concludes.

2. Methodology: Compilation of the database and the concepts used

2.1 Compilation of data base

The corpus of patent applications used in this paper has been extracted from the European Patents Office's PATSTAT[5] database which incorporates applications at various patent offices both national and supra-national. These include USPTO[6] and JPO, as well as EPO and WIPO patent applications. The data collected for Nano S&T includes applications (13567 applications and 3757 assignees) deposited from 1975 onwards up until 2009, while the Materials S&T data (158410 applications and 30736 assignees) is for 2008 and 2009. The shorter time period is a response to the much larger amount of data available for Materials S&T, which makes the network too dense to be amenable to network analysis. But, methodologically this is not problematic, because Materials S&T is a much older technology niche and therefore collaborating patterns in it are bound to be set, whereas Nano S&T is a very recent and evolving field and therefore we need to gather as much data as possible to have a critically large dataset and also to identify the dominant patterns. As the materials science data falls within the last years collected for the Nano S&T data this criterion has been satisfied.

The patent data for both areas was identified using IPC[7]classification codes. In the case of Nano S&T this is more straight-forward than in the case of Materials S&T. For Nano S&T applications a specific IPC class has been created; B82. For Materials S&T we first started with a few queries looking for materials manipulation and processing in titles and abstracts after which we used the resulting codes to further define the field. The top 25 IPC classes, in terms of number of applications retrieved, can be found in table A2 in the Appendix.

An organisation can apply for a patent alone or with a set of collaborators. Patent applications involving more than one assignee are referred to as collective patents and the set of collaborating organisations which are associated with a collective patent application are its co-patentees. Thus, from the set of patent applications, we extracted the assignee and co-assignee

[5] PATSTAT= EPO Worldwide Patent Statistical Database
[6] USPTO = United States Patent and Trademark Office. JPO = Japan Patent Office; EPO = European Patent Office; WIPO = World Intellectual Property Organisation.
[7] IPC= International Patent Classification.

names and addresses. These names and addresses needed to be cleaned as for instance synonyms, and misspellings are common errors that occur in this type of data. Using fuzzy matching algorithms contained within the VantagePoint bibliometric software we were able to clean the data. Next, we extracted the collective patents using co-assignee matrices while validating the results manually through direct observation.

After these procedures, we had a set of 517 Nano S&T patent applications, with 160 (co-) assignees, for Germany and 1507 patents application, with 267 (co-)assignees, for South Korea. For Materials S&T, there were 14168, with 2871 (co-) assignees, for Germany and 6713 patent application, with 1310 (co-) assignees, for South Korea. Next, we performed desk-top research to further categorize the patentees as follows: large national firms, large international firms, small and medium sized firms national (SMEs) and national public laboratories/universities and foreign universities. Companies with less than 300 employees were classified as SMEs. As national policies are the ultimate goal of analysis, the technology generation activities of foreign owned subsidiaries located in the nation of interest were also considered. Thus our data included patent applications by affiliates and subsidiaries of foreign firms as well as different country locations.

2.2 Concepts used

A set of collective patents and its associated set of co-patentees can be represented as a network, where the nodes of the network represent the patentees. Each patentee is associated with a finite number of other patentees for a single patent application. Similarly, summing over the entire stock of patent applications, each patentee is linked to a finite set of other patentees through its stock of patent applications. Again, considering all co-patentees, a network can be generated to represent the links between all co-patentees associated with a set of collective patents in a corpus of patent applications. Two kinds of relationships are particularly useful to visualise: a dyadic relationship or a link between two organisations and a triadic relationship or a link between three organisations. Three concepts are then used to understand the nature of the collaboration as revealed by the networks.

Density of collaboration between two organisations: This is simply the number of patents, which they have deposited together. In this paper densities were identified using UCINET 6 social network analysis software. This software builds 'adjacency matrices' or a square matrix between all co-patentees indicating the number of patent applications that any two organisations have applied for in common. In a network, a higher density can be visualized by a thicker arc representing the stronger dyadic relationship between, or a greater number of joint patent applications by, the two associated co-patentees.

If the organization which is leading the research effort is known, or if a direction is discernible in some other way from the data, a direction of knowledge flow can be inferred and the network of collaborating organizations is called a directed network. In our patent application data no direction was evident and although we could theorize that where public research institutes and universities are cooperating with industry, the former is likely to have come up with the basic science informing the applied work, this cannot be inferred without reservations. Similarly, it could be true that collaborative behaviour was forced upon the actors through government policy where funding requirements entailed a public-private partnership. Thus, we considered our networks to be un-directed.

Betweeness centrality of an organisation: This centrality concept gives an indication of the extent to which an actor, or organization in this case, controls the flow of information and knowledge between two other actors which are not directly connected. An organisation with a high betweenness centrality score can be considered as a gate keeper of knowledge flows in the network[8]. One of the advantages of the type of network data[9] we are working with is that we can more easily apply the Betweenness Centrality measure. The 'Betweenness Centrality' of a certain node is equal to the number of geodesic (shortest) paths from all nodes to all others that pass through that certain node, and as such measures the control this node has over the knowledge transferred along the connecting links. The geodesic path is the shortest distance from one node to the other travelling along the least amount of "edges" or links. To illustrate; for instance if organization A has to communicate "through" organization B in order to reach the information or knowledge owned by organization C, we can see that organization B has the power to influence and control various attributes of the information or knowledge owned by organization C and desired by organization A. Then organization B might be deemed to have a powerful position in this network. However, this will be so only if there are no alternative geodesic paths of similar distance for organization A to choose from in order to reach organization C. Here network redundancy measures come into play.

