

# 1 Collaborative Networks and Technology Clusters – The 2 Case of Nanowire

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8

## 9 **Abstract**

10 Patenting activities and technology diffusion in high-tech sectors are being increasingly driven by collaborative,  
11 international and technology-based new entrants. In the realm of nanotechnology, one of the most mature  
12 structures is nanowire. This paper is concerned with the technology transfer process in the nanowire field; in  
13 particular it examines how patent collaborations occur and how the key actors interact with each other to support  
14 this process. This study uses a different methodology than previous studies in terms of patent data extraction.  
15 The methodology offers a new taxonomy that could make a significant impact on accurate patent data quests  
16 and increase the reliability of patent analyses in emerging fields such as nanotechnology. As patent data are  
17 valuable sources of technology innovation data and for forecasting technical change, this study utilises patent  
18 network analysis to visualise the actors' clusters and their relationships at the organisational, national and  
19 international levels. Overall, this study proposes a new collaborative network model to assist with analysing  
20 patenting activities between actors in regard to types of linkages. Different types of linkages between countries  
21 and organisations can be found for nanowire-related patenting activities by following the proposed network  
22 model. Findings indicate that some nations have highly centralised networks where large organisations dominate  
23 most linkages, as in the case of South Korea with regard to Samsung. Nations such as the US and Japan have a  
24 more distributed network where academic and industrial players are linked with each other. In the case of China,  
25 there were mono-linkages between large organisations such as Foxconn and Tsinghua University, which was  
26 key with regard to collaborative innovation there.

27 **Keywords:** nanotechnology, systems of innovation, patent analysis, collaborative networks, clusters,  
28 linkages, nanowire

## 29 **1 Introduction**

30 Nanotechnology is the process of understanding, manipulation and production of materials  
31 and devices at the level of atomic and molecular precision [1], particularly at dimensions of  
32 roughly 1 to 100 nanometers, where unique phenomena enable novel applications. This field  
33 is highly interdisciplinary [2-4], as it depends on the knowledge and expertise found in  
34 conventional disciplines such as chemistry, physics, biology, material sciences and medicine  
35 [5]. For this reason, there is much varied research being conducted in order to gain insights  
36 into this field and to forecast its possible outcomes. The wide range of studies in this field  
37 may increase the rate of nanotechnology diffusion and shorten the pre-commercialised era,  
38 and so help it to move on to its highly commercialised era. However, the outcomes of current  
39 nanotechnology innovation systems, with their commercial progress, their possible positive  
40 and negative effects on the environment and existing industries (e.g. whether they are  
41 disruptive innovations or the extent of their market penetration) are uncertain [1, 6-8].

42 The uncertainty of nanotechnology in a business context is even higher when the  
43 subcategories of this field are considered. Nanomaterials, nanomedicine and nanoelectronics  
44 are some of these subcategories of nanotechnology. However, the applications of these  
45 subcategories have differences; there are common nanostructures and nanoparticles that are  
46 used in these different fields of research such as nanotubes, nanowires and nanocrystals. All  
47 these nanostructures have different characteristics and their own particular novelties [9]. For  
48 this study, the nanowire field was chosen for analysis, there being two main justifications for  
49 this. Firstly, nanotechnology is not a clearly defined sector, so the scope of this study requires  
50 specifying linkages between countries or organisations for a specific field. Secondly, the field  
51 of nanowires is one of great interest for researchers and industry, when the number of  
52 granted/applied patents for this technology is considered. According to the collected patent

53 data, 4484 patents out of 49544 nanotechnology patents are for nanowire, which represents  
54 almost 10% of all nanotechnology patents.

55 Reliable and valid information about a particular technology or innovation system can be  
56 gathered if the patent data is analysed systematically [10, 11]. Some of the reasons why  
57 patent analyses are pursued include the discovery of promising technologies, assessment of  
58 technological advances and new trends, or helping organisations in their strategic decision-  
59 making [12]. Patent analysis can benefit various individuals and organisations such as  
60 inventors, R&D departments, policy-makers, academics and managers. Generally, looking at  
61 various patent analyses, the most commonly used methods are bibliometric and quantitative  
62 analysis; if some of these studies are clustered under various categories, these can then be  
63 subjected to network analysis, citation analysis, trend extrapolation/impact analysis, life cycle  
64 analysis, innovation system modelling, road mapping studies and economic base analysis  
65 [13-17].

66 Relevant studies conducted by Huang et al. [18] present a longitudinal patent analysis on  
67 nanotechnology patents between 1976 and 2002, focusing on content map analysis and  
68 citation network analysis. Accordingly, they showed how countries, institutions, and  
69 technology fields are linked with each other in terms of cited and citing actors by visualising  
70 linkages of the largest patent citation centre, institutional patent citation centres and  
71 dominating technologies that are cited most. Another similar study by Li et al. [19] identified  
72 key influential players and subfields, knowledge transfer patterns, and overall knowledge  
73 transfer efficiency. Porter and Youtie [20] examined nanotechnology positions in relation to  
74 other disciplines by considering their multidisciplinary nature, and linkages of these  
75 disciplines amongst each other. Similar work was conducted by Miyazaki and Islam [17],  
76 focusing on cross-country comparisons, actors and institutions by using similar quantitative  
77 methods (bibliometrics and tech mining) to understand the sectorial innovation systems in

78 nanotechnology from a global perspective. Shapira et al [21] observed the influence of cross-  
79 border international invention linkages by using patent data. Our study differs from the  
80 previous studies, as the focus of this work is to examine the types of linkages by focusing on  
81 co-ownership of patent documents rather than citation linkages. Patent co-ownership analysis  
82 is a better model for this study since our objective is to study collaboration linkages between  
83 actors, while citation analysis is a more appropriate method for studying knowledge flow  
84 between actors.

85 The objective of this paper is to analyse various linkages by examining granted and applied  
86 nanowire patents until the present time. To assist with the investigation process of types of  
87 linkages within a network, a new collaborative network model is proposed. This model is  
88 tried with the nanowire case bearing in mind the international and organisational contexts that  
89 assist gathering information on collaboration trends, linkages and the key players. The case of  
90 Samsung is analysed to examine a cluster and to support the findings further.

91 Considering the limited number of studies in this field in terms of collaborations in patenting  
92 activities, this study contributes to the field with a specific case of nanowire patent analysis.

93 There are few studies that examine how nano-patents are linked to each other and in what  
94 form they are interconnected. In any event, there is a need for up-to-date studies in various  
95 areas of nanotechnology, as it is an emerging field undergoing rapid development. In this  
96 study, the patent collection method and the search query are well defined and the patent  
97 database was the best among those available for use. The accuracy of the patent database was  
98 increased by using lexical queries with a combination of patent classification codes.

99

## 100 **2 Theoretical Background**

101 In the course of time, innovation management theories have evolved and the perspective on  
102 how innovation processes work has changed. After Schumpeter's identification of innovation  
103 and his studies [22], there were various theories that have been used by technology or  
104 innovation management specialists. The first theories that received attention and were  
105 implicit in the work of many innovation specialists were the technology push [23-26] and  
106 market pull theories [26-30]. These models were widely accepted in the technology  
107 management field but until the 1990s, they failed to take account of other influences that  
108 were affecting the innovation process. Lundvall [31] introduced a more comprehensive model  
109 to explain systems of innovation. In this model, linkages of various actors were taken into  
110 account in the innovation process and included many actors under a single system. Various  
111 important aspects are highlighted such as the functions of actors, linkages of actors, and  
112 knowledge flow between them. As the focal point of this study is the collaboration  
113 mechanisms within an innovation system, the relevant literature is thoroughly reviewed in the  
114 following section.

115

### 116 **2.1 Systems of Innovation Approach**

117 The system of innovation (SI) concept has captured the attention of a growing number of  
118 researchers involved in the fundamentals of SI as it explains the system in terms of actors,  
119 processes and flow of information. The SI comprises the linkages and flow of information  
120 among actors such as inventors and organisations in terms of innovative processes [31-35]  
121 and describes the processes of interactions among the actors to facilitate the innovation value  
122 chain [35, 36]. Various SI studies are described in the literature, including national systems of

123 innovation [31, 37, 38], regional innovation systems [39, 40], sectoral systems of innovation  
124 [41], technological innovation systems [42], and functions in innovation systems [43].

125 Looking at these different models, the notion common to all of them is to explain how an  
126 innovation system develops, diffuses, and utilises innovations within different contexts.  
127 However, the focal point of each study varies at some level and these studies emphasise  
128 different aspects of innovation systems. For each approach, the innovation system model  
129 differs in terms of the concepts used and the actors identified and highlighted.

130 The regional innovation system model describes the dissemination of knowledge within a  
131 geographic area that is at the regional level. By regional, this study means a region within a  
132 country such as the London area in the UK, or California in the US. The main characteristic  
133 of this model is the fact that it examines collective learning processes among regional actors  
134 in a particular technology or industry. It stresses the advantages that are gathered from a  
135 localized innovation group and different kinds of innovation cultures, norms and linkages in  
136 terms of the way knowledge is created and disseminated between regional actors [44]. The  
137 national innovation system has many similarities to the regional innovation system in terms  
138 of actors considered and the way they are linked to each other. Sectoral systems of  
139 innovation, on the other hand, involve the analysis of innovation processes, the linkages  
140 between innovation and industry, the determinants affecting innovation and the international  
141 performance of organisations and nations in various sectors [41]. There are three variable  
142 groups that are explained in this model: knowledge and technologies, actors and networks,  
143 and institutions [41].

144 Having examined the similarities and differences of various models in SI research, it can be  
145 seen that one of the key aspects within an innovation system is the structure of the

146 collaboration mechanism among actors. For this purpose, models related to the type of  
147 networks, clusters, and linkages of actors are examined in the following section.

148

## 149 **2.2 Collaboration Models and Network Types**

150 Collaboration is a course of action in which actors share information, resources and  
151 responsibilities in the attainment of a common goal that is jointly planned, implemented, and  
152 evaluated by the participants [45]. There are different collaboration models including  
153 informal collaborations, strategic alliances, joint ventures, partnerships, R&D consortia,  
154 licence agreements, coalitions, associations, clusters and networks. Networks function over  
155 linkages between individuals, organisations and shared interests. Sometimes networks can  
156 form formal or informal structures within or outside a partnership setting. Basically,  
157 networking involves communication and information exchange for mutual benefit. The  
158 difference between clusters and networks can be described by four dimensions, which are  
159 geographic, industry sector, nature of the relationship, and objectives [46]. Clusters are  
160 generally distinct from networks in that the geographical linkages between partners are from  
161 a set of associated sectors while such linkages in networks may come from a variety of fields  
162 or sectors [47]. Networks of organisations do not have to be limited to a specific geographical  
163 area, and a particular sector and its structure of networks can be designed in such a way as to  
164 allow active collaboration [46].

165 Collaboration networks can take different forms, for example that of an industry cluster [48].  
166 Industry clusters are the primary stage and comprise a group of companies which are  
167 characteristically located in the same region and form part of a common industry [48]. Due to  
168 regional and sectoral bonds, an industrial cluster aims to escalate the overall competitiveness  
169 of its members in their region and also tries to expand it to other regions. Some of the

170 benefits of being a part of such a collaborative network can be sharing information and  
171 expertise such as buyer/supplier externalities, or making use of common resources such as  
172 technological tools, or providing support to each other when various business  
173 opportunities/challenges arise. Patents can be a part of this kind of collaboration, as  
174 sometimes patents are used as barriers. However, patents may also be the starting point of an  
175 industry cluster in terms of spin-offs and academic institutions.

176 Nanotechnology can be classified as a science-based cluster [49] which is highly R&D-and  
177 patent-focused and is likely to have a close relationship with the public research sector (i.e.  
178 universities, government research bodies etc.) This is due to their requirement for basic  
179 research and so it is essential for the public research sector to become involved for there to be  
180 an effective innovation structure.

181 There are various models that analyse linkages of actors within an SI, for example the triple  
182 helix model, the TEN model, and network models. These different models are examined to  
183 gain information about the structure or types of linkages within an SI. The Triple Helix  
184 concept comprises a model for collaborative relationships between three major institutional  
185 spheres that comprise universities, industry and government, in which innovation is an  
186 outcome of interaction. This model presents manifold mutual relationships at various stages  
187 of the knowledge capitalization process [50]. There are three main different actors within this  
188 model and these actors may or may not be linked effectively in terms of patenting activities.  
189 Through patent analysis, it may not be possible to see the linkages between government and  
190 other actors, as the fund providers cannot be identified through patent analysis. However, it is  
191 possible to identify the linkages between academia and industry and relate this information to  
192 the model. This model can be used to understand insights of interactions between two  
193 spheres, which are academia and industry.