Network Redundancy[10]: Network redundancy is an indicator of the robustness of the network to the exit of the economic actors involved in the network. There is 'redundancy' in a network if there is a pathway that to connect all nodes even if one link goes down. If we take the example used above where organization A would like to reach organization C in order to communicate information and knowledge. The shortest route from A to C would be through organization B giving organization B a relatively important position with a higher betweenness centrality measure. However if organization B would be removed from the network, organization A would need to look for alternative routes to organization C. If there is an alternative longer path, say through organizations D and E then there is redundancy in the network. The higher is the number of alternative paths, the higher is the redundancy in the network. What is also clear from this example is that in the case of a stable network, organization B can only maintain its high betweenness centrality if there are no other organizations which can fulfil its gate keeping role. Hence for policy purposes it would be important to have some but not too much redundancy in the network governed by the possible policies. When we look at the redundancy of information and knowledge in a network we can also see something of a trade-off. In networks with high redundancy all nodes would have access to all information or knowledge available in the network, theoretically speaking, For innovation this would be not such good news as no re-combination of new knowledge would be possible. Looked at redundancy from this perspective, a certain amount of non-redundancy would also be beneficial (Jensen and Greve, 2002, Reagans and Zuckerman, 2008)

3. Results on collaborative networks

With respect to the triple helix model, the differences in the two technology areas and between the two countries were evident from the start. Table 1 presents two main features of assignees in the two technologies and countries.

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[8] Betweenness is in this case a more logical metric to use instead of Degree Centrality as we are not interested in the popularity of a certain node, e.g. the number of edges or links leading to or from the aforementioned node, but in the impact of a certain node's position in the network on the network.

[9] The data we have collected is undirected in nature. This means that we cannot discern in- or out-going links, e.g. we do not know which of the organizations is providing the knowledge and which organization is using the knowledge. It might even be both; each organization is receiving from, and giving knowledge to, the other partner(s).

[10] This is a concept which was developed to explain, and implement in real life, specific elements introduced into a network to increase the reliability of a network and to safeguard against network failure. This was initially done by duplicating network structures, where, in case the original structure would fail the duplicate could pick up the activity of the network and as such make sure the network would remain in same or similar state of operation. This concept is of extreme importance in a utility network such as an electrical power network (eg. national grid) or other infrastructural networks (one can think of traffic networks or communication networks). However in social networks this concept can also play a valuable role.

Table 1. A comparison of assignees in the patent applications of South Korea and Germany

	Nano S&T		*Materials S&T*	
	Korea	*Germany*	*Korea*	*Germany*
Total number of assignees in the total number of patent applications	1622 (100%)	552 (100%)	7008 (100%)	14650 (100%)
Total number of collaborative assignees	128 (7.9%)	57 (10.3%)	403 (5.8%)	1047 (7.1%)
Total number of foreign collaborative assignees	13 (0.8%)	22 (4%)	108 (1.5%)	565 (3.9%)

Note: Assignees determined on the basis of their address data, after cleaning organization names and addresses.

As can be seen, the triple helix model concerns less than 11% of the total number of assignees in any technology and in any country. This means that collaboration is still the exception rather than the norm of patent application. This is not surprising since there are commercial stakes involved, but nevertheless it is noteworthy. The propensity to opt for collaboration seems higher in Germany than in South Korea whether the technology is broad and mature (7.1% compared to 5.8%) or narrow and young (10.3% as compared to 7.9%). However, within each country, the propensity to choose the collaboration avenue is higher in Nano S&T as compared to Materials S&T (7.9% as compared to 5.8% in South Korea and 10.3% as compared to 7.1% in Germany). Similarly, there is a higher propensity for the German to include foreign organisations as collaborators as compared to South Korea in any technology (3.9% vs. 1.5% in Materials and 4% vs.).8% in Nano). Very strangely, despite the commercial interests associated with a new technology paradigm, the propensity to be involved with foreign organisations is less in Nano as compared to Materials in South Korea (0.8% vs. 1.5%) but not in Germany (4% vs. 3.9%). However, this last fact could be due to the European Commission Programmes which enforce collaboration between different European countries in order to avail of funds.

Now, the networks representing the collaborative behaviour of the above co-patentees can be visualised using UCINET 6, and the Netdraw software embedded therein. If we were to examine all the different clusters existing, it would not be possible to analyse them given their density and complexity, especially in the Materials S&T. Thus, the networks visualized are those of the core clusters, which are the largest set of interconnected nodes. These main components of the network are calculated by the software, while node size and links thickness is established using Betweenness Centrality and tie strength measures. The tie strength is simply the strength of the dyadic relationship between the two nodes as given by the number of joint patent applications by the two associated co-patentees.

South Korean Nano S&T

Figure 1 presents the core Nano S&T cluster in South Korea using *Betweenness Centrality* as a network measure corresponding to the years 1975-2009. We see that Samsung Electronics is a central node in this network. Other Chaebol (South Korean business conglomerates that are multinational, often with a high degree of family control and close links with the government) are present in this network, although not that prominent, chiefly among which is Hyundai Motors. A small number of SMEs are also present although they do not fill any knowledge controlling positions. Compared to the German nano S&T network it is more considerable in size, as it does not only have more nodes but also more links between the nodes.