194 Another framework that illustrates the roles and linkages of actors within an innovation  
195 system is the Techno-Economic Network (TEN) [5]. The TEN framework is a useful  
196 framework to analyse the systems of innovation in a comprehensive manner for a chosen  
197 sector [5]. The TEN concept is an effective framework when the aim is to study an  
198 innovation system at a large scale, to consider its complexity. There are four different poles  
199 within the TEN framework and it has been organized around three major poles that are  
200 technology, science, and market. Another minor pole that is presented within this system is  
201 the Finance Pole, due to its indirect players or innovation links. Each of these poles is  
202 categorized by the type of actors and intermediaries in regard to their duties. Intermediaries  
203 vary in terms of tangible and intangible resources for those actors within TEN. Moreover, it  
204 shows how the poles are linked to each other in terms of their direct or indirect linkages and  
205 also it shows which intermediaries they are linked by, for example the Transfer Pole  
206 (between the Science and Technology Poles) and Development Pole (between the  
207 Technology and Market Poles). Following this model it should be possible to identify various  
208 collaboration mechanisms within a system. Even though the TEN model and the triple helix  
209 model illustrate actors and their linkages, these models do not identify collaboration  
210 mechanisms in regard to types and formation of networks.

211 Having examined different collaboration methods, the network structures of these linkages  
212 should be analysed as well. One can assume there would be academic and industrial linkages  
213 in nanowire patenting activities, but it is not clear if the form of linkages consists of small  
214 clusters or a network on a larger geographical scale.

215 One of the basic categorisations of networks describes them as centralised, decentralised, or  
216 distributed [51]. Accordingly, there can be a network with a dominant central ego to which  
217 other nodes are directly linked. This network may not have a very healthy structure as the  
218 network is controlled by an individual organisation and the progress of the network may be

219 slow and unstable. The structure of a network is likely to be vulnerable and unstable if there  
220 is a single node in it, as it is too dependent on the central ego.

221 A decentralised network can be considered as a more efficient model in terms of knowledge  
222 flow compared to the centralised model, as the structure consists of clusters or smaller  
223 networks with a higher number of central organisations. The most effective and stable  
224 network structure is the distributed network, as risk factors are lower compared to other types  
225 of networks. Distributed networks are likely to have lower levels of formalised interactions  
226 among comparatively equal organisations and the distribution of knowledge and resources  
227 will be more balanced.

228 Considering previous models, the following collaboration model in Figure 1 is being  
229 proposed as an analytical framework for this study. The core idea of this paper is to analyse  
230 the network structure and collaboration system of this particular field. However, it is assumed  
231 that there will be various structures where there are central players or multiple dominant  
232 actors appearing within nanowire SI networks. The proposed model consists of five different  
233 network linkage types, which for the purposes of this study have been termed: mono-linkage,  
234 oligo-linkage, central-linkage, decentral-linkage and distributed linkage (see Figure 1).  
235 Considering the triple helix and TEN models, it is expected that there will be various types of  
236 linkages in terms of actors and information flow. For example, a mono-linkage might exist  
237 between an academic and an industrial player where the information flow is between the  
238 science and the market poles.

239 [Insert Figure 1 here]

240 This study will apply the proposed model to analyse the nanowire case, where the  
241 institutional networks of nanowire technology will be examined in terms of the structure by  
242 which organisations are linked to each other and what the national differences are with regard

243 to the various network types as previously described (i.e mono-linkage, oligo-linkage,  
244 central-linkage, decentral-linkage and distributed linkage), and what the network  
245 characteristics are for nanowire technology. To fulfil the purpose of the study, it attempts to  
246 answer the following fundamental questions: 1) how the leading actors are linked to each  
247 other and how effective their network is; 2) what the collaboration trends are in respect to the  
248 dominant and emerging actors in the nanowire case; and 3) what the current network  
249 structures are in terms of the linkages between organisations.

250

### 251 **3 Methodology**

252 The present study applies tech-mining methodology, proposed by Porter and Cunningham  
253 [52], combining bibliometrics using patent abstracts from patent databases. Tech mining  
254 analyses relations between actors and technologies within a given innovation system, using  
255 specialist keywords, derived from the Nano Science and Technology Institute publications.  
256 The subsequent analysis was performed using dedicated tech mining software Thomson Data  
257 Analyser (TDA), automating mining and clustering of terms occurring in article abstracts and  
258 article descriptors such as authors, affiliations or keywords. The outline of this paper,  
259 including methodology and the general process, can be seen in Figure 2. In general, gathering  
260 the valid patent data, efficient analysis of large data sets, and handling and interpreting the  
261 outcomes of the analysis is crucial for the accuracy of the results. There are crucial steps for  
262 tech mining analysis and these are: searching for required data (e.g., key terms), gathering the  
263 required data (patents or publications), importing data into text mining software (e.g.,  
264 Thomson Data Analyzer, VantagePoint), cleaning and optimization, and analysis and  
265 interpretation of results. These steps are explained in the methodology section.

266 In the methodology section, sampling and its link to generalizability and quality of  
267 implications is key to the whole research process [53]. It is essential to justify the type of  
268 samples for the internal and external validity of this research [54]. The type of sampling, and  
269 the external and internal validity of results are highly interconnected, as will be explained in  
270 the following section.

271 [Insert Figure 2 here]

272

### 273 **3.1 Taxonomy of Patent Databases**

274 In considering the validity and reliability of this research, one of the key issues is to use an  
275 expedient patent database in terms of the required size and the coverage of patents. For this  
276 purpose, various patent databases were compared to find the best offering in terms of the  
277 number of patents offered and the coverage of patent authorities as shown in Table 1. The  
278 strengths and weaknesses of each patent database are considered.

279 Delphion is a reasonable tool for quick or occasional patent searches; however, it is not ideal  
280 for detailed patent analysis compared to other systems, as there is a ceiling of 500 patent  
281 documents. MicroPatent has more advantages compared to the Delphion patent database  
282 given its 20,000 hit list and 20,000 patent documents export option; however, if the research  
283 area is about a broad and mature field, MicroPatent is likely to be insufficient as the required  
284 data would be larger than 20,000. Moreover, the data coverage of MicroPatent is smaller than  
285 its competitors. PatBase offers the highest number of patent authority coverage and the  
286 greatest hit list of 100,000. However, the export option is limited to 20,000 records per month  
287 and this would be a drawback if the required patent database is higher than 20,000, giving it  
288 the same drawback as MicroPatent. Thomson Innovation has a significant number of patent  
289 authority coverage but it is smaller than Patbase's coverage. The maximum offered hit list is

290 60,000 which is lower than the PatBase offering. The total export option is 60,000 with an  
291 analyst subscription, which gives it the highest export option compared to its competitors.  
292 Also, it is possible to download the maximum allowed records more than once, so it is  
293 possible to gather the patent documents even if there are more than 60,000 records by  
294 breaking them down to the required level by year or by sub-category.

295 For this research, some criteria were crucial, namely the patent authority coverage, maximum  
296 hit list, availability of various patent database export options and the maximum allowed  
297 export quantity of patent documents. This is due to the fact that the required patent database  
298 was large and exceeded some of the patent database providers' maximum allowed patents  
299 document export options. Delphion and MicroPatent provide a limited number of patent  
300 authorities while their competitor, PatBase, does have a significant degree of patent authority  
301 coverage but there are service restrictions in terms of search hit list and the number of patent  
302 documents that would limit the potential data size. As a result of this comparison between  
303 various patent database providers, Thomson Innovation was the preferred patent database as  
304 the required large data set could be gathered and analysed by TDA. Additionally, the provider  
305 of the Thomson Data Analyser and Thomson Innovation patent database is the same  
306 organisation so the patent data and the software are optimized in the TDA export function  
307 and therefore the gathered results are improved even further.

308 [Insert Table 1 here]

309

### 310 **3.2 Patent Data Collection Method**

311 One of the biggest challenges in a patent analysis is to gather required patent data by  
312 selecting the appropriate terms for the search so that the data set includes the relevant patents  
313 and excludes unnecessary patents, thus increasing the validity of the research. Moreover, it is

314 an even greater challenge if the analysed field is an emerging technology and there are many  
315 similar terms that are used by other technologies. In the case of nanotechnology, the USPTO  
316 created a nanotechnology patent class labelled 977 in 2005 as a cross-reference art collection,  
317 and its sub-categories, to gather all the nanotechnology related patents within this category.  
318 Class 977 presents additional collections for patent searches, but it is not very useful for  
319 categorizing patents as a basis for assigning applications. Nanotechnology related US patents  
320 are only classified in class 977 as a secondary or a cross-reference classification and they are  
321 not primary classifications. For primary classifications, B82 by IPC is used and this  
322 classification is very helpful if nanotechnology patents are required to be analysed in terms of  
323 nanotechnology's sub-domains or sector analysis. This was a great approach considering the  
324 consistency of the nanotechnology related patent analysis, as this field is very dispersed  
325 among various fields such as electronic biological and robotic applications. The negative  
326 aspect of this new nanotechnology patent classification is that nano-related inventions were  
327 patented first in the 80s, so many patent authorities such as USPTO assigned teams to  
328 reclassify the records of patents granted previously to the established nanotechnology patent  
329 classification because at the time these classifications were introduced by patent authorities,  
330 many nanotechnology related patents had been introduced with different patent  
331 classifications. However, the majority of existing nanotechnology related patents have been  
332 reclassified into their respective patent classifications and new nanotechnology patents are  
333 classified into the required classification. The main problem in finding nanotechnology-  
334 related patents is that there are some patents within the nanotechnology class that are not  
335 related to the nanotechnology field (e.g. the following patents have been classified under the  
336 patent code B82; however, they are not really at the nano level, please see the patent  
337 documents: WO2001097295 A3, EP1688735 B1 and WO2012047042 A3).

338 Various approaches are followed by patent analysts and researchers in this field. There are  
339 many limitations and drawbacks in terms of the search terms that are used and the  
340 nanotechnology patents which are obtained. There are two main approaches in this field. One  
341 of the approaches is to use all the required nanotechnology related terms such as nanotube,  
342 nanowire and nanosensors in the patent search and to try to get the highest possible hit list as  
343 a result. This type of search may face two major problems. The first one is that the researcher  
344 may not cover all the required nano-terms and as a result may not be able to access all the  
345 required nanotechnology related patents, for example colloidal crystals, quantum dot, and  
346 fullerene do not include the term "nano", but they involve nanotechnology-related patents.

347 Another issue with this type of research is that there are many patents that mention  
348 nanotechnology-related materials within patent documents that are not for a nanotechnology  
349 invention. For example, if the details of some of the patents are analysed, it can be seen that  
350 the nanotechnology-related term is used in the description of a non-nanotechnology patent  
351 that states the invention can also be used with one type of nanomaterial such as nanotube. As  
352 a result, it is possible to include unnecessary patents and exclude necessary patents in the  
353 analysed patent data set.

354 The second common approach in nanotechnology-related patent analysis is to obtain all the  
355 patents that include terms that start with prefixes as "nano" or "quantum" by using Boolean  
356 search logic such as nano\* OR quantum\* and excluding all the unnecessary patents from the  
357 result which include terms such as nanosecond and nanometre. The problem with this  
358 approach is that there are many nanotechnology-related patents that include those terms, for  
359 instance there are many nanotechnology patents that include both 'nanowire' and  
360 'nanosecond'. Also, as was explained with the previous approach, there is a possibility of  
361 obtaining unrelated patents that mention the possible compatibility of a particular  
362 nanomaterial or nanoparticle with the patented invention.

363 Given the limitations and drawbacks of the above approaches, it was thought that the best  
364 nanotechnology search practice would be to use all available nanotechnology classifications  
365 to gather all the nanotechnology classified patents such as 977 by USPTO, B82 by IPC,  
366 Y01N by ECLA and 3C082 by Japanese F-Terms. All irrelevant patents classified within  
367 these categories could be eliminated by using Boolean search logic with very broad  
368 nanotechnology related terms, such as ‘nano\*’, ‘quantum\*’ and ‘fullerene\*’. Afterwards, the  
369 DWPI (Derwent Patent Index) is used to exclude patents that appeared more than once in the  
370 search results, as, due to nature of patent applications, inventions are granted more than once  
371 in various patent authorities to secure the invention in that respective country or region. For  
372 the nanowire case, the following search terms are used;

373 (AIOE=(B82\*) OR FIC=(B82\*) OR UCC=(977\*)) AND (ALLD=(nanowire\* or nano-wire\*  
374 or quantum ADJ wire\* or nano ADJ wire\*))