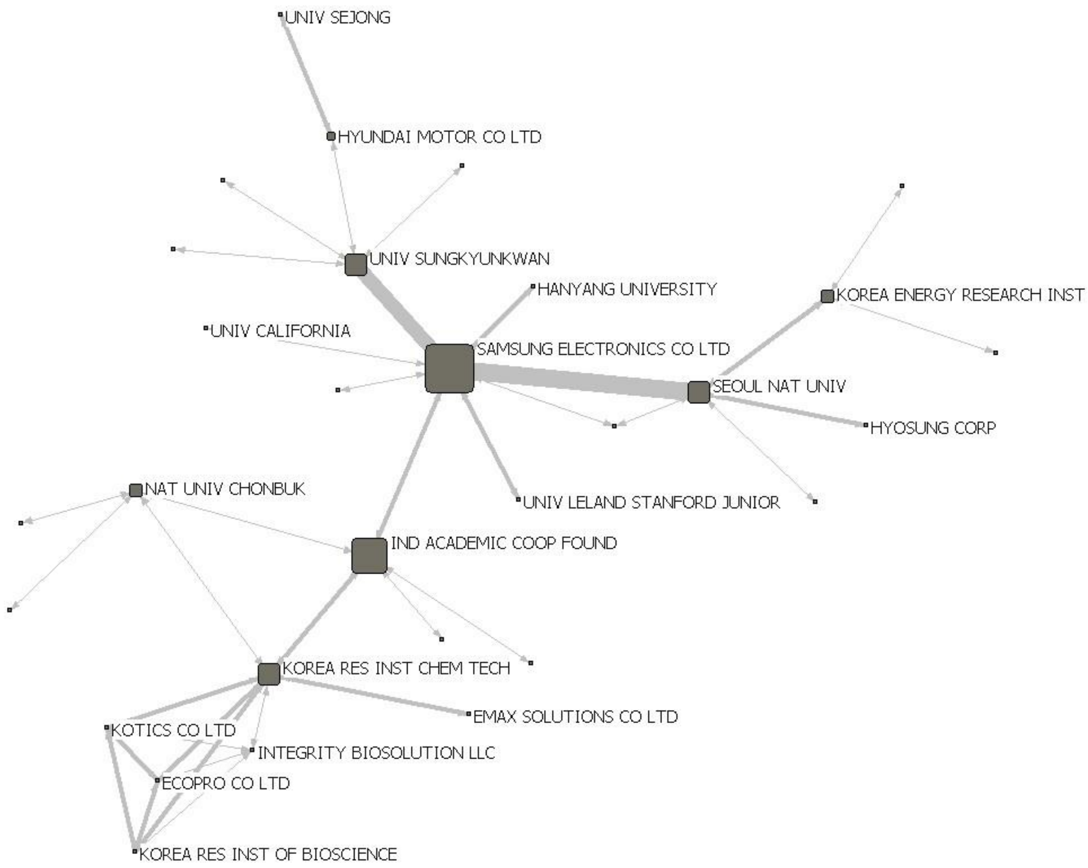

Figure 1: Core sectoral cluster in collaborative South Korean Nano S&T

Note: Author's own calculations

As the figure shows, redundancy is present only in the cluster around the node representing the Korean Research Institute of Chemical Technology. The technology associated with the patent applications corresponding to this cluster is nanobiotechnology. Another striking feature of this cluster is that it is the only one involving industry-industry collaboration. As shown in the figure, the Korean Research Institute of Chemical Technology has collaborations with KOTICS Co Ltd, Integrity Biosolutions LLC, Ecopro Co Ltd and the Korean Research Institute of Bioscience.

According to figure 1, eight of the top ten South Korean organizations which occupy a position of importance for the control of knowledge flows are universities and public research institutes. A special position is taken by the Industry University Cooperation Foundation (IUCF), these are centrally regulated intellectual property offices set-up by most universities in South-Korea as a response to technology transfer promotion policies instituted by the Ministry of Education and S&T (MEST) enabling intellectual property (IP) protection for public research. In terms of internationalization we see that the network incorporates two US universities; University of California and Standford University which directly attach to Samsung Electronics

South Korean Materials S&T

Extending the above methodology to Materials S&T, a large field encompassing part of Nano S&T, we get a somewhat different picture as in figure 2. Materials S&T is a much more mature field and hence the collaborating networks are much more dense. Hence, for clarity of analysis, we have had to take shorter time series, using 2008 and 2009 data. Again we see that the Chaebol, such as Samsung Electronics, Hyandai Motors, and POSCO, take most of the high Betweenness Centrality positions and as such have important knowledge brokerage roles. Public research institutes have a less prominent presence, which is corroborated by the analysis of the complete network, where 5 of the top 10 organizations in terms of Betweennness Centrality, for Materials S&T are Public research institutes [11]. Also the IUCF plays a much less prominent role, confirming the notion that in mature fields government influence is less prominent (Audretsch and Feldman, 1996).