375 Establishing the validity and reliability of the collected patents in the nanotechnology field is  
376 a great challenge. To explain how the collected data differs from the existing studies, four  
377 different “nano”-related patent categories are introduced. The first of them comprises relevant  
378 nanowire-related patents. The second type of patents includes nanotechnology-classified  
379 patents with nanowire-related terms but which are not really nanowire-related patents. To  
380 give an example, there are many documents that mention nanowire related terms such as,  
381 “this new material also can be used with nanotubes, nanowires and nanocrystals,” but the  
382 patent is not really related to nanowire patents. This group is very difficult to eliminate from  
383 the patent data as it contains cases categorized under nanotechnology related categories, so  
384 the only way of eliminating these patents is to examine patents individually. The third group  
385 are those patents that include “nano” terms but are not nanotechnology-related patents, such  
386 as nanosecond or the iPod nano. Patents in this group are easy to eliminate using the patent  
387 collection method used in this study as it consists of patent codes with lexical queries where



388 nanowire and nanotechnology related terms are used. The last patent type comprises those  
389 patents that are classified under the nanotechnology category such as B82 or 977, but are not  
390 nanotechnology-related patents. There are many micro structural related patents under these  
391 categories and the main problem with them is that they are not really nanotechnology-related  
392 patents, given the requirements and the definition of the nanotechnology field, However, this  
393 issue is improving as the B81 (micro structural technology) classification is now being used  
394 more carefully and there are assigned teams that work on this issue. If only a list of “nano”  
395 terms is used to collect required patents, there is a big possibility that unrelated patents will  
396 be collected. Moreover, if one attempts to exclude unnecessary patents by utilising such  
397 terms as “-nanosecond\*”, there is a possibility that required patents also will be excluded, as  
398 there is a significant number of patent documents which mention nanotechnology related  
399 terms and nanoseconds. It can be argued that there is a possibility of having non-nanowire  
400 related patents or missing nanowire related patents in the collected data due to the issues  
401 stated above. However, this patent collection method is an effective method in terms of  
402 having higher reliability and validity of patent data when compared to other patent collection  
403 methods. Huang et al. [19] categorised lexical and patent classification queries by analysing  
404 related methodological studies. Porter et al. [55], Mogoutov and Kahane [56] and other  
405 similar studies have used lexical queries to gather all patents with nano terms but excluding  
406 those patents that have non-related nano terms such as ‘nanosecond’. Given the limitations  
407 and drawbacks of the above approaches, our method uses a combination of the two, as we use  
408 both patent classifications and lexical queries. The reason why both approaches are utilised is  
409 because as is mentioned in Scheu et al.’s [57] study, using only patent codes has a weakness  
410 in that unrelated patents appear in the patent data due to their wrong classification. Also,  
411 using only lexical queries as suggested by Porter [55] resulted in with almost 140.000 patents  
412 among which were found many unrelated patents after reviewing samples from the collected

413 data. Moreover, even if the data were optimized further, results would not be noticeably  
414 different given the type of analysis being followed.

415 As a result, 4484 nanowire patents were analysed with the data covering all the granted and  
416 applied patents until March 2012. The obtained results were imported into the Thomson Data  
417 Analyser (TDA) and, to validate the results further, duplicate results were eliminated and  
418 variations of company, inventor, institute, and university names were unified where they  
419 appeared as separate patent assignees. After the dataset was prepared, various functions were  
420 utilized using the same tool, Thomson Data Analyser, to generate the required analysis.

421 There are many other relationships that can be captured and visualized with TDA software.  
422 TDA software allows the analysis of patent data and their visualization in many ways, such as  
423 mapping, clustering and citation networks. TDA software was used to analyse the  
424 collaboration level of organisations in terms of patenting activity, the linkages of  
425 organisations within/outside their establishment in whichever country they operated, their  
426 collaboration with other actors within the nanotechnology innovation system (universities,  
427 institutes and corporations) and the technology diffusion process following the linkages  
428 between various academic and non-academic organisations.

429

#### 430 **4 Results: The Case of Nanowire**

431 Nanowire is one of the most mature nanostructures that are available today and so an analysis  
432 of the patents in this field is significant as there are more patent applications for nanowires  
433 compared to many other nanotechnology-related fields [58]. Nanowires (also known as  
434 quantum wires) are nanostructures less than ten nanometres long [58]. Nanowires consist of  
435 two quantum confined directions when compared to other low dimensional nanostructures  
436 [58]. Various types of nanowires are available, the features of which embrace the metallic

437 (i.e. Pt), semiconducting (i.e. Si), and insulating (i.e. SiO<sub>2</sub>) fields, which means that they  
438 have a large variety of applications in different industries [58]. For this study, 4484 nanowire  
439 patents were analysed with the data covering all the granted and applied-for patents until  
440 March 2012. Patent documents were organized according to their priority years (priority  
441 dates) as there are two different dates for a patent document; when it is applied for and when  
442 it is granted.

443 There are many possible future applications for nanowires. It is possible that silicon  
444 nanowires will provide the next architecture for transistor designs [58]. Nanowire transistors  
445 can be at least four times faster than traditional silicon devices and could result in high-  
446 performance, low-cost, flexible and miniaturized electronic circuitry for many products and  
447 applications [58]. Silicon nanowires will be designed to contour transistor channels,  
448 surrounded on all sides by a wrap-around silicon oxide, high-K metal gate [59]. These new  
449 nanowire transistors will have different characteristics to the best FinFET transistors [59].  
450 FinFET transistors have a three-dimensional gate (FinFET/Tri-Gate) while nanowires have a  
451 cylindrical shape so the gate can be in multipoint all around the device [60]. Another  
452 promising application of nanowires is likely to be in highly sensitive nanosensors for the  
453 detection of single molecules [61]. As nanowires are at a very small scale, when molecules  
454 make contact with the nanowires, they will generate a measurable change in the current  
455 passing through the nanowires [61]. There are many possible applications for nanowires in  
456 nanosensors, one important one being the detection of cancer proteins. This would allow  
457 cancer tests to be more accurate in an inexpensive manner [61].

458 Patenting activity for nanowire technology started in 1994, since when there have been 8420  
459 inventors, 1619 organisations and 32 countries involved in nanotechnology patenting activity.

460 As shown below in Figure 3, for this particular set of patents, the highest number of annual

461 records was 731 in 2009.. It appears that, there has been a rapid increase in the number of  
462 nanowire patents starting from 1999 to 2010.