[11]E.g. Korean Institute of Science and Technology, Korean Industrial Technology Institute, POSTECH, National University Pukyong, and University of Sungkyunkwan

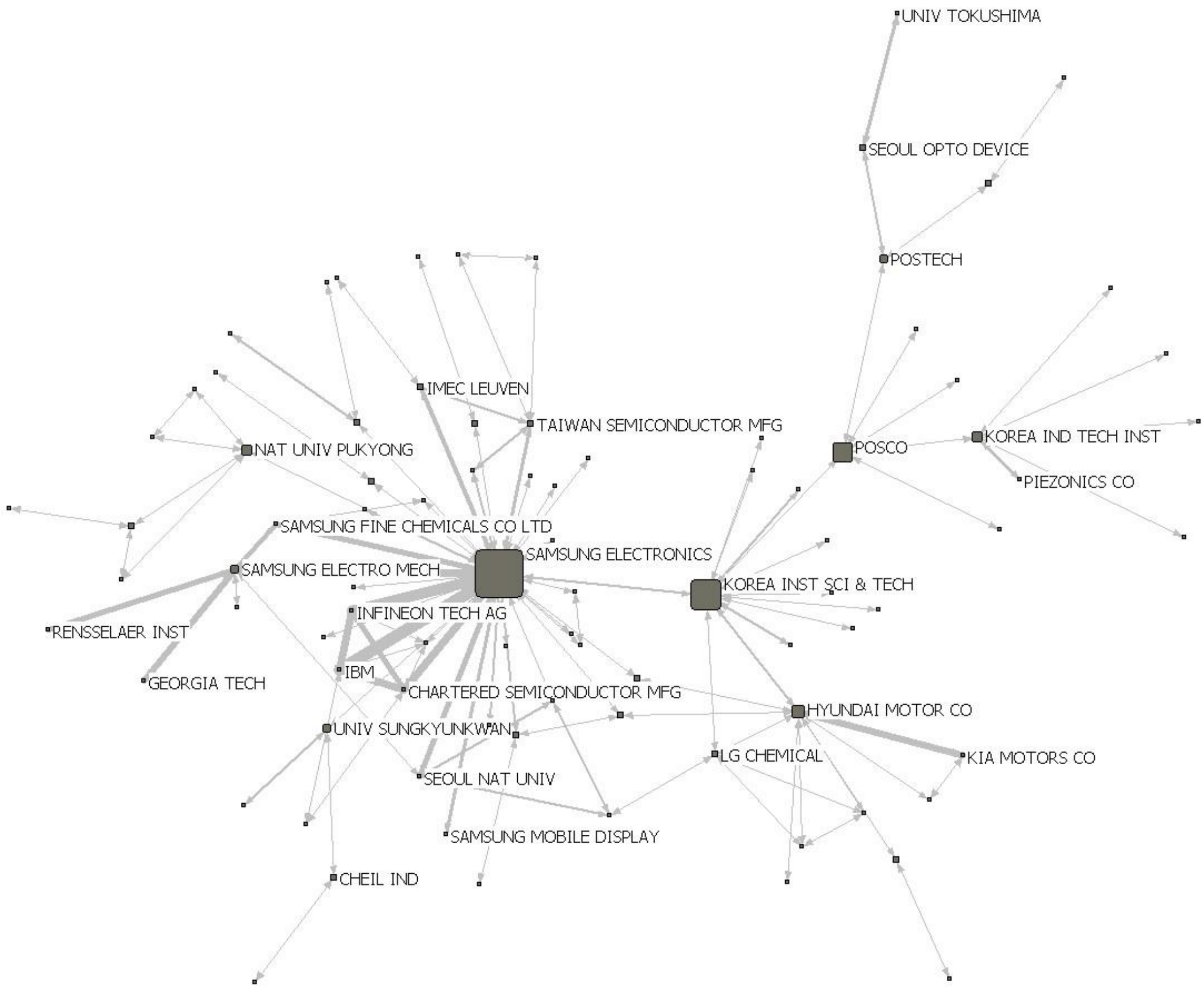

Figure 2: Core sectoral cluster in collaborative South Korean Materials S&T

Note: Author's own calculations

Although in the South Korean Nano S&T network international collaborations are not a prominent feature, we note in the South Korean Materials S&T network the presence of several international organizations such IBM, Infineon, CSM, the Rensselaer Institute, Georgia Tech, and the Belgian government sponsored research institute IMEC and Taiwan Semiconductors as major non-local nodes in the visualized cluster. As with the Nano S&T cluster examined before we see there is redundancy in the network making it more resilient to failure. Triadic relationships exist even between industrial partners, which mean that the failure of one of the high Betweenness Centrality nodes would not lead to a total collapse of the network. The extent of the redundancy however is such that government institutions are still well positioned to control knowledge flows between different entities. This means that the interplay between university, industry and government partners, as set out in the triple helix theory (Etzkowitz and Leydesdorff, 2000) is vital in making the Korean Materials Science network work efficiently.

The German Nano S&T and Materials S&T landcape

The German networks for the same technologies are very different from those of the Korean ones. First, there is a more significant inclusion of SMEs in both the German Nano S&T and Materials S&T networks. Second, public research institutions on the whole play a larger role as knowledge brokers, as exemplified by the fact that in both networks the Fraunhofer Gesellschaft replaces Samsung in its role as the main knowledge broker. Third, there is a stronger presence of multinational firms in Germany. This is also evident from table 1 which showed the percentage of overall collaborations and of collaborations with organizations with a foreign address.