463

464 [Insert Figure 3 here]

465

## 466 **4.1 Nanowire Patents – International Focus**

467 This section will look at nanowire patenting activity in two separate sub-sections. Firstly,  
468 different countries patenting activities are presented in terms of leading and emerging regions  
469 to see the general trend. Secondly, linkages between countries are analysed to see how  
470 international collaboration occurs in the nanowire field.

### 471 ***4.1.1 International Involvement in Nanowire Patenting Activity***

472 Table 2 presents the top countries with regard to patents but the order of leading countries is  
473 different for nanowire technology as compared to the whole nanotechnology field. At present,  
474 when considering the total number of nanotechnology related patents, consisting of 49544  
475 nanotechnology patent dataset, the US is the top country, while Korea and China are below  
476 Japan, but in the case of nanowire patents, Korea and China have now overtaken Japan. It is  
477 remarkable that the number of nanowire patents granted to or applied for by Korean  
478 organisations is nearly twice the number of those granted to or applied for by Japanese ones,  
479 even though Korea became involved in nanowire technology 3 years after Japan did (please  
480 see Table 3). Also, another Asian player, Taiwan, has emerged as a key player in nanowire  
481 technology. As shown in Figure 4, China and Korea are catching up with the US, while Japan  
482 continues to grow in the nanowire field. Other countries have shown quite a slow increase in  
483 their numbers of patents in this field.

484

[Insert Table 2 here]

485

486

[Insert Figure 4 here]

487

488

[Insert Table 3 here]

489

#### 490 ***4.1.2 International Linkages in Nanowire Patenting Activity***

491 This section examines the linkages between countries in terms of organisational

492 collaborations and involvement in different regions. The TDA software performs

493 multidimensional statistical analysis to identify clusters and relationships among these nodes.

494 The size of a node represents the number of documents that belongs to it, while its centrality

495 represents how often that particular node occurs with other nodes. As shown below in Figure

496 5, the US appears at the centre of linkages and all presented nanowire patenting regions are

497 linked to the US, so it is clear that highest number of nanowire patents are filed in the US.

498 The closeness of nodes and the thickness of lines are calculated on the basis of the

499 significance level between each node, which in turn is calculated on the basis of how many of

500 those documents belong to the node and how many of those documents are shared with the

501 linked node. For example, if node A has twenty documents and ten of those are shared with

502 node B, and five of those are shared with node C, nodes A and B would have thicker line

503 between them whereas nodes A and C would have a weaker line. The closeness of these

504 nodes is based on the ratio of shared documents between nodes. If node B has ten documents

505 in total and they are all shared with node A then these two nodes would be very close to each

506 other. Considering the significance level, the linkages between US-KR, US-TW and US-SG

507 appear to be the highest in comparison to other linkages. This is calculated according to the

508 number of total patents and number of shared patents that are granted/applied for within those

509 regions. The high significance between US-KR is mainly due to patenting activity of

510 Samsung in both regions. Moreover, Samsung's patenting activity in this field has resulted in  
511 KR being part of the second highest number of linkages in this field. The distance between  
512 ego points designates the closeness of the relationship between regions, and so US and JP  
513 appear to have a strong linkage as well. Even though CN is one of the key regions in terms of  
514 number of patents, this region does not appear to have a high number of linkages and it  
515 appears isolated compared to other leading countries in this field. Referring back to the  
516 linkage mechanism that was introduced in the literature review section, this figure illustrates  
517 the fact that the current structure of international linkages still very much has the US at the  
518 centre. However, it is moving towards a decentral-linkage network structure as KR gains  
519 significant positions and an increasing number of linkages with other countries.

520 [Insert Figure 5 here]

521

## 522 **4.2 Collaborative Networks and Clusters in the Nanowire Field**

### 523 **4.2.1 Organisational Involvement in Nanowire Patenting Activity**

524 As shown in Table 4, the leading organisations in the nanowire field are Samsung, Hewlett-  
525 Packard and IBM. All the top electronics companies except Hewlett-Packard became  
526 involved in nanowire patenting activity after the millennium. IBM has been granted 54% of  
527 their nanowire patents within the last three years, which indicates their growing interest in  
528 this field, probably as a result of its applicability in electronics. This table proves the fact that  
529 the key applicability of nanowires is in the electronics industry, as the main patent holders in  
530 the field are the top players in that particular industry. The dominant countries for this  
531 technology with regard to top organisations appear to be the US and Korea. Examining  
532 Samsung's progress, it can be seen that their involvement in nanotechnology started with  
533 their focusing on nanowire technology. Even though Samsung are a recent player in

534 nanotechnology compared to other companies such as IBM, 17% of its nanowire patents have  
535 been granted within the last 3 years.

536 Table 4 also shows a notable involvement of academic institutions in nanowire technology.  
537 For example, the University of California appears to be a leading academic player, which  
538 strengthens US dominance even further. In addition, the Korean institutions, the University of  
539 Seoul and University of Korea, play a vital role in the technology diffusion process. These  
540 academic institutions' involvement may positively affect the commercialisation process in  
541 view of their high number of granted patents and their role within technology transfer activity  
542 networks.

543 Another dominant player, Nanosys, was only founded in 2001 and their first involvement  
544 with the nanowire field started in 2002. In the last three years, they have not performed well,  
545 as they have only been granted 4% of their overall nanowire patents in this time, but they still  
546 play a key role within this sub-domain. The French government-funded technological  
547 research organisation, CEA, appears to be the second highest organisation in terms of  
548 progress, considering that 43% of their nanowire patent documents have been granted within  
549 the last three years. However, it is notable that even though CEA has a strong dominance in  
550 the nanowire field, there is no French corporation within the top players. This may be due to  
551 poor collaboration between academic and non-academic organisations in France.

552

553 [Insert Table 4 here]

554

#### 555 ***4.2.2 Visualisation of Networks and Types of Linkages in Nanowire***

556 In the case of nanowires, the strongest link appears to be between Hon Hai Precision  
557 (Foxconn) and Qinghua University (Tsinghua University) (see Figure 6). These two

558 organisations share 20 patent documents within the realm of nanowire technology. The  
559 second highest number in patent collaboration is between two South Korean players,  
560 Samsung and Seoul National University, with their 14 shared nanowire patent documents.  
561 Seoul National University (SNU) is one of the leading players in graphene as well, and  
562 Samsung and SNU collaborate in various nanotechnology fields. The third highest degree of  
563 collaboration is between Samsung and Sungkyunkwan University, with 12 shared patents  
564 within the nanowire field.