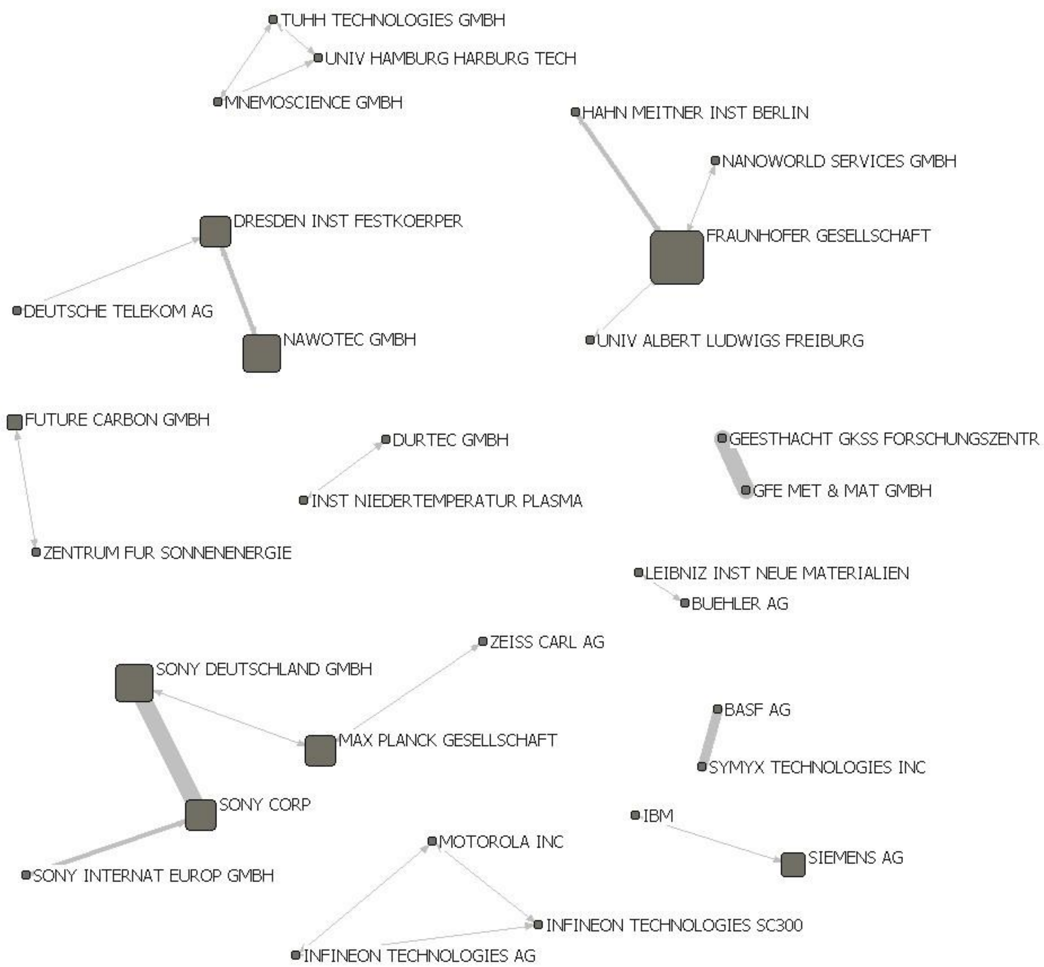

Figure 3: Core sectoral clusters in collaborative German Nano S&T

Note: Author's own calculations

What we can see in figure 3 is that the German Nano S&T network is highly fragmented, with little to no redundancy. As with South Korea, internationalization is almost completely missing from this network. The inclusion of a foreign owned company (Sony Corp) as a collaborative partner is most probably down to the local subsidiaries (Sony International Europe GMBH and Sony Deutschland GMBH) of this company.

German Materials S&T

The network for Materials S&T in Germany, in figure 4, shows that contrary to South Korea, a public research institute occupies the central position in the largest cluster in the Materials S&T network. The Fraunhofer Gesellschaft, along with the Max Planck Gesellschaft, is leading the control of the knowledge flowing through this cluster. However, a substantial and diverse number of multinational firms are supplementing these lead nodes. Redundancy in this network is great with a large number of industry-industry relationships. Although public research institutes take important positions, as mentioned, we also see that instead of relying purely on public research organizations to create the geodesic paths necessary for knowledge transfer as was the case for the South Korean network, in the German network there are quite some triadic relationships which could serve as back-up knowledge linkages in case of failure of the public research institutes nodes. Whether this is a government goal is not clear, however it reduces the importance of government institutions as conduits of knowledge to some extent. In any case, in the network visualized this is offset by the central positions taken by the larger government organizations in Germany which can in this way project their influence.