565 By looking at the general picture for nanowire technology, the strongest cluster occurs in  
566 South Korea (cluster 2). South Korea appears to have a highly centralized network around  
567 Samsung and there are some international linkages with other networks. It is to be expected  
568 that US players (cluster 1) should be in the centre of nanowire patent activity collaboration as  
569 the US has the highest number of nanowire patents, but South Korea has a greater degree of  
570 collaborative involvement. The US cluster appears to be decentralized and this type of cluster  
571 has better characteristics in terms of its stability and efficiency. Another interesting result that  
572 can be gathered from Figure 6 is that even though there are high numbers of patents in Japan,  
573 the Japanese nanotechnology cluster (cluster 4) does not look very effective when the number  
574 of collaborative nanowire patents is considered. With regard to US-based collaborations,  
575 universities and academic institutions appear to have the strongest relationships, such as that  
576 between Harvard University, State University of New York and Massachusetts Institute of  
577 Technology.

578 China does not appear to have a cluster but the linkages between Chinese organisations are  
579 very significant (cluster 5). In fact, the strongest bond is found between Tsinghua University  
580 and Foxconn. However, this is due to their special collaboration terms by which both  
581 organisations share all of their nanotechnology-related patents. Moreover, their linkage is a  
582 mono-linkage, as it is presented in the proposed model and it appears to be an effective model



583 considering the number of shared patents produced. This kind of structure may be an  
584 effective model due to two factors. Firstly, it is a linkage between an academic and industrial  
585 player so there is great mutual interest in each other's activities and involvement. Secondly,  
586 the size of the organisations is significantly large and it is very balanced in respect to their  
587 own academic and industrial activity. This is very important for the nanowire field given the  
588 fact that required investment is high in respect to the related industries such as the  
589 semiconductor industry and it requires scientists from very diverse scientific departments  
590 such as material sciences, electronics, and chemistry.

591 Cross-country collaboration can also be found. The strongest collaboration between US and  
592 Korea is that between Hewlett-Packard and two key Korean players, namely Samsung and  
593 Sungkyunkwan University. Another strong international collaboration appears between the  
594 US and France as was seen when the nanotechnology field was analysed as a whole (cluster  
595 3). In the case of nanowire, the strongest linkage appears to be between CNRS and the  
596 California Institute of Technology. Some large organisations are not involved in any  
597 collaboration in nanowire patenting activity, such as IBM, Sony and Toshiba. IBM owns 100  
598 nanowire patents and none of these patents is the result of any type of collaboration.

599 Looking at the general structure of nanowire technology networks and clusters, it can be  
600 claimed that the structure of innovation systems may begin with a key collaboration between  
601 two or more organisations which agree to form the bidirectional linkage or the first narrow-  
602 scoped cluster as in the China case. This new formation enlarges and establishes the  
603 centralized cluster due to the presence of a dominant player in the system such as Samsung.  
604 After the development of centralised clusters, the structure evolves to a decentralized cluster  
605 model as in the US case. The next stage is the international connection of organisations that  
606 takes place as the cluster moves to the stage where there is a network established. For this  
607 case, Samsung is a great example when one sees how they created their network of national

608 and international linkages. It is also interesting to see the progress of the Korean innovation  
609 system in the nanowire case as a marketing-oriented network moves towards being a  
610 complete innovation network.

611 [Insert Figure 6 here]

612

### 613 **4.2.3 Visualisation of an Organisational Cluster – The Case of Samsung**

614 In the previous section, key players are identified in terms of linkages with other  
615 organisations. Considering the number of patents and linkages in this field, the cluster  
616 containing Samsung was chosen for analysis to examine the details of a collaboration  
617 mechanism. Following this type of analysis it is possible to see the internal linkages between  
618 their collaborative scientists as well.

619 Figure 7 shows Samsung's nanowire patenting cluster in terms of co-ownership of patent  
620 documents. This cluster consists of a central-linkage mechanism and it is highly reliant on the  
621 patenting activity of Samsung. It appears that 260 of Samsung's nanowire related patent  
622 documents are not co-owned and this shows that Samsung relies on in-house R&D, as overall  
623 that would equate to over 80% of total patents being generated without collaboration.  
624 Depending on Samsung's legal agreements, it may also be the case that Samsung appears as  
625 the only holder of those patents even though some of those are the result of collaborations.  
626 However, given the significant ratio of co-owned patents to single-owned patents (0.17), this  
627 is a noteworthy indication of Samsung's successful internal collaboration for the generation  
628 of nanowire-related patents.

629 [Insert Figure 7 here]

630 To evaluate possible effects of a central network, Figure 8 is presented to illustrate how South  
631 Korea's linkage mechanism would vary if Samsung's significant input did not exist. It is, of

632 course, not possible to claim what the linkages would be if Samsung had never existed;  
633 however, this section examines the potential effects on a central network if the dominant  
634 player were missing. Taking into account Samsung's current position, such a dramatic change  
635 is not expected; however, this may be the case in a central-linkage mechanism if an  
636 organisation such as Samsung minimizes or suspends their investment within a particular  
637 field. In this case, it appears that South Korea's central-linkage mechanism would change  
638 into a structure of mono-linkages in the case of Samsung's absence. The collaboration  
639 structure would completely change and the number of linkages would decrease in a  
640 noteworthy fashion. One of the most drastic changes in the Figure is that the linkages  
641 between academia and industry would almost disappear and be replaced by linkages between  
642 academic institutions. This can be a very dangerous outcome of such a change in a network  
643 with regard to the efficiency of technology transfer and commercialisation of nanowire-  
644 related technology. Overall, South Korea's current network appears efficient in terms of  
645 granted/applied nanowire patents but its structural risk factors should be avoided in similar  
646 networks that have a central-linkage structure. As a result, it can be stated that outside of  
647 Samsung most linkages are academic, which indicates that other Korean corporations are not  
648 as driven to collaboration with academia or there are possible barriers inhibiting these kinds  
649 of collaborations in nanowire technology.

650 [Insert Figure 8 here]

651

652 Table 5 below shows the top three collaborators with Samsung in descending order of  
653 number of patents under co-ownership. All of Samsung's collaborations appear to have been  
654 with South Korean academic players. If the percentage of shared patent records is examined  
655 for the last three year period, the increasing importance of collaborations between academic

656 and corporate organisations can be seen, as at least 10% of collaborations happened in this  
657 period with each actor. Moreover, it is possible to see if the collaboration mechanism is a  
658 continuous process, since it is possible to see the time period when these organisations are  
659 collaborating. If a visual network figure was used, it would only be possible to see the  
660 number or types of linkages, but it would not be possible to see which are active or passive.  
661 This table also allows the reader to see the key inventors that play important roles in terms of  
662 collaborations between these organisations. Accordingly, this type of study can be used as the  
663 basis for a qualitative study of these key inventors to gather determinants about the  
664 collaboration mechanism.