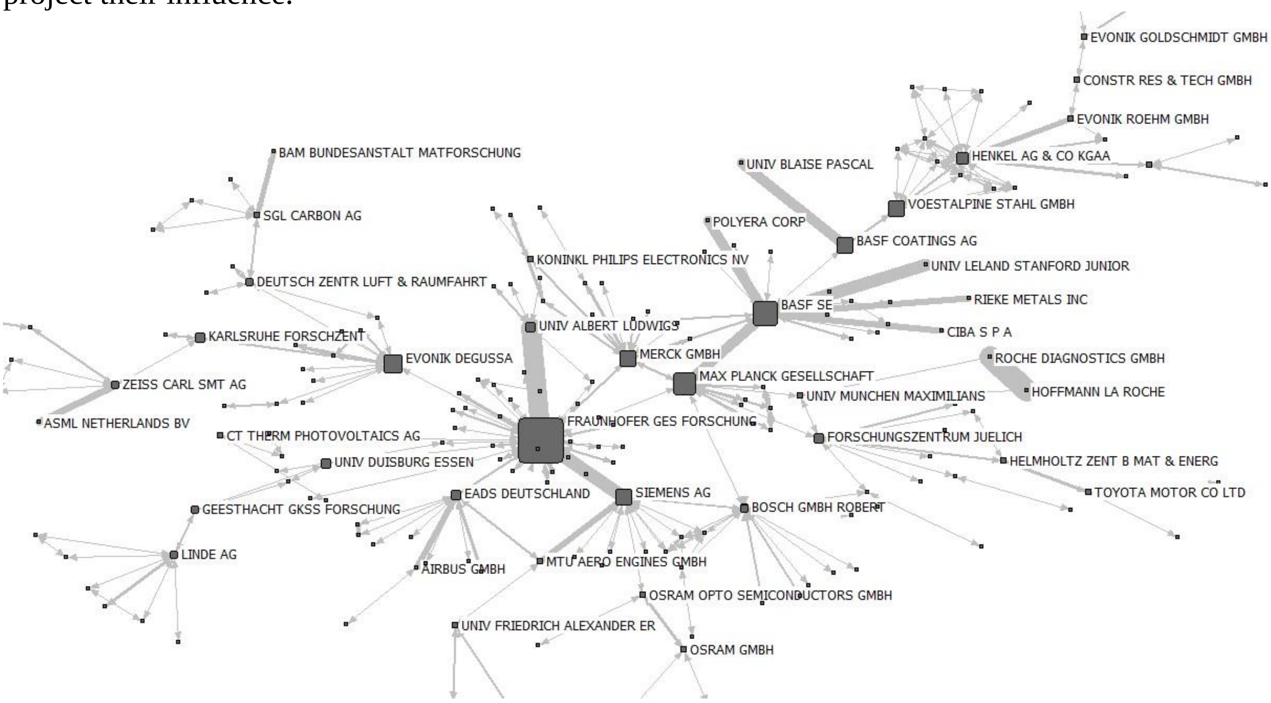

Figure 4: Core sectoral cluster in collaborative German Materials S&T

Note: Author's own calculations

A substantial number of SMEs are incorporated in the cluster shown which have direct links to both public as well as private/industry partners. Similar to South Korea, international collaboration is not an obvious feature of this cluster with just a few non-local organizations involved, mostly from neighbouring countries. However on a whole we must conclude that international collaboration is more visible in the German networks then in the South Korean ones.

4. Discussion of results

An organisation, say a firm, can patent alone, or with another organisation, which may be another local firm, a foreign firm or a public laboratory. Among firm partners, it could be either a large firm or a small firm. At the start of the life cycle of a radically new knowledge intensive technology paradigm, public laboratories, university spin-offs, and other small start-ups are likely to be the motors of knowledge transfer. Then as the technology matures, large firms could be expected to take over. International collaborations are more likely as the technology matures rather than at the start, unless there is outsourcing of research. Thus, we would expect the triple helix model in any country that has made inroads into nanotechnology to confirm public-private cooperation in terms of joint patents. As the preceding sections showed, this has indeed been the case in both South Korea and Germany. However, there seem to be significant differences in their triple helix model to which we turn now in tables 1 and 2, which further confirm the intuition of table 1.

Table 2: A comparison of the collaborative networks of South Korea and Germany

	Nano S&T		*Materials S&T*	
	Korea	*Germany*	*Korea*	*Germany*
Number of substantial clusters besides the main cluster	++	+	+++	++++
Robustness of collaborative network	++	+	+++	++++
Betweenness centrality of public research institutions	++	++++	+	++++
Betweenness centrality of large firms	+++	+	+++	++
Betweenness centrality of SMEs	+	+++	+	++

Note: + is indicative of the order of magnitude.

While Germany leads in terms of the density and robustness of collaborations in the older field in Materials S&T, South Korea seems to have leap-frogged to build more dense and robust collaboration clusters in Nano S&T. And, although it has obviously been only partially successful for SME inclusion, this cluster is sufficiently large to enable the possible diffusion of knowledge throughout a large number of dyadic relationships. In contrast the German Nano S&T field is quite fragmented with only a few sizable clusters, leaving this network vulnerable. Indeed, in Germany given its high number of disparate clusters, of which only a few are shown, better coordination or intensified collaboration may be able to make up for the lack of direct connectivity between the players. Due to the fragmentation, knowledge transfer capabilities in Germany are less noticeable and, as with redundancy, this could be remedied by an intensification of inter-cluster collaborative activity.

Table 3: A comparison of the role of key players in collaborations in South Korea and Germany

	Nano S&T		*Materials S&T*	
	Korea	*Germany*	*Korea*	*Germany*
Highest betweenenss centrality of a public research organisation	IND ACADEMIC COOP FOUND (217)	FRAUNHOFER GES FORSCHUNG (6)	KOREA INST SCI & TECH (1813)	FRAUNHOFER GES FORSCHUNG (13189,59)
Highest betweeness centrality of a large national firm	SAMSUNG ELECTRONICS CO LTD (304)	SIEMENS AG (2)	SAMSUNG ELECTRONICS CO LTD (3026)	BASF SE (6435,199)
Highest betweenenss centrality of a foreign firm	INTEGRITY BIOSOLUTION (0)	SONY DEUTSCHLAND GMBH (4)	TAIWAN SEMICONDUCTOR MFG (171)	VOESTALPINE STAHL GMBH (3633)
Highest betweenness centrality of an SME	MIJITECH CO (1)	NAWOTEC GMBH (4)	DOONAM C & M CO LTD (1)	LITEC LLL GMBH (193)

Table 3 reveals the more profound difference in their Triple helix models. In Korea, the leading organization, in terms of knowledge control in both S&T fields, is a commercial organization (Samsung Electronics and its subsidiaries). Large and diversified firms (Chaebol) make up the largest part of the private partners in the collaborative networks and seem to have kept small and medium sized companies (SMEs) at a distance. Although the geographical focus of the commercial sector, and especially the Chaebol, is international in outlook, this is not evident from our analysis (recall table 1). The internationalization could then be described as primarily export-oriented and not (yet) directed at knowledge and technology transfer through international collaboration at the fundamental S&T level. However, projects like the "Korean-German Cooperation Committee on Science & Industrial Technology"[12] show that there is considerable government pressure on internationalizing at least at the level of fundamental research. Thus, the current goal is to encourage collaborations with SMEs, while a decade earlier the industrial cooperation goal was to actively seek public-private partnerships with the Chaebols (Chung, 2011).[13] The lingering effects from these earlier policies may be making the transition to collaborative relationships with SMEs more difficult to realize.

In Germany, it is a public research organization (the Fraunhofer Gesellschaft) that is the main gate keeper of knowledge flows. In Germany, since 2006 policies have been promoting SME collaborations in public-private R&D partnerships. For instance, under the KMU-innovativ[14] program a sizeable amount of funding has been set aside for the stimulation and enhancement of SME level R&D and production. Also in this case we can question whether Germany has been

[12]See: http://www.internationales-buero.de/en/1281.php
[13]See: Chung, Ji Yoon (2011) The National Innovations System (NIS) and the Automobile Industry in South Korea, Discussion Papers; *Innovation Systems and Policy Analysis* No. 29, Karlsruhe: Fraunhofer ISI
[14]See: http://www.foerderinfo.bund.de/de/2248.php , accessed 24 October 2012

successful in extending this policy goal to the SME level with respect to nano and to what extent the former focus on strengthening the bigger commercial R&D infrastructures (Rammer, 2011) is a remaining factor. This is especially clear from the German Materials S&T network where the large MNEs, such as Siemens, BASF, and Merck, are still playing important knowledge brokerage roles, although not at the scale of the Korean Chaebol.

5. Conclusions

National science, technology and innovation policies try to promote collaboration between public laboratories, universities and firms in order to develop industrial capabilities in knowledge intensive sectors such as nanotechnology. This thrust is strongly supported by innovation studies and especially the Triple Helix Model. While it may be supposed that countries with a better leadership position have more public-private collaboration, the existing literature has little to offer by way of possible typologies of public-private cooperation. Hence, the present chapter sought to examine if there could be variety in the public-private cooperation models by studying collaboration patterns in joint patents in Nano S&T and Materials S&T issuing from South Korea and Germany. The choice of countries also provided insight on patterns of collaboration that can be associated with the different stages of the life cycle of a technology and different leadership positions. Materials S&T is an older technology niche of which Nano S&T forms a part. Currently, Germany is leading in terms of both patent applications (individual and collective) and the subset of collective patents in Materials S&T, while it is South Korea which has more in Nano S&T.

In Materials S&T, in both countries, the frequency of collective patents, the number of patentees involved and the variety of partners associated with patent applications is greater as compared to Nano S&T. However, the triple helix model seems to be functioning differently in South Korea as compared to Germany. In South Korea, the main gatekeepers controlling the flows of knowledge involved in patent applications are large business conglomerates, the Chaebol; while in Germany, this role is played by the networks of large public research institutes. Furthermore, SMEs and foreign organizations are more present in the German collaborative landscape in Materials S&T.

In Nano S&T, country differences are even more pronounced. The size and number of collaborating clusters is greater in South Korea as compared to Germany. Again, the Chaebol are more central and involved in the knowledge flows associated with patenting than in Germany, which remains dominated by the large public research institutes. This could be one of the reasons for the leap-frogging of South Korea in the realm of nanotechnology as compared to many of the European players.

Our inferences about the policy thrust in these countries, assuming that the present different pattern of collaboration could be due to different policy thrusts, are as follows. In both Korea and Germany governments have clearly realized the importance of the interplay between different entities in the Triple Helix model. However, in South Korea, industrial development seems to be the focus of government funding and infrastructural support for both front-line and mature science and technology fields. In Germany, institutional knowledge production and transfer seems to be targeted, with government organizations being the major players in government supported research and development both in front-line research, where it is expected, but also in the more mature science and technology field studied. This hypothesis seem to be confirmed by their stated policies, where private sector funding and involvement in R&D for South Korea has been one of the constant features in its national innovation system, while in Germany, the focus has been much more on SME development and government control over funding to boosting the leading position of the country's manufacturing industry.