665 [Insert Table 5 here]

666

## 667 **5 Discussions and Conclusions**

668 In this article, nanowire patent documents were carefully analysed with four foci, which are  
669 international, organisational, technological and institutional. In addition, this paper explored  
670 different models within innovation system theory and various network and cluster models  
671 were examined to form the theoretical basis of the study.

672 The international profile of nanowire technology provided valuable information, such as key  
673 regions, with regard to the number of nanowire patents. This research has also presented  
674 country-based key technology domains and dominant players within those countries. An  
675 interesting outcome was to see the changing trend of countries' involvement in nanowire  
676 technology as Asian players in the last year had huge involvement in this area. It appears that  
677 South Korea and China are now ahead of Japan and close to the US in terms of the number of  
678 nanowire patent documents granted.

679 Considering the networks or clusters for nanowire technology, it can be said that these vary  
680 greatly from one country to another. It was found that the largest network was Samsung's  
681 centralized network in South Korea. This network has international linkages with other  
682 countries, for example with organisations based in the US. This is due to the international  
683 externalities of multinational companies such as Samsung. On the other side, talking about  
684 international externalities, the biggest collaboration was identified as being between the US  
685 and France in nanowire patenting activities. There was a high degree of co-ownership by  
686 French and US organisations both in the academic and private spheres. However, it was  
687 found that the main focus of these relationships was within the electronics sector. This is of  
688 course due to the application of nanowire technology to semiconductors, batteries and display  
689 technologies. From the point of view of the proposed network model, with five different  
690 classifications of mono-linkage, oligo-linkage, central-linkage, decentral-linkage and  
691 distributed linkage, the general structure of nanowire networks was found to be somewhere  
692 between centralised and decentralised and very far from being a distributed network  
693 structure. That means the network relies greatly on organisations such as Samsung, which  
694 dominates the Korean centralised network. It would be expected that the US would have the  
695 highest number of linkages considering the fact that it is at the centre of nanowire patenting  
696 activity in the international linkages figures, but looking at patent activities at the  
697 organisational level, it can be noted that the US has a national cluster rather than a network  
698 and the number of collaborating organisations is lower than in the Korean case. Another  
699 surprising fact that can be gathered from this analysis is that the Chinese collaboration  
700 mechanism is not very strong in terms of linkages between private and public organisations.  
701 The key linkage in the Chinese context is between Tsinghua University and Foxconn, an  
702 organisation with its headquarters in Taiwan, but which has most of its production assets in  
703 China. In China, the number of collaborative organisations should be increased to move it to

704 the stage where there is an innovative cluster to increase the technology diffusion process.

705 This research suggests that the government should take action to bring this about.

706 With respect to the key actors within the nanowire case, it was found that within the

707 electronics industry, ownership of patents is dominated mostly by large organisations. There

708 are two main reasons why there is considerable heterogeneity in nanowire patenting activity.

709 Firstly, large organisations have the capability to provide the huge investment necessary for

710 R&D activities, and they are aware of the benefits of nanowire technology in terms of its

711 efficiency and its nature for bringing about incremental innovative characteristics. Secondly,

712 they collaborate with academic organisations such as universities and institutions to benefit

713 from their inventions as well. The second point is not found in every national innovation

714 system, but Korea, the US and Japan appear to have a more effective environment compared

715 to other nations in this case.

716 To summarise the important implications of this study, the following conclusions are listed:

717 Asian organisations, especially in South Korea and the Chinese region appear to be having a

718 great impact in the nanowire field.

719 Considering the linkages between organisations, there is a sector concentration in the

720 electronics industry in terms of patenting activity, especially in central linkage mechanisms.

721 This is due to the large investment of global players and their related interest in nanowire

722 applications such as semiconductors and energy storage-related devices.

723 In terms of collaboration and innovation models, nanowire technology was found to be in its

724 initial stage where various centralised clusters or networks exist. However, some nations such

725 as South Korea, US and JP are far ahead in terms of number of linkages between academia

726 and industry in the nanowire field.

727 In relation to this study a path is proposed for innovation systems; that is key participants lead  
728 to clusters, and clusters to networks, and networks result in innovation systems. This was the  
729 result of examining the progression of various nations and organisations involved in nanowire  
730 technology. For example, in the case of mono-linkages in CN, it would be expected that their  
731 linkage mechanism would move into an oligo-linkage, a central-linkage or a decentral-  
732 linkage and this would lead to a network after the region progresses further.

733 This paper also illustrates a great example of a central network by using Samsung's cluster.  
734 When considering the efficiency of this model, there are many points open to argument, as  
735 various scientists have proposed different ideas in terms of large players' involvement in  
736 innovation activity. Looking at this type of collaboration mechanism purely based on type of  
737 linkages as it is mentioned in the TEN model (Technology Pole, Science Pole and Market  
738 Pole) and structure of linkages (mono-linkage, oligo-linkage, central-linkage, decentral-  
739 linkage and distributed linkage), if the central ego (Samsung in the KR case) were missing or  
740 if their contribution was minimized due to various factors, it would affect the whole network,  
741 as some of the mentioned poles would disappear or be minimized to a low number of  
742 linkages or technology transfer processes, or the diffusion of technology would be drastically  
743 affected as the whole network would need to form into a new model. This was also illustrated  
744 by examining the structure of KR with and without Samsung to see the possible differences  
745 in the network. It was obvious that the number of linkages would be drastically reduced and  
746 linkages between academia and industry would almost completely disappear. Considering the  
747 fact that even large players struggle in any type of market (even large automobile players)  
748 and given Samsung's crises in 1997, it can be expected any central network will risk losing  
749 its structure in crises as compared to a decentral-linkage and distributed linkage structure.

750 To take this study further, there are many other relationships that can be looked at within  
751 nanowire technology. As was mentioned in the findings section, there are some organisations

752 and inventors that hold a high number of nanowire patent documents but the question is  
753 whether they are highly influential patents in terms of citations, commercial potential and  
754 quality. Accordingly, a follow-up study could be conducted on nanowire patent documents to  
755 look at this field in terms of quality in comparison with quantity.

756

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765

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