Appendix

Nano Science and Technology				Materials Science and Technology	
	Patent Applications	IPC Class Symbol		Patent Applications	IPC Class Symbol
1	8712	B82B 3/00		3164	H01L 21/00
2	6947	B82B 1/00		2758	H01L 21/336
3	1886	C01B 31/01		2327	H01L 21/027
4	1038	A81K 9/14		2315	H01L 33/00
5	813	H01L 29/06		2135	H01L 51/50
6	449	H01L 29/06		1884	H01M 8/04
7	430	B01J 19/00		1787	H01L 29/78
8	425	H01J 9/02		1633	H01L 29/786
9	400	H01L 51/30		1622	H01M 8/10
10	373	H01J 1/304		1593	H01L 21/027
11	343	H01L 51/00		1517	H01L 21/60
12	333	C12Q 1/68		1494	H01M 8/02
13	332	G01Q 80/00		1325	H01L 21/20
14	299	G11C 13/02		1320	H01L 27/146
15	294	G01N 37/00		1239	H01L 21/768
16	293	C12N 15/00		1233	C09K 11/06
17	292	G11B 9/00		1222	C08J 5/18
18	275	B81C 1/00		1214	H01M 10/36
19	263	G01N 33/543		1213	H01L 23/48
20	256	G03F 7/20		1087	H01L 31/18
21	253	D01F 9/127		1084	H01L 21/66
22	245	G03F 7/00		1082	H01L 31/042
23	244	H01L 21/336		1064	Ho1L 21/28
24	239	B22F 1/00		1035	C09D 11/00
25	234	H01L 51/05		1033	G03F 7/20

Table A2. Top 25 IPC classes for Nano S&T and Materials S&T
Note: Authors would like to thank Dr. Lili Wang for the information and data on the applicable IPC classes.

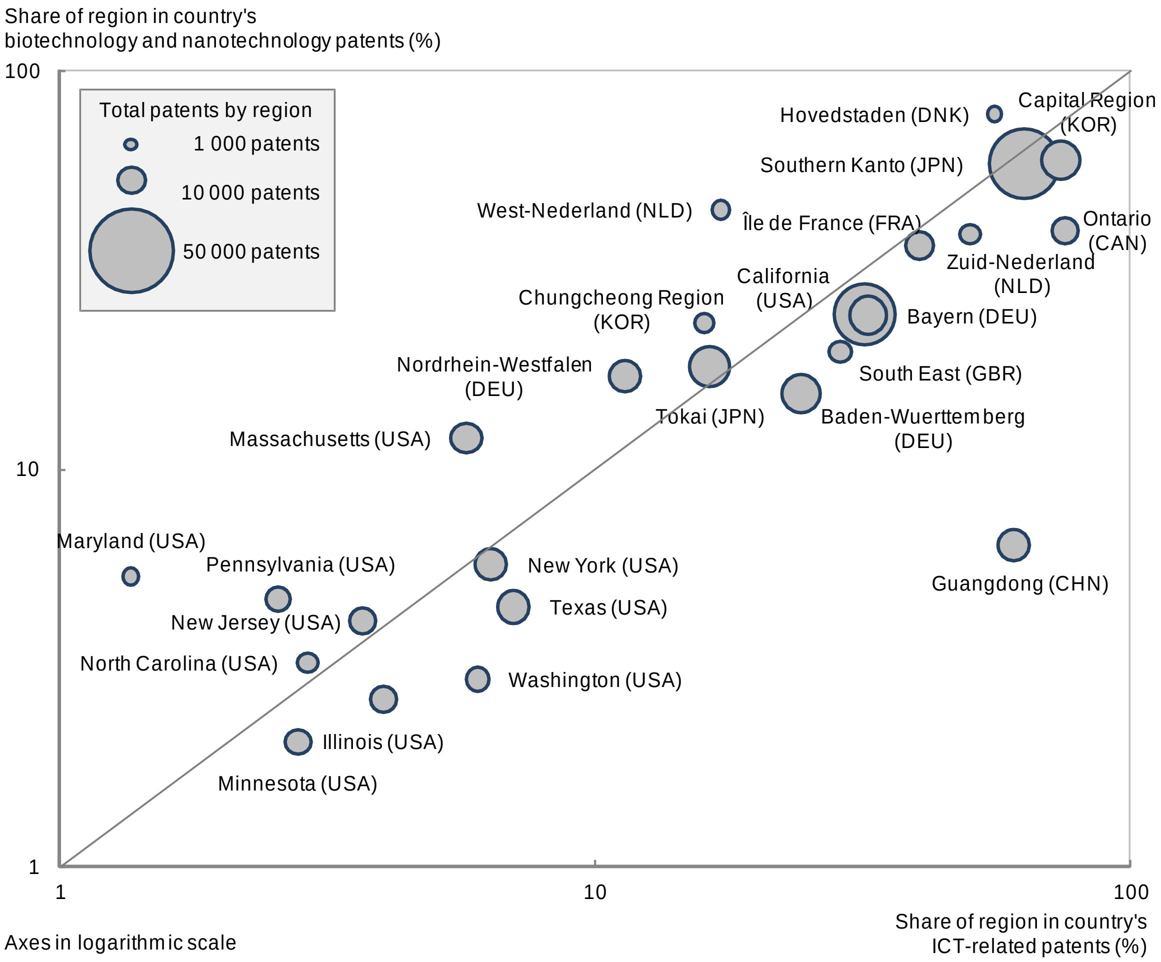

Figure A1: Division of ICT, BT and NT patents over regional clusters. Note: Data taken from OECD STI Outlook 2011: statlink: http://dx.doi.org/10.1787/888932485329

